Iodine in Early Life

A cross-sectional study of children 0–2 years of age and their mothers in Norway

Tonje Eiane Aarsland

Thesis for the degree of Philosophiae Doctor (PhD)
University of Bergen, Norway
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Scientific environment

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Abstract

Background: As a component of the thyroid hormones (THs), iodine is a micronutrient essential for normal neurodevelopment and metabolism. Both iodine deficiency and iodine excess may alter TH production and are associated with an increased risk of adverse health effects. While there has been substantial global progress in tackling iodine deficiency disorders over recent decades, mild-to-moderate iodine deficiency remains a threat in certain countries and population groups, including Norway. Despite the importance of iodine in early life, data on iodine nutrition in young children are scarce.

Objectives: The main objective of this thesis was to describe iodine nutrition (iodine status and intake) in children between 0–2 years of age and their mothers in Innlandet County, Norway, and relate it to markers of maternal iodine nutrition.

Methods: A two-phase cross-sectional study in Innlandet County was performed: phase I in mother-infant pairs (infants 0–12 months of age) in two municipalities from October to December 2018, and phase II in mother-child pairs (children 0–2 years of age) in 30 municipalities from November 2020 to October 2021. Urine and breast milk samples were collected and analyzed for iodine. Iodine intake was estimated using different dietary assessment methods: phase I) questionnaires addressing the recent and usual intake of iodine-rich foods, and phase II) repeated 24-hour dietary recalls (24-HRs) and a food frequency questionnaire (FFQ). The second phase applied the Multiple Source Method to estimate usual iodine intake distributions from the repeated 24-HRs.

Results: In total, 463 mother-child pairs were included in the final analyses of iodine nutrition (130 from phase I and 333 from phase II). In phase I, the infant median urinary iodine concentration (UIC) was 146 µg/L, indicating sufficient iodine status according to the current WHO cut-off of 100 µg/L. Usual iodine intake was not estimated for the whole group of children, but the median recent (24-hour) iodine intake was 50 µg/day and within the recommended intake (RI) at that time point of 50–70 µg/day (NNR2012).

In phase II, which evaluated a representative sample of mother-child pairs in Innlandet County, the median UIC in the children was 145 µg/L, which was also above the current WHO cut-off for iodine sufficiency. The median usual iodine intake based on the repeated 24-HRs was 83 µg/day, which was below the updated adequate intake (AI) for this age group of 90–100 μg/day (NNR2023). Further, 35% of the children had a suboptimal usual iodine intake [below the proposed estimated average requirement (EAR) of 72 μg/day], and <1% had an excessive usual iodine intake [above the upper limit (UL) of 200 μg/day].

The median maternal UIC in phase II was 92 μg/L, indicating insufficient iodine status in the women (<100 μg/L), and the median breast milk iodine concentration (BMIC) was 74 μg/L. Further, 23% of the women had a suboptimal usual iodine intake (below the AR of 100 μg/day), while none had an excessive usual iodine intake (above the UL of 600 μg/day). The children's UIC and iodine intake was positively associated with all markers of maternal iodine nutrition (BMIC, UIC, and estimated iodine intake).

Conclusion: The children had an adequate iodine status on a population level, as indicated by a median UIC above the current cut-off of 100 μg/L. However, the extensive dietary data in phase II suggested that more than a third of the children had a suboptimal usual iodine intake. Furthermore, the proportion of children with an excessive usual iodine intake was low. Our findings support previous findings of a low iodine intake in postpartum and lactating women. Considering the role of iodine for growth and development, urgent measures are required to improve iodine intake in young children and women of childbearing age.

Sammendrag på norsk

Bakgrunn: Jod trengs for produksjonen av tyreoideahormoner, som er viktige for metabolismen og for normal vekst og utvikling av hjernen og nervesystemet. Både for mye og for lite jod kan medføre endringer i produksjonen av disse hormonene og føre til uheldige helseeffekter. Selv om andelen med jodmangel og relaterte sykdommer har blitt betydelig redusert de siste tiårene, er mild-til-moderat jodmangel utbredt i enkelte befolkningsgrupper, både i Norge og i andre land. Til tross for viktigheten av jod for vekst og utvikling, er det kunnskapshull om jodstatus og jodinntak blant små barn.

Mål: Det overordnede målet var å beskrive jodtatus og jodinntak blant barn mellom 0–2 år og deres mødre i Innlandet, samt å estimere sammenhengen mellom mors og barns jodinntak.

Methode: En tverrsnittsstudie ble gjennomført i to faser i Innlandet: fase I) blant mor-barn par (barns alder 0–12 måneder) i to kommuner fra oktober til desember 2018, og fase II) blant mor-barn par (barn 0–2 år) i 30 kommuner fra november 2020 til oktober 2021. Prøver av urin og morsmelk ble samlet inn og analysert for jod. Jodinntak ble beregnet ved bruk av ulike metoder: fase I) spørreskjema for nylig og habituelt inntak, og fase II) repeterte 24-timers kostintervju og matvarefrekvensspørreskjema. I fase II ble det statistiske verktøyet «Multiple Source Method» brukt til å estimere distribusjonen av habituelt inntak av jod fra 24-timers kostintervju.

Resultater: Totalt ble 463 mor-barn par inkludert i analysene av jodinntak og jodstatus (130 fra fase I og 333 fra fase II). I fase I var barnas median jodkonsentrasjon i urin (UIC) 145 μg/L, som indikerer tilstrekkelig jodstatus ifølge grenseverdien satt av WHO på 100 μg/L. Habituelt jodinntak ble ikke estimert for alle barna i fase I, men median nylig (24-timers) jodinntak var 50 μg/dag og innenfor anbefalt inntak [«recommended intake» (RI)] på 50–70 μg/dag (NNR2012).

I fase II, som inkluderte et representativt utvalg mor-barn par fra Innlandet, var barnas median UIC 145 μg/L, også over WHOs grenseverdi for tilstrekkelig jodstatus. Median habituelt jodinntak basert på repeterte 24-timers kostintervju var 83 μg/dag og under nylig oppdatert referanseinntak [«adequate intake», (AI)] for denne aldersgruppen på 90–100 μg/dag (NNR2023). Videre hadde 35% av barna et suboptimalt jodinntak [under «estimated average

requirement» (EAR) på 72 µg/dag], og <1 % hadde et for høyt jodinntak [over «upper limit» (UL) på 200 µg/day].

Median UIC blant mødrene i fase II var 92 µg/L, som indikerer utilstrekkelig jodstatus (<100 µg/L). Median jodkonsentrasjon i morsmelk (BMIC) var 74 µg/L. Videre hadde 23% av kvinnene et suboptimalt habituelt jodinntak [under «average requirement» (AR) på 100 µg/dag], mens ingen hadde et for høyt jodinntak (over UL på 600 µg/dag). Barnas UIC og jodinntak var positivt assosiert med BMIC, mors UIC, og mors habituelle jodinntak.

Konklusjon: Barna hadde en adekvat jodstatus på gruppenivå, indikert ved en median UIC over gjeldende grenseverdi på 100 µg/L. 24-timers kostintervjuene indikerte at mer enn en tredjedel av barna hadde et utilstrekkelig jodinntak, mens veldig få barn hadde et for høyt jodinntak. Funnene samsvarer med tidligere funn av lave jodinntak blant ammende kvinner. Med tanke på viktigheten av jod for vekst og utvikling er det behov for tiltak for å øke jodinntaket blant små barn og kvinner i fertil alder.

List of publications

Paper I

Bakken KS, Aarsland TE, Groufh-Jacobsen S, Solvik BS, Gjengedal ELF, Henjum S, Strand TA. Adequate Urinary Iodine Concentration among Infants in the Inland Area of Norway. Nutrients. 2021;13(6).

Paper II

Aarsland TE, Kaldenbach S, Bakken KS, Solvik BS, Holten-Andersen M, Strand TA. Inadequate Iodine Intake in Mothers of Young Children in Innlandet County, Norway. Curr Dev Nutr, 2023. **7**(3): p. 100047.

Paper III

Aarsland TE, Solvik BS, Bakken KS, Sleire SN, Kaldenbach S, Holten-Andersen M, Nermo KR, Fauskerud IT, Østvedt TH, Lohne S, Gjengedaal ELF, Strand TA. Iodine Nutrition in Children ≤2 years of Age in Norway. J Nutr, 2023. 153(11): p. 3237-3246.

Previous publications from the PhD project

- Groufh-Jacobsen S, Mosand LM, Bakken KS, Solvik BS, Oma I, Gjengedal ELF, Brantsæter AL, Strand TA, Henjum S. Mild to Moderate Iodine Deficiency and Inadequate Iodine Intake in Lactating Women in the Inland Area of Norway. Nutrients, 2020. 12(3).

- Bakken KS, Oma I, Groufh-Jacobsen S, Solvik BS, Langfjord MM, Gjengedal ELF, Henjum S, Strand TA. The Reliability of Iodine Concentration in Diaper-Retrieved Infant Urine Using Urine Collection Pads, and in Their Mothers' Breast milk. Biomolecules, 2020. 10(2).

Other contributions from the PhD work

- Co-authored an editorial, entitled "Balancing Iodine Recommendations in Populations". Published in the Journal of Nutrition, October 31, 2023.
- Poster at the 24th European Congress of Endocrinology (Milan, May 2022), entitled "Inadequate Iodine Intake in Lactating Women in the Inland Area of Norway".
- Oral presentation at the 2nd World Iodine Association Conference (Rotterdam, November 2022), entitled "Inadequate Iodine Intake in Lactating Women in the Inland Area of Norway".
- Oral presentation for Norwegian participants at the 5th Nordic Iodine Seminar (Helsinki, December 2022), entitled "The Iodine Project in Innlandet County".
- Oral presentations at seminars for healthcare professionals working with child and maternal health (Lillehammer, Norway, September 2021 and October 2023). Titles: Iodine Status and Intake in Children 0–2 Years of Age in Innlandet County.
- News article in "Bergens Tidende", November 15, 2023 – "Mangel på jod kan gi konsekvensar for barnas vekst og utvikling" (Iodine deficiency may have consequences for child growth and development). Also published in "Stavanger Aftenblad" and "Aftenposten". Available from https://www.bt.no/helse/i/0Q6yzJ/mange-barn-faar-i-seg-for-lite-jod-kan-faa-konsekvensar-for-utvikling#:~:text=konsekvensar%20for%20utvikling-,Mange%20barn%20får%20i%20seg%20for%20lite%20jod%3A%20–%20Kan%20få,ein%20liter%20mjølk%20om%20dagen.

- News article from the University of Bergen, November 15, 2023: “Mange norske småbarn får i seg for lite jod” (Many Norwegian children consume too little iodine). Available from https://www.uib.no/med/166330/mange-norske-småbarn-får-i-seg-lite-jod
- News article from the University of Bergen, April 23, 2021: “Lagde kokebok for å øke jodinntaket” (Created a cookbook to increase iodine intake). Available from https://www.uib.no/med/144559/lagde-kokebok-å-øke-jodinntaket
- Authored a cookbook, “Jodkokeboka” (The Iodine Cookbook), April 2021 with recipes to increase both intake and knowledge of iodine. Available from: https://www.flipsnack.com/a7flipbook/jodkokeboka/full-view.html

List of abbreviations

24-HRs	24-hour dietary recalls
24-H UIE	24-hour urinary iodine excretion
AI	Adequate intake
AR	Average requirement
BMIC	Breast milk iodine concentration
EAR	Estimated average requirement
EFSA	European Food Safety Authority
FCD	Food composition database
FFQ	Food frequency questionnaire
GW	Gestational week
HPT	Hypothalamus-pituitary axis
ICC	Intra-cluster correlation
ICP-MS	Inductively coupled plasma mass spectrometry
IDDs	Iodine-deficiency disorders
IGN	Iodine Global Network
IHT	Innlandet Hospital Trust
IOM	Institute of Medicine
IQ	Intelligence quotient
LOD	Limit of detection
LOQ	Limit of quantification
MoBa	Norwegian Mother and Child Cohort Study
MSM	Multiple Source Method
NIS	Sodium and iodide symporter
NNR	Nordic Nutrition Recommendations

NOK	Norwegian krone
RDA	Recommended dietary allowance
REC	Regional Committee for Medical and Health Research Ethics
RI	Recommended intake
RNI	Recommended nutrient intake
T3	Triiodothyronine
T4	Thyroxine
Tg	Thyroglobulin
THs	Thyroid hormones
TRH	Thyrotropin-releasing hormone
TSH	Thyroid-stimulating hormone
UIC	Urinary iodine concentration
UL	Upper limit
VKM	Scientific Committee for Food and Environment
WHO	World Health Organization

1. Introduction

1.1 Iodine - an essential micronutrient

Iodine is an essential micronutrient that is required for normal neurodevelopment and growth in infants and young children (1) and for metabolism throughout life (2). All the known biological functions of iodine are attributed to its incorporation into the thyroid hormones (THs), triiodothyronine (T3), and thyroxine (T4) (3), which contain three and four iodine atoms, respectively (4).Thus, all the consequences of iodine deficiency and excess are likely attributed to the production of these hormones. Hereafter, T3 and T4 will be collectively referred to as the “thyroid hormones” (THs). Both a deficient and excess iodine intake can impair TH synthesis and thereby cause adverse health effects (5). However, the global focus primarily revolves around combating iodine deficiency. Although programs for salt iodization have been successfully implemented in many countries, mild-to-moderate iodine deficiency remains in all regions worldwide and occurs in both low- and high-income countries (6). Due to the role of iodine in neurodevelopment, infants and women of childbearing age, including pregnant and lactating women, constitute the target population for the prevention and control of iodine deficiency (7-9).

1.1.1 Functions and physiology of iodine

Iodine is not synthesized in the body and must be supplied externally through foods or supplements (10). After ingestion, dietary iodine is reduced to iodide and almost completely absorbed in the stomach and small intestine via the sodium (Na^+) and iodide (I^-) symporter (NIS) (11). Following absorption, iodine from the blood flow is rapidly taken up by the thyroid gland, where it is concentrated and used for synthesis of the THs (12, 13). The degree of thyroidal uptake is related to individual iodine status. When iodine status is adequate, around 10% of ingested iodine is transported to the thyroid gland for TH production. In the state of iodine deficiency, more iodine is prioritized for TH production (up to 80%) (12, 14). Iodine uptake is autoregulated; as concentrations in the gut rise, a regulatory mechanism is activated that downregulates the genetic expression and, thereby, the production and activity of the NIS (13). NIS is also identified in extrathyroidal tissues, such as the placenta and lactating mammary glands. This facilitates the delivery of iodine to the developing fetus and the breastfed child (15). Most of the ingested iodine not used for TH synthesis is excreted in the urine, but small amounts are also excreted through feces (14) and sweat (11).

The healthy adult body contains approximately 15–20 mg of iodine, of which most (70–80%) is concentrated in the thyroid gland (16, 17). Neonatal iodine stores are restricted (on average 50–100 µg), and iodine turnover in the newborn and infant is higher than at any other stage of life (18). Thus, infancy represents the time when iodine requirements are highest relative to body weight (18-20). Since iodine cannot be stored in the body for long periods, a continued supply is needed in all ages and life stages for the synthesis of THs (21). However, an adequate supply in the fetal period and infancy is particularly important for proper neurodevelopment (7, 22). The first 1000 days, spanning from conception until two years of age, is recognized to be a vulnerable period where deficiency of key nutrients can compromise normal development of the brain and nervous system, with possible long-term consequences (23). Thyroidal iodine stores will decrease when exposed to low iodine intake over time, especially during life stages where there is an increased demand, such as pregnancy and lactation (24).

1.1.2 Functions and importance of the thyroid hormones

THs are essential for the biological function of almost all tissues. They play a vital role in the regulation of bodily functions such as the metabolic rate, energy expenditure, and the function of organs like the heart and the brain (25). They also have an essential role in the reproductive system (26). T3 is considered the biologically active TH, while T4 is a prohormone that must be converted to T3 by deiodination in peripheral organs to exert its functions (27). The synthesis and release of THs is tightly regulated between the hypothalamus, pituitary, and thyroid gland, which together form the hypothalamus-pituitary axis (HPT) (28). Thyrotropin-releasing hormone (TRH) is released from the hypothalamus in response to the detection of low circulating TH levels. TRH, in turn, stimulates the secretion of thyroid-stimulating hormone (TSH) from the pituitary, which increases prohormone T4 production and, to a lesser extent, production of the active T3 hormone (29). In target tissues, THs bind to specific TH receptors in cells, forming a complex that acts as a transcription factor inducing or repressing gene expression (30).

In the fetal period and infancy, THs are essential for many metabolic reactions influencing growth and development, including neuronal and glial cell differentiation, myelination, and synaptogenesis (31), stimulation and expression of growth hormone (32), and regulation of basal metabolic rate (2). TH receptors are expressed in the human brain already by gestational week (GW) 10, and THs have been detected in the cerebral cortex by

GW 12 (33). The fetal thyroid begins to concentrate iodine at 10–12 weeks of gestation, but it is not able to produce THs until mid-gestation (around 20 weeks). Until then, the fetus is entirely dependent on maternal TH crossing the placenta to ensure normal neurodevelopment (34). Even after the onset of fetal TH production, maternal TH supply continues to play an important role in neurodevelopment until birth (35). Further, for the fetal thyroid to be able to produce THs, maternal iodine delivery across the placenta is needed, as this is the only source of iodine for the fetus during gestation (36).

During pregnancy, maternal TH production and iodine requirements increase to ensure a proper amount for both the pregnant mother and the developing fetus (36). An inadequate production of THs (hypothyroidism) during pregnancy has been associated with an increased risk of miscarriage, premature birth, low birth weight, and congenital abnormalities (37). In postpartum women, abnormal TH concentrations may complicate lactation; hypothyroidism may suppress milk production, while there is limited data on the effects of excessive TH production (hyperthyroidism) on milk production (38). Although small amounts of THs are present in breast milk, breastfed infants rely on their own production, which requires iodine, to meet their needs (18, 39). Thus, maternal iodine requirements remain high during lactation.

1.1.3 Health concequences of iodine deficiency

In humans, the most adverse consequence of iodine deficiency is cretinism, which is related to TH deficiency in the early stages of embryonal development (neurological cretinism) (40) or during late pregnancy or early infancy (myxedematous cretinism) (41). Cretinism is characterized by severe and irreversible alterations in brain development, mental retardation, dysfunction of hearing and speech, and growth defects (7, 42). Today, cretinism is rare since widespread programs of iodine supplementation have almost eradicated severe iodine deficiency globally (43). Also, in many countries, newborns are screened for congenital hypothyroidism, ensuring prompt TH replacement to improve neurodevelopmental outcomes (44). Insufficient iodine intake and impaired TH production can have clinical and subclinical health consequences in all life stages, collectively known as iodine-deficiency disorders (IDDs). IDDs refer to all the consequences of iodine deficiency in a population that can be prevented by an adequate iodine intake. Besides cretinism and impaired growth, IDDs include hypothyroidism, thyroid enlargement (i.e., goiter), impaired mental function, and iodine-induced hyperthyroidism (45). Thus, an adequate and continued iodine intake is needed across the entire lifespan.

As outlined earlier, mild-to-moderate iodine deficiency is still a public health concern in many countries, especially in Europe (6, 46, 47). Although low iodine intake is common in pregnant and lactating women, the consequences of mild-to-moderate iodine deficiency on child development are not clear. As summarized by Dineva et al (48), some observational studies in pregnant women have linked it to adverse effects on neurodevelopmental outcomes including executive functions (49), intelligence quotient (IQ) scores (50), reading ability (50, 51), school performance (52, 53), cognitive scores (54), and language skills (55). However, not all studies have found significant associations (56-58). The brain needs THs for its development, particularly during the first two years of life. Thus, it is important that the early diet supplies an adequate intake of iodine (10, 23).

1.1.4 Health consequences of excessive iodine intake

Excessive iodine intake is associated with an increased risk of impaired thyroid function (5, 59). This can cause goiter, increased and decreased TH production (hyperthyroidism and hypothyroidism, respectively), autoimmunity, and inflammation of the thyroid gland (thyroiditis). While the clinical and developmental consequences of iodine excess in early life are uncertain (59), the fetus and infant may be less able to adapt to high iodine intakes than adults (22). Thus, when introducing measures to improve iodine intake, such as salt iodization programs, it is important to ensure a safe iodization level that does not lead to excessive iodine intake in vulnerable groups. Excessive iodine intake during lactation may increase the maternal susceptibility to thyroid dysfunction, and it has also been associated with hypothyroidism in infants, induced by excessive amounts of iodine in breast milk (59). The consequences of iodine excess are less understood than the consequences of iodine deficiency. Nevertheless, iodine intake far above requirements are unnecessary and should generally be avoided (43).

1.2 Iodine in the environment

Iodine occurs naturally in the environment and is distributed in rocks, soils, water, plants, animal tissues, and foodstuffs. Like other elements, iodine is part of a natural cycle, with most being present in the ocean. From the ocean, iodine is released into the atmosphere and returned to the soil and groundwater by rain (60). Its concentration in foods and drinking water differs with geographical location and can vary considerably between and within countries (61). Mostly, the iodine content in soils and drinking water is relatively low and does not contribute substantially to the overall intake (62).

1.2.1 Dietary sources of iodine

The main sources of iodine in many diets are iodized salt (not in Norway), cow's milk, seafood, and eggs (46). Mandatory or voluntary salt iodization is implemented in many countries and is the most effective method of controlling and eliminating IDDs (43) (continued in section 1.5). Cow's milk has a low native iodine content but often contains iodine due to the use of iodized cattle fodder or disinfecting agents. Depending on dairy practice, products such as yoghurt and whey cheese may therefore also be good sources of iodine (63). Seafood has a naturally high iodine content, particularly lean saltwater fish (e.g., cod, saithe, and haddock) and seaweed (64). Some seaweed species can accumulate considerable amounts of iodine and should be used with caution in order to avoid an excessive intake of iodine (65, 66). In Norway, cow's milk and lean fish are the main sources of iodine in the diet. However, the consumption of milk and fish has decreased considerably during recent decades, particularly among young women (67). This is highly concerning considering the outlined importance of iodine prior to, during, and after pregnancy. Individuals with a low consumption of milk and lean fish in Norway are at high risk of iodine deficiency due to few other iodine sources in the diet. Thus, individuals with a low intake of milk and/or lean fish are recommended iodine-containing supplements (68) (further described in section 1.5). **Table 1** presents some of the dietary sources of iodine in the Norwegian diet, with iodine content per 100 g and in the given portion of the item.

Table 1. Sources of iodine in the Norwegian diet and their contributions to iodine intake.

Food item	Iodine (µg/100 g)[1]	Portion size (g/dL)[2]	Iodine (µg) per portion
Cow's milk	15	2 dL	30
Yoghurt, plain/flavored	15	125 g	13
White cheese	13	20 g	3
Brown cheese	203	16 g	21
Cod fillet, prepared	279	200 g	372
Salmon, farmed, raw	6	150 g	6
Mackerel in tomato sauce	15	40 g	4
Caviar	85	40 g	91
Egg	35	56 g	13

[1]Iodine concentrations from the Norwegian Food Composition Table, available from www.matvaretabellen.no (69) (accessed September 21, 2023). The values do not take into account the variation in iodine concentrations in foods.
[2]Standard Norwegian portion sizes from "Mål, vekt og porsjonsstørrelser for matvarer" (70).

Sources of iodine in early life

Before the introduction of complementary foods at 4–6 months of age, infants must receive sufficient iodine for TH production through breast milk and/or formula. The iodine concentration in breast milk (BMIC) depends on maternal iodine intake and status and reflects the maternal iodine intake the few hours before breastfeeding (22). The iodine concentration in formula is highly variable, but in EU countries, it ranges from 15–29 µg per 100 kcal according to legislation (71). Other sources of iodine for infants and young children include enriched baby porridge, saltwater fish, eggs, and cow's milk (72, 73). In Norway, cow's milk is not recommended as a drink before one year of age, as it is low in iron (74). Infants and young children in Norway with a vegan diet are recommended iodine-containing supplements, also exclusively breastfed infants of mothers who have a vegan diet (75).

1.3 Reference intakes of iodine

Only 5 g of iodine are sufficient to cover the lifetime needs of an individual with a lifespan of 70 years (17). However, the thyroid gland needs a regular iodine supply for TH production. Recommended intakes of iodine differ with age and life-stage and vary between authorities. The association between iodine intake level and the risk of thyroid disease is U-shaped, as both low and high iodine intakes are associated with reduced TH production (5). Thus, iodine intake should be kept within a relatively narrow range to prevent IDDs. The iodine recommendations increase during pregnancy due to increased maternal TH production, increased urinary iodine excretion, and iodine transfer to the fetus (76). Lactating women also have increased requirements as they excrete iodine not only through urine but also through breast milk (22).

Table 2 gives the recommended intakes of iodine at different life stages from the Nordic Nutrition Recommendations (NNR) (77, 78), the World Health Organization (WHO) (45), the European Food Safety Authority (EFSA) (79), and the Institute of Medicine (IOM) (80). Of note, in the most recent NNR edition (NNR2023), there was an increase in the recommendations for young children compared with the previous edition (NNR2012) based on a 2016 balance study in Swiss infants (18). Both are presented in the table since they were both used in the work presented in this thesis. Also, in the NNR2012, the reference value for iodine was recommended intake (RI), while in the NNR2023 it was adequate intake (AI). The AI has larger uncertainty than the RI and is often used when an RI cannot be determined (77). The RI is the average daily intake level that is sufficient to meet the requirements of nearly all individuals (usually 97.5%) in a particular life-stage group in the general population (78). The term corresponds to the recommended nutrient intake (RNI) used by the WHO, the recommended dietary allowance (RDA) used by the IOM, and the AI used by EFSA. The AI from NNR2023 is the average daily intake expected to meet or exceed the needs of most individuals in a life-stage group (77).

Table 2. Daily iodine reference intakes (µg/day) by different authorities.

Authority	Children and adolescents (µg iodine/day)	Adults (≥18 y) (µg iodine/day)
NNR2023 (77) (Adequate intake, AI)	<12 mo: 80–90[1] 1–10 y: 100 11–17 y: 120–140[2]	Non-pregnant: 150 Pregnant: 200 Lactating: 200
NNR2012 (78) (Recommended intake, RI)	6–11 mo: 50 12–23 mo: 70 2–5 y: 90	Non-pregnant: 150 Pregnant: 175 Lactating: 200
WHO (45) (Recommended nutrient intake, RNI)	0–59 mo: 90 6–12 y: 120	Non-pregnant: 150 Pregnant: 250 Lactating: 250
EFSA (79) (AI)	7–11 mo: 70 1–17 y: 90–130[3]	Non-pregnant: 150 Pregnant: 200 Lactating: 200
IOM (80) (Recommended dietary allowance, RDA)	1–9 y: 90 9–13 y: 120 14–18 y: 150	Non-pregnant: 150 Pregnant: 220 Lactating: 290

[1]80 µg/day in developing countries and 90 µg/day in developed countries.
[2]120 µg/day in females, 130 µg/day in 11–14 y males, and 140 µg/day in 15–17 y males.
[3]90 µg/day for 1–10 y, 120 µg/day for 11–14 y, and 130 µg/day for 15–17 y.
EFSA, European Food Safety Authority; IOM, Institute of Medicine; NNR, Nordic Nutrition Recommendations; y, years; WHO, World Health Organization.

Another reference used to evaluate iodine intake is the estimated average requirement (EAR) or the average requirement (AR), which are similar terms from different authorities. The EAR/AR defines the average daily nutrient intake that is suggested to meet the requirements of 50% of the healthy individuals in a particular life-stage group (77, 81). The percentage of individuals with usual nutrient intakes below the EAR/AR are at risk of nutrient inadequacy (82-84). Further, the upper limit (UL) defines the highest intake level of a nutrient that is unlikely to pose adverse health effects for the population (77, 81). Optimally, long-term iodine intake should fall between the RI/AI and the UL (85). **Table 3** gives the EAR/AR and UL of iodine for infants and young children and adults from the NNR and the IOM.

Table 3. Estimated average requirement/average requirement and upper limit of iodine (µg/day) by the Nordic Nutrition Recommendations and the Institute of Medicine.

Authority	**Infants and young children, (µg iodine/day)**	**Adults (≥18 y) (µg iodine/day)**
NNR2023 (77)[1]	AR: 64–72 (≤6 mo), 80 (1–3 y) UL: not defined	AR: 120, 160 (lactating women) UL: 600
NNR2012 (78)	Not defined	AR: 100 UL: 600
WHO	Not defined	Not defined
EFSA (79)	EAR: Not defined UL: Not defined <1 y, 200 (1–3 y)	EAR: Not defined UL: 600[2] (including lactating women)
IOM (80)	EAR: 65 (1–8 y) UL: Not defined <1 y, 200 (1–3 y)	EAR: 95, 209 (lactating women) UL: 1100, 900–1100 (lactating women)[2]

[1]Provisional ARs, with a larger uncertainty than AR (77).
[2]900 µg/day for 14–18 y and 1100 µg/day for 19–50 y.
AR, average requirement; EAR, estimated average requirement; UL, upper limit; IOM, Institute of Medicine; NNR, Nordic Nutrition Recommendations; y, years.

1.4 Assessment of iodine nutrition

The current guidance on indicators for assessing iodine status in a population was published by the WHO in 2007 (45). This guidance is currently undergoing revision by an expert group formed by the WHO. Five primary indicators for the assessment have been proposed: urinary iodine concentration (UIC), BMIC, thyroid volume, TSH, and thyroglobulin (Tg) (86). In certain contexts, dietary assessment methods can also be used to estimate usual iodine intake and to identify major sources of dietary iodine (87). For instance, this is often done in Norway due to a low iodine concentration in salt (5 µg/g), few dietary sources of iodine, and regularly updated food composition data including iodine concentrations in foods. The following section will briefly describe the five proposed indicators for assessment of iodine nutrition, as well as methods for evaluating iodine intake.

1.4.1 Urinary iodine concentration (UIC)

The recommended and most used measure of population iodine status is median UIC from spot urine samples (88). After digestion of iodine and transport to the thyroid gland, the remaining iodine is rapidly (within 24–48 hours) excreted by the kidneys in the urine (89). Thus, UIC is reflective of recent iodine intake. Due to large intraindividual variations in UIC (e.g., with iodine intake and hydration status), it is not a reliable individual biomarker of iodine status unless at least 10 spot samples are collected (90, 91). Nevertheless, it is a useful measure to assess the iodine status of populations (45).

The standard approach to assessing iodine status in a population is to measure spot UIC and compare the median to established cut-off values. This is a non-invasive, relatively cheap, and easy procedure (88, 92). The amount of iodine excreted can also be measured over a 24-hour period (24-hour urinary iodine excretion, 24-H UIE). Although 24-H UIE is considered a better proxy of recent iodine intake than spot UIC (93), it is costly and impractical in large study settings (94). According to the WHO, a median UIC of 100–199 μg/L defines adequate iodine intake in school-age children and non-pregnant adults. This range is based on epidemiological data in school-age children, showing a higher prevalence of goiter at a median UIC <100 μg/L (22). Further, a median UIC within the range of 50–99 and 20–49 μg/L is defined as mild and moderate iodine deficiency, respectively (88). For lactating women and children <2 years of age, a median UIC >100 μg/L can be used to define adequate iodine intake (45). Yet, for these groups, no upper adequacy level or thresholds to define the degree of iodine deficiency have been set. Nevertheless, the terms "mild" and "moderate" iodine deficiency are often used to describe iodine status in lactating women and children, and also in the papers included in this thesis. The epidemiological criteria for assessing iodine nutrition in population groups based on median UIC are described in **Table 4**.

Table 4. Epidemiological criteria from the World Health Organization for assessing iodine nutrition in a population based on median urinary iodine concentration (45).

Median UIC (μg/L)	Iodine intake	Iodine status
School-age children[1]		
<20	Insufficient	Severe iodine deficiency
20–49	Insufficient	Moderate iodine deficiency
50–99	Insufficient	Mild iodine deficiency
100–199	Adequate	Adequate iodine nutrition
200–299	Above requirements	Likely to provide adequate intake for pregnant/lactating women, but may pose a slight risk of more than adequate intake in the overall population
≥300	Excessive	Risk of adverse health consequences (iodine-induced hyperthyroidism, autoimmune thyroid diseases)
Pregnant women		
<150	Insufficient	
150–249	Adequate	
250–499	More than adequate	
≥500	Excessive	
Children <2 years of age and lactating women		
<100	Insufficient	
≥100	Adequate	

[1]Applies to adults.
UIC, urinary iodine concentration.

1.4.2 Breast milk iodine concentration (BMIC)

During lactation, iodine is also excreted into breast milk. Thus, BMIC has been proposed as a promising marker of iodine status in lactating women (95). However, its use is somewhat limited since the optimal BMIC to support infant iodine requirements is unclear. A median BMIC of 100–200 μg/L has been suggested (22, 96, 97), but there is a need for more studies investigating BMIC to gain a better understanding of its utility and to establish thresholds for assessing iodine status (95). When assessing iodine status in lactating women, BMIC should be interpreted in conjunction with UIC. An additional reason is that partitioning of iodine between urine and breast milk may vary with iodine status (98).

1.4.3 Thyroid volume

In chronic iodine deficiency, the volume of the thyroid gland will expand in an attempt to trap more iodine from the bloodstream (99). This results in an enlarged thyroid size (goiter), which can be measured by ultrasound, seen, or felt by palpation. The size of the thyroid gland may take years to shrink after correcting iodine deficiency and is not a sensitive marker in populations with recent changes in iodine intake or populations with mild-to-moderate iodine deficiency (100). It is also difficult to measure thyroid size in young children with small thyroid glands (45).

1.4.4 Thyroid stimulating hormone (TSH)

TSH stimulates the thyroid gland to synthesize THs to maintain homeostasis of THs in the bloodstream. It is a sensitive indicator of iodine status in newborns, but not in older children and adults as the intraindividual changes vary and the levels can remain within the normal range even in iodine deficient populations (87).

1.4.5 Thyroglobulin (Tg)

Tg is a glycoprotein synthesised in normal thyroid cells and secreted by the thyroid gland (101). It binds iodine and is needed to produce T3 and T4. Tg is widely used in monitoring thyroid cancer and in diagnosing certain other thyroid diseases but is increasingly being used as an indicator of population iodine status as well (102). Tg is measured in serum or in dried blood spots, and elevated levels are seen both during iodine deficiency and iodine excess (101). It is considered a sensitive marker for iodine status; however, validated reference ranges are lacking to assess iodine status in some population groups, including pregnant women and neonates (102).

1.4.6 Dietary iodine intake

In many countries, the consumption of iodized salt contributes significantly to iodine intake, which makes estimation of iodine through the diet difficult (67). In Norway, with few dietary sources of iodine and a low iodine concentration in salt, dietary assessment tools are often used in combination with UIC to assess iodine nutrition. Methods commonly used for estimating short-term iodine intake include 24-hour dietary recalls (24-HRs) and food records, which typically capture dietary intake over a 1-day period. These instruments can also be used to estimate usual (long-term) intake if repeated measurements are available from at least a subgroup of the population. Long-term instruments, such as food frequency questionnaires (FFQs), aim to assess long-term intake directly (103). All dietary assessment methods have limitations and are associated with measurement errors, as further elaborated on in the discussion section (section 5.1.4).

1.5 The global iodine situation and efforts to prevent iodine deficiency

The current global iodine nutrition status (year 2021) in school-age children, which is often used as a proxy indicator of population iodine status within a country, is shown in **Figure 1**. The figure shows that among 143 countries with UIC data, iodine intake is sufficient in 112 countries (median UIC 100–299 μg/L), insufficient in 20 countries (median UIC <100 μg/L), and excessive in 11 countries (median UIC ≥300 μg/L). Many countries lack updated data on iodine status as national surveys are costly and often not prioritized over other, more urgent matters (47). Of note, it has been argued that UIC in school-age children does not adequately reflect iodine status in all population groups, such as pregnant women and young children (46). Thus, the WHO and the Iodine Global Network (IGN) are currently working on extending global reporting on iodine status to also include adults and pregnant women (47). In Europe, countries that have dietary data on iodine intake (in addition to UIC data) suggest low intakes in a considerable proportion of the population, especially in women of childbearing age (46). Yet, data on iodine nutrition in young children have been scarce and are available from few countries.

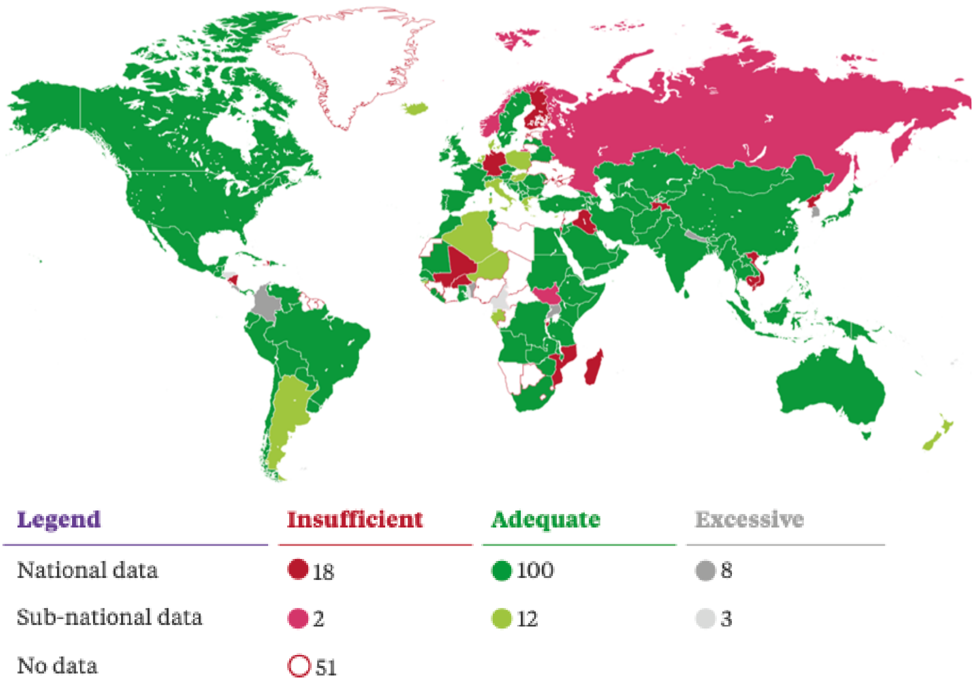

Figure 1. Estimated iodine nutrition in 194 WHO member states in 2021 based on median UIC in school-age children obtained from studies conducted between 2007–2021.
Insufficient, median UIC <100 µg/L; adequate, median UIC 100–299 µg/L; excessive, median UIC ≥300 µg/L. UIC, urinary iodine concentration. Figure reproduced from IGN Annual Report 2022 (47) with permission.

To prevent and control iodine deficiency and IDDs, the WHO recommends fortifying all food-grade salt, used in household and food processing, with 20–40 mg iodine per kg of salt. The fortification level should be based on local salt consumption and population iodine status. Salt is an effective vehicle for iodization due to its widespread daily use regardless of socioeconomic status, and the function and culinary properties of salt are not affected by iodine. Also, the iodine concentration can easily be adjusted to the relevant conditions of the local population (104). Salt iodization over the past decades has almost eradicated severe iodine deficiency worldwide. In 2022, UNICEF estimated that 88% of the world's population used iodized salt; 126 countries had legislation in place for mandatory iodization, and 21 countries had legislation allowing voluntary iodization (105). Nevertheless, mild-to-moderate iodine deficiency is still prevalent, even in many high-income countries, including Norway

(6). Among the Nordic countries, Denmark has implemented mandatory salt iodization, while Norway, Finland, and Sweden have voluntary salt iodization (106).

In areas with few dietary iodine sources and insufficient access to iodized salt, the WHO recommends iodine-containing supplements for pregnant and lactating women (250 μg/day), women of childbearing age (150 μg/day), and children <2 years of age (90 μg/day) (45). Several other scientific societies, including the European and American Thyroid Associations, also recommend iodine-containing supplements for women who are pregnant, lactating, or planning pregnancy (107, 108), but the practice is variable between countries. The Norwegian Directorate of Health recommends iodine-containing supplements for individuals who do not meet their recommendations through food sources (68). Further, in 2018, iodine-containing supplements were specifically recommended for women of childbearing age, pregnant, and lactating women with low intakes of milk and/or lean fish. The same year, iodine was implemented in antenatal care as a nutrient that requires special attention, similar to nutrients such as folic acid, vitamin D, and iron (109). The group-specific recommendations for iodine-containing supplements are outlined in **Table 5**. Supplements based on kelp or macroalgae can have a very high and variable iodine content and should be used with caution (66, 110).

Table 5. Recommendations for iodine-containing supplements for groups at risk of iodine deficiency by the Norwegian Directorate of Health (68).

Population group	Intake of iodine sources	Recommended dose from supplement (μg/day)
Women of childbearing age	<3 dL milk/yoghurt per day, combined with a regular intake of lean fish, *or* 5 dL milk/yoghurt per day, combined with little to no lean fish	100
Pregnant and lactating women	<6 dL milk/yoghurt per day, combined with a regular intake of lean fish, *or* 8 dL milk/yoghurt per day, combined with little to no lean fish	150
Allergic, vegetarians, and others	All individuals who exclude dairy or consume <3.5 dL milk/yoghurt per day (depending on lean fish consumption)	100–150

1.6 The iodine situation in Norway and knowledge gaps

In Norway, severe iodine deficiency and goiter was widespread until the 1950s, when iodine was added to cow fodder to improve animal welfare (67). Goiter was especially prevalent in inland districts where the availability of saltwater fish was low (111). Following the addition of iodine to cow fodder, goiter as a public health problem was nearly eradicated as iodine from enriched fodder was excreted in cow's milk and the human consumption of cow's milk was high (67). In 2013, findings from the Norwegian Mother and Child Cohort Study (MoBa) revealed insufficient iodine intake among pregnant women from all over Norway (112). Since then, multiple studies have reported inadequate iodine intakes in population groups such as young (113), pregnant (114, 115), and lactating women (115-117), as well as the elderly and individuals following a vegan diet (118). However, studies focusing on iodine nutrition in young children have been limited.

In 2016, the National Council of Nutrition in Norway released a report claiming an acute need for action to improve iodine status in vulnerable population groups (111). At that point in time, Norwegian regulations permitted only 5 µg iodine per g of salt on a voluntary basis. The council strongly advised an increase in the iodine fortification of salt, and to implement a national monitoring program. This was further assessed in a risk-benefit report by the Scientific Committee for Food and Environment (VKM) in 2020 (119). VKM estimated the effect of different fortification scenarios by modulating iodine exposure in children (aged 1, 2, and 13), pregnant women, and lactating women, with four levels of iodization (15, 20, 25, and 50 µg/g salt). The conclusion was that no level of salt iodization could ensure sufficient iodine intake in pregnant and lactating women without also exposing young children, particularly 1- and 2-year-olds, to the risk of excessive iodine intake. Nevertheless, the year after (2021), the Council of Nutrition once again advised the health authorities to implement immediate mandatory iodization of household salt and salt in industry bread and bakery products with 20 µg iodine/g salt, up from the current 5 µg/g (120). Legislation to raise the concentration was approved in 2023 (121). However, the industry has not been encouraged to alter their procedures, and no producers have made changes thus far. The case is currently under consideration with the Ministry of Health and Care Services, and a proposal for a national monitoring program has been outlined to ensure a proper iodization level (67). As highlighted in the VKM report, there is a need for more data on iodine nutrition in Norway, especially in groups susceptible to both low and high intakes, such as infants and young children (119).

2. Objectives

The overall aim of this PhD project was to generate population-based data on iodine nutrition (iodine status and iodine intake) in children between 0–2 years of age and relate it to markers of maternal iodine nutrition. This was investigated in a cross-sectional study comprising mother-child pairs recruited from public healthcare clinics in Innlandet County, Norway.

Specific objectives

Paper I

Describe iodine nutrition in infants (0–12 months of age) in Innlandet County, Norway.

Paper II

Describe iodine intake (not status) in mothers of young children (0–2 years of age) in Innlandet County, Norway.

Paper III

Describe iodine nutrition in a representative sample of young children (0–2 years of age) in Innlandet County, Norway, and relate it to maternal iodine nutrition.

3. Materials and methods

All data and biological samples presented in this thesis are from the "Iodine in Early Life" study – a two-phase cross-sectional study conducted in Innlandet County, Norway. In the following sections, the data collection procedures and methods used throughout the thesis will be described. An overview of the study designs, study participants, and outcomes of Papers I-III are presented in **Table 6**.

Table 6. Overview of the characteristics of the papers included in this thesis.

	Paper I	Paper II	Paper III
Study design and information	Cross-sectional Phase I of the "Iodine in Early Life" study	Cross-sectional Phase II of the "Iodine in Early Life" study	Cross-sectional Phase II of the "Iodine in Early Life" study
Study participants and recruitment	Infants 0–12 months (n = 130) Convenience sampling	Mothers of young children (0–27 months) (n = 300) Random sampling	Young children (0–27 months) (n = 333) Random sampling
Study cites	2 municipalities in Innlandet County, Norway	30 municipalities in Innlandet County, Norway	30 municipalities in Innlandet County, Norway
Outcomes	Recent (24-hour) and usual intake of iodine-rich foods, UIC from spot urine samples	Usual iodine intake by 2 x 24-HRs and FFQ	Usual iodine intake by 2 x 24-HRs and FFQ. UIC from mother and child and BMIC (all spot samples)
Study period	Oct–Des 2018	Nov 2020–Oct 2021	Nov 2020–Oct 2021

24-HRs, 24-hour dietary recalls; FFQ, food frequency questionnaire; UIC, urinary iodine concentration; BMIC, breast milk iodine concentration.

3.1 Study design

The main aim of the "Iodine in Early Life" cross-sectional study was to describe iodine nutrition in a population of young children in Innlandet County, Norway, and relate it to maternal iodine nutrition. The reason for the two-phase design of the study was initial funding constraints and unforeseen challenges posed by the COVID-19 pandemic. As outlined in **Table 6**, phase I comprised infants 0–12 months of age. As additional funding was achieved after phase I was completed, opportunities for expansion of the study emerged. This coincided with a risk-benefit report by the VKM published in 2020, warranting more knowledge on iodine nutrition among children up to two years of age (119). Thus, in phase II of the study, the geographical scope was widened to cover a larger part of Innlandet County, to select the public healthcare clinics randomly, and the children's age was raised from 12 months to two years. Moreover, the additional funding facilitated the integration of a PhD student into the project, which enabled a more comprehensive collection of dietary data.

3.2 Study population

The study comprised two phases, both conducted in collaboration with public healthcare clinics in Innlandet County. The healthcare clinics were part of the national infant healthcare programme (0–5 years of age), offering free care for children and their parents with 13 routine consultations after birth until two years of age. The inclusion criteria were: (1) ability of the mother to read and write in Norwegian; (2) child's age between 0–12 months in phase I and 0–2 years in phase II; and (3) no known ongoing, congenital, or chronic illness in the child. In phase I, mother-infant pairs from two public healthcare clinics were recruited, one located in Lillehammer municipality and the other in Gjøvik. The two municipalities were selected based on convenience (population size and proximity to some of the investigators). If the child attended the consultation with another caregiver than the mother, the caregiver was asked to provide written information about the study to the mother. In phase II, the recruitment covered a larger part of Innlandet County. First, municipalities were randomly selected from a list of all municipalities in the county. In this list, each municipality was represented from 1–10 times according to the birth rate in 2019, prompting equal probability to be invited into the study regardless of population size. Following the selection of municipalities (44 out of 46 municipalities in the county as of 2020), the corresponding healthcare clinics within these municipalities were invited to take part, of which 30 accepted. For each time a municipality was listed, the public healthcare nurses within that municipality were asked to consecutively recruit a total of four mother-child pairs. In other words, if a healthcare clinic was approached once (listed once), a maximum of four mother-child pairs could be enrolled. If a healthcare clinic was approached twice (listed twice), a maximum of eight mother-child pairs could be enrolled. The maximum number of mother-child pairs enrolled from one municipality was 40. The public healthcare nurses received training with instructions and support for recruitment from the study team at Innlandet Hospital Trust (IHT).

In total, from both phases, 516 women completed the informed consent form. Out of these, 53 withdrew or were excluded from the study. Thus, 463 mother-child pairs were included in the final analyses. Assessment of iodine nutrition was carried out using questionnaires, interviews, and biological samples, as further described in the upcoming sections. A flow chart of the study population and collected data is given in **Figure 2.**

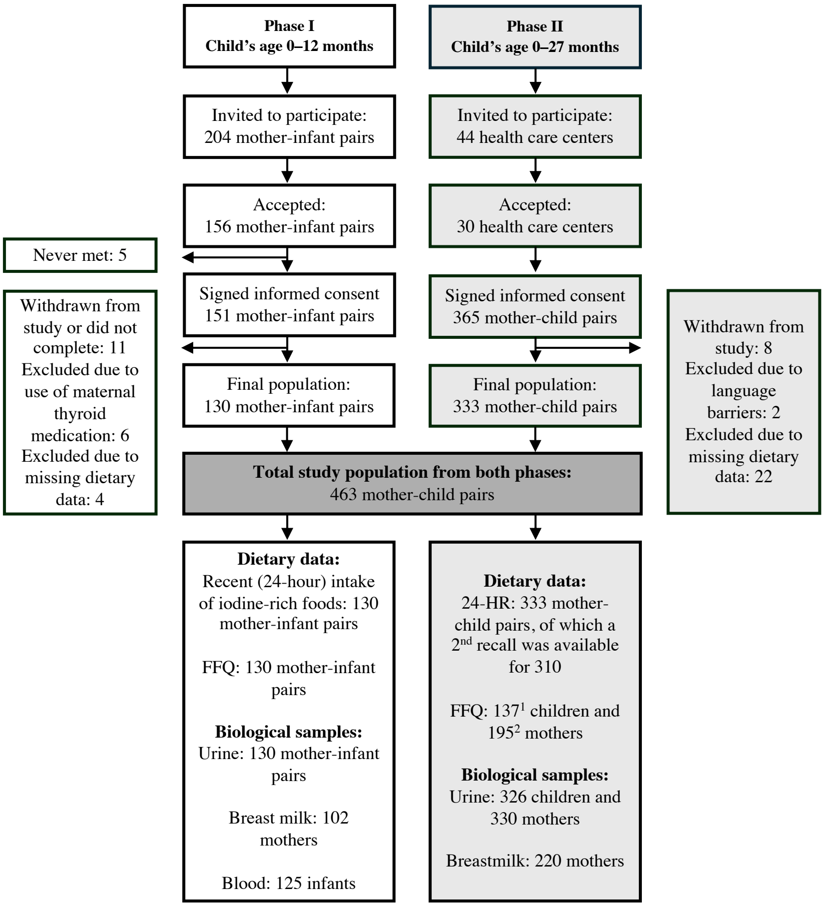

Figure 2. Flow chart of the study population and collection of urine, breast milk, and dietary data. [1]FFQ was completed for 251 children, but calculations of iodine intake were only computed for children $\geq$6 months of age (n = 137).[2] FFQ was completed for 242 women, but in the distributions of iodine intake by FFQ, women who did not complete 2 x 24-HR (n = 19), and women with implausible energy intake (estimated energy intake outside the range of 500–3500 kcal/day based on the mean of two 24-HRs) were excluded (n = 28).
24-HR, 24-hour dietary recall; FFQ, food frequency questionnaire.

3.3 Data collection methods

3.3.1 Collection and analysis of biological samples

Spot samples of urine and breast milk were collected from the mother-child pairs. Maternal UIC and BMIC from phase I was not part of the papers included in this thesis and has been described elsewhere (122). Briefly, in both phases, urine and breast milk samples were collected at home, marked with unique ID numbers, kept refrigerated, returned to the healthcare clinics, picked up by the study team, and analyzed for iodine concentrations with inductively coupled plasma mass spectrometry (ICP-MS). A brief overview of the sample preparations and measurements are given below, but full details are provided in Papers I and III.

Urine samples

Data on UIC were presented in Paper I (infant UIC, phase I) and Paper III (maternal and child UIC, phase II). In phase I, the child's UIC was measured in a spot urine sample collected in the morning, on the same day as the maternal breast milk sample. In phase II, for compliance and convenience, the mothers could sample the spot urine at any given time point during the day. For sampling of urine from the children, a urine collection pad (Sterisets urine collection packs, Sterisets International BV, Oss the Netherlands) was placed inside the diaper, and the urine was extracted using a disposable syringe. An alternative method was to open the pad and squeeze the urine from the wet cotton directly into the urine container. A repeat spot urine sample from the same day was collected for a subsample of the infants to assess the reliability of the diaper-pad collection method that was used to retrieve the urine. Further, a spot urine sample from the mother was collected using a 100 mL Vacuette® urine beaker (Greiner Bio-One, Kremsmünster, Austria) and a 9.5 mL Vacuette® urine tube (Greiner Bio-One, Kremsmünster, Austria). The samples were kept refrigerated (4 °C) until pick up by the study team.

Breast milk samples

All lactating women were asked to provide a breast milk sample. As described, maternal iodine nutrition from phase I was not part of the papers included in this thesis and, thus, further description of maternal UIC and BMIC focus on the women from phase II. In phase II, one spot breast milk sample of 20 mL (or any volume below the woman was able to provide) was requested from any given time point during the day. The breast milk was sampled by manual or mechanical expression into a 50 mL polypropylene centrifuge tube (Sarstedt, Nümbrecht, Germany). The samples were kept refrigerated (4 °C) until pick up by the study team.

Inductively coupled plasma mass spectrometry analyses

Iodine concentrations in urine and breast milk was determined by ICP-MS. In Paper I (infant urine, phase I), the limit of detection (LOD) was 0.1 µg/L and the limit of quantification (LOQ) was 0.44 µg/L. In Paper III (maternal and child urine, and breast milk), the LOD was

0.20 μg/L and the LOQ was 0.79 μg/L. The analyses were conducted at the Faculty of Environmental Sciences and Natural Resource Management at the Norwegian University of Life Sciences, Norway. This is a research and teaching laboratory that specializes in inorganic instrumental analysis, with particular emphasis on analytical methods based on atomic spectroscopy and associated sample preparation. The laboratory imparts knowledge on how to ensure measurement quality, that a method is technically appropriate for the intended purpose, that the method is validated, and that the method performance is under control (123).

Infant blood Samples

Infant blood samples were collected in phase I of the study. We originally planned to measure Tg and thyroid function among the infants, but this was not possible due to several reasons, including the COVID-19 pandemic and poor statistical power to examine the relation between UIC and thyroid function.

3.3.2 Dietary assessment methods

To assess nutritional adequacy in population settings, detailed information on dietary intake data is needed. Several methods have been developed for this purpose, including the 24-HR and the FFQ that assess short-term and long-term intake, respectively. Different approaches to dietary assessment were taken in the two phases of the study, though both phases applied methods that examine short-term (24-hour) and long-term iodine intake. In phase I of our study, the dietary assessment focused on iodine-rich food sources, while in phase II, a more general assessment of the diet was conducted. In phase II, the short-term measurements were repeated to provide estimates of usual (long-term) iodine intake using a statistical modeling method (continued in section 3.5). Details on the data collection methods and the processing of dietary data will be provided in this section. As already mentioned, maternal iodine intake from phase I was not part of the papers included in this thesis and has been described in detail previously (122).

Short-term assessment: 24-hour intake of iodine-rich foods and 24-hour dietary recalls

In phase I, short-term iodine intake of the infants was recorded by the mothers using a paper-based questionnaire with specific questions about the intake of iodine-rich foods the past 24 hours. The questionnaire (Appendix I) was specifically developed for the study and included questions regarding the consumption of 15 individual iodine-rich foods or food groups, including porridge (industry-produced/homemade), yoghurt, eggs, lean fish and fish-derived products, and cheese. There were open-ended fields for specifying type/brand and consumption amount, in addition to questions about breastfeeding status, formula use, and use of iodine-containing supplements. The questionnaire was completed at the healthcare clinic when the women came to deliver the biological samples.

In phase II, short-term iodine intake was assessed using 24-HRs. A 24-HR is a structured interview that aims to capture detailed information about all the foods and beverages (and possible use of dietary supplements) consumed by an individual in the past 24 hours. By telephone interviews with one of the three certified dietitians in the study team, the mothers were asked to recall as freely as possible their own and their child's consumption the day before the recall, commencing with the first food or drink consumed after waking and the following 24 hours. Next, questions about portion sizes, ingredients, and preparation methods were obtained, and the interviewer ensured that nothing was missed using a list of easily forgotten foods (e.g., butter/oil in cooking, snacks between meals, dietary supplements, and foods eaten while outside the home). For the children, all interviews were initiated with questions about the intake of breast milk and/or formula. We aimed to conduct two 24-HRs per mother-child pairs, with three days to two weeks in between. The dietitians created and adhered to an interview protocol to sustain the interview structure while preserving the inclusion of open-ended questions. The structures of the interviews are described in more detail in Paper II for the mothers and Paper III for the children.

Long-term assessment: Food frequency questionnaire

In both phases, a semi-quantitative FFQ was employed to gather information about usual iodine intake. This addressed the consumption of individual foods and food groups, dietary supplements, past and present breastfeeding, use of formula, and timing of introduction to solid foods. In phase I, the infant FFQ (Appendix II) was specifically developed for the study using available questionnaires from the second national dietary survey among infants in Norway (Spedkost 6, 2008 and Spedkost 12, 2005, a survey in 6- and 12-month-old infants, respectively) (124, 125) and a questionnaire for a survey of iodine status among children in Norway with cow's milk protein allergy (126). The FFQ was completed at the healthcare clinic before or after completing the 24-hour questionnaire. The mother was asked to indicate how frequently in the past two weeks her child consumed 16 specific food items or food groups with predefined frequency categories, ranging from "never or rarely" to "five or more times per day". Portion sizes (g, dL, or pieces) were predefined for all items except breast milk, formula, and foods that are generally low in iodine (e.g., bread and homemade baby porridge). For breast milk and formula, the frequency of meals per day/week was reported.

In phase II, two distinct FFQs were used for the children, one for those aged <6 months (Appendix IV) and one for older children (Appendix V). The FFQs were adapted from the third national dietary survey among infants in Norway (Spedkost 6, 2018 and Spedkost 12, 2019) (72, 73). The FFQs assessed the children's intake of approx. 200 individual foods or food groups over the past two weeks, with frequencies of intake ranging from "never/seldom" to "five or more times per week/month". Questions about portion size, estimated using food photographs or Norwegian household measures were included. The maternal FFQ in phase II (127) was developed at the University of Oslo and included questions on 279 different foods and beverages. The FFQ assessed maternal food habits over the past six months, or after pregnancy if the mother had given birth less than six months ago.

3.3.3 Processing of dietary data

Calculation of iodine intake

In phase I, to calculate infant 24-hour iodine intake (μg/day) from food, the iodine concentration in each food item was retrieved from the Norwegian Food Composition Table (128) and multiplied with the 24-hour consumption amount given by the mother in open-ended fields (e.g., g or quantity of pieces). Further, iodine from breast milk was estimated using reference volumes in 0–12-month-old infants in industrialized countries published by the WHO in 1998 (129), as presented in **Table 7**. Specifically, the breast milk volume corresponding to the child's age (in months) and breastfeeding status (exclusive or partial) was multiplied by the measured BMIC of the child's mother. Iodine from formula was estimated in a similar way, using the same reference volumes, but multiplied with the iodine concentration in formula from the Norwegian Food Composition Table of 130 μg/L (128). For infants who consumed both breast milk and formula, only iodine from breast milk was included, unless the mother reported that formula was consumed more frequently than breast milk. For those children, only iodine from formula was included. To calculate the iodine intake from the FFQ in phase I, answers from the questions related to the intake of milk, formula, cheese, fish, eggs, and iodine-enriched baby foods (porridge, smoothies, etc.) were converted to daily consumption amounts (g/day) and multiplied by the iodine concentrations for each food item/dish retrieved from the Norwegian Food Composition Table (128). In phase I, iodine from breast milk was not included in the estimates of usual iodine intake by FFQ. The reason was that we only had one spot breast milk sample per woman, which does not reflect day-to-day variation in BMIC. Thus, usual iodine intake in phase I was only given for partially breastfed and weaned children, and only included iodine from foods, beverages, and possible iodine-containing supplements.

In phase II, the Norwegian dietary estimation tool "Kostholdsplanleggeren" (130) was used to compute total daily intakes of iodine from the 24-HRs for the mother-child pairs. This tool multiplies the registered consumption amount of each food item with the iodine concentration registered in the Norwegian Food Composition Table (128). For items not found within this system, we chose similar items when appropriate, or obtained nutritional values from the producers of the food items. Iodine from dietary supplements was added using labelled iodine values of the reported products. For the estimation of iodine intake from breast milk, we used other reference volumes than in phase I since updated volumes were available from 2023. In phase II, global age-specific reference volumes by Rios-Leyvraz et al. (131) (**Table 7**) were multiplied with the measured BMIC of the corresponding mother. If the BMIC was not measured, the BMIC from the Norwegian Food Composition Table of 70 μg/L was used (128). If intake of other kinds of milk in addition to breast milk was reported (formula, cow's milk, or plant-based milk replacements), the volume of consumed breast milk (from the global age-specific breast milk volumes) was reduced by the corresponding volume for these. To calculate the iodine intake by FFQ in phase II, the food composition database and calculation system "Kostberegningssystem" (KBS, version AE-18) from the University of Oslo was used.

Table 7. Reference volumes of breast milk intake (mL) used to estimate iodine intake from breast milk in the "Iodine in Early Life study".

Age (months)	**WHO, 1998 (129)** Applied in phase I		**Rios-Leyvraz et al. 2023 (131)** Applied in phase II
	Exclusively BF (mL)	Partially BF (mL)	BF (mL, 95% CI)
1	699	611	624 (605–642)
2	731	697	705 (690–721)
3	751	730	735 (719–750)
4	780	704	743 (728–758)
5	796	710	740 (724–755)
6	854	612	729 (713–745)
7	867	569	713 (697–730)
8	815	417	694 (676–711)
9	890	497	671 (652–691)
10	-	691	647 (625–668)
11	910	516	620 (596–645)
12	-	497	593 (566–620)
13	-	-	563 (533–594)
14	-	-	533 (500–567)
15	-	-	502 (465–539)
16	-	-	470 (430–511)
17	-	-	438 (393–482)
18	-	-	404 (356–452)
19	-	-	370 (318–422)
20	-	-	336 (280–392)
21	-	-	301 (241–361)
22	-	-	266 (202–330)
23	-	-	231 (162–299)
24	-	-	195 (122–267)

BF, breastfed; CI, confidence interval; WHO, World Health Organization.

Feeding practice categories

In phase I, the infants were classified according to three categories of feeding status: *exclusively breastfed*, *partially breastfed* (complementary foods or formula in addition to breast milk), and *weaned* (no breast milk consumption, only solid foods, liquids and/or formula). In phase II, the feeding status categories did not distinguish between the different degrees of breastfeeding. This adjustment was made because two 24-HRs per child was conducted. Consequently, a child could be exclusively breastfed in the first 24-HR and partially breastfed in the second 24-HR. To ease the classification, we used the following categories: *breastfed* (exclusively, or in combination with complementary foods, no use of formula); *formula-fed* (exclusively, or in combination with complementary foods, no breast milk); *mixed milk-fed* (breast milk and formula, with or without complementary foods); and *weaned* (only solid foods, no breast milk or formula).

Iodine supplement use

In both phases of the study, iodine-supplement consumption was assessed both in the short-term and long-term dietary assessment. None of the children were reported to have consumed iodine-containing supplements. For the women, the FFQ did not specifically ask for the use of iodine-containing supplements, only multivitamin and mineral supplements. Thus, the repeated 24-HRs were used to classify women as either regular iodine-supplement users or non-regular users. Regardless of dosage, the women were classified as regular iodine-supplement users if they: (1) reported taking iodine-containing supplements in both 24-HRs, or (2) reported taking iodine-containing supplements in one of two 24-HRs plus multivitamin and mineral supplements a minimum two to three times weekly in the FFQ. Iodine intake for all women was reported in two ways: from food alone, and from food and supplements (total iodine intake). Total maternal iodine intake was also reported separately for regular and non-regular users of iodine-containing supplements.

3.4 Demographic data

In phase I, demographic questions were included in the maternal FFQ (Appendix III). In phase II, these data were collected over the telephone before conducting the 24-HR. The following data were collected: age of the mothers (years) and children (months), parity, marital status (single, cohabiting, married, other), maternal anthropometrics (height in cm, weight before pregnancy, and current weight), education (<12 years, 12 years, 1–4 years college/university, >4 years college/university), country of origin, nicotine use, and history of thyroid conditions. Child anthropometrics were collected in phase II, through the FFQ (weight and length at birth and at 6 or 12 months of age, Appendices IV and V, respectively).

3.5 Statistical analyses

Data processing and statistical analyses were performed using STATA/SE 16.1 (Statacorp, College Station, TX, USA). Before conducting the statistical analyses, a plan of analyses was made by the first author of each paper with input from the co-authors.

The estimated sample size of the study population was based on the absolute precision of the estimated proportion with low iodine intake or iodine deficiency. The planned sample size of 500 mother-child pairs in total from both phases ensured a margin of error of 4% at a 95% confidence interval at an assumed prevalence of 50%.

The iodine intakes, UIC, and BMIC were expressed as a median (P25, P75) since the data were skewed. The correlation between variables was evaluated using Spearman's rank order test. In Paper I, we used kernel regression to assess the univariate associations between the dependent variable infant UIC and independent variables (e.g., maternal educational level and breastfeeding status). In Paper II, we used the non-parametric Kruskal-Wallis test to assess whether UIC and iodine intake differed across different child age groups and feeding categories. In Papers II and III, the Multiple Source Method (MSM) was used to calculate usual iodine intake distributions from the repeated 24-HRs (132). Using repeated short-term measurements, the MSM adjusts for within-subject variability and mitigates the impact of extreme datapoints (e.g., very high or very low iodine intakes). In this way, the range of iodine intakes becomes narrower, with upper percentiles decreasing and lower percentiles increasing. While the MSM allows for the incorporation of FFQ data alongside short-term dietary data, we chose not to include FFQ data in our analyses since this is found to have minimal impact on the estimates of usual intakes from 24-HRs (133). More information regarding the statistical analyses is found in the included papers.

3.5.1 Cut-off values applied in the included papers

In both phases, we used the WHO cut-off of a median UIC >100 μg/L for iodine sufficiency, which applies to adults, lactating women, and children <2 years of age (45). In phase I, for the infants, we used the RI from the NNR2012 of 50–70 μg/day (78). In phase II, we calculated the proportion of individuals with usual iodine intake below the AI, below the EAR (suboptimal iodine intake), and above the UL (excessive iodine intake). For the women (Paper II), we used the following thresholds from the NNR2012: RI of 200 μg/day for lactating women and 150 μg/day for non-lactating women, AR of 100 μg/day, and UL of 600 μg/day (78). For the children (Paper III), we used the following cut-offs: AI from the NNR2023 of 90 μg/day for infants <12 months of age and 100 μg/day for children ≥12 months of age (77), EAR from a Swiss dose-response crossover iodine balance study of 72 μg/day (18), and UL from the EFSA of 200 μg/day (134).

3.6 Literature search

To be updated on relevant literature, the author of this thesis subscribed to newsletters from the IGN, as well as email updates from PubMed for the following literature searches:

- Weekly subscription: ("iodine"[Mesh] OR "iodine status"[tw] OR "urinary iodine concentration"[tw] OR UIC[tw] OR "breast milk iodine concentration"[tw] OR BMIC[tw]) AND ("thyroid function"[tw] OR "thyroid hormone*"[tw] OR triiodothyronine[tw] OR T3[tw] OR thyroxine[tw] OR T4[tw] OR thyroglobulin[tw] OR goiter[tw] OR goitre[tw]) AND ("Iodine intake"[tw] OR "iodine nutrition"[tw] OR "dietary iodine intake"[tw])
- Monthly subscription: (FFQ[tw] OR "food frequency questionnaire"[tw]) AND ("24-h recall*"[tw] OR "24-h dietary recall*"[tw] OR "24-hour recall*"[tw] OR "24-hour dietary recall*"[tw] OR R24W[tw]) AND ("Multiple source method"[tw] OR MSM[tw])

3.7 The PhD candidate's role in the work

Phase II of the "Iodine in Early Life" study was started by the time the PhD candidate was involved in the project. From employment in February 2021, the candidate took part in recruitment and assisted with data collection (telephone-based 24-HRs) and the processing of dietary data. Additionally, the candidate contributed to sample preparation before iodine analyses with ICP-MS. The PhD candidate conducted the statistical analyses in Papers II and III, with guidance and input from supervisors and the writing group. In Paper I, the statistical analyses were conducted by the first author K.S.B.

3.8 Ethics

This study was approved by the Regional Committee for Medical and Health Research Ethics (2018/1230/REC South East) and the Data Protection Officer at IHT (reference number 94326). The study was conducted in accordance with the ethical principles in the latest version of the Declaration of Helsinki. Participation was voluntary, and the participants were informed that they could withdraw from the study at any timepoint without giving any reason. Written informed consent was obtained from the participating mothers for themselves and their children, after receiving both written and oral information about the study. All recruiters were either public healthcare nurses or members of the study team at IHT. Biological samples were stored at IHT in a research biobank which expires in 2027.

4. Summary of results

Altogether, 463 mother-child pairs were included in the final analyses of iodine nutrition (130 from phase I and 333 from phase II) (**Figure 2**, section 3.2). As mentioned, maternal iodine nutrition from phase I was not part of the papers included in this thesis and will not be in focus. The following sections will summarize the main results from Papers I–III.

4.1 Paper I

Specific objective: Describe iodine nutrition in infants (0–12 months of age) in Innlandet County, Norway.

4.1.1 Main results

This paper assessed UIC and recent (24-hour) and usual iodine intake in 130 infants recruited from Lillehammer and Gjøvik municipalities, Norway. The infants were divided in three groups according to their feeding status: *exclusively breastfeed* (n = 56), *partially breastfed* (n = 46), and *weaned* (n = 28). Since iodine from breast milk was not included in the estimates of usual iodine intake, only 24-hour iodine intake was presented for the whole group of infants.

- The median (P25, P75) UIC in all infants was 146 µg/L (93, 250), indicating adequate iodine status according to the current WHO cut-off of 100 µg/L. Weaned infants had a significantly higher median UIC (210 µg/L) than exclusively breastfed (130 µg/L) and partially breastfed infants (135 µg/L). The latter two groups had on average a 79.6 µg/L (P = 0.006) and 70.2 µg/L (P = 0.014) lower UIC than weaned infants, respectively.
- The median (P25, P75) 24-hour iodine intake in all infants was 50 µg/day (31, 78). Contrary to the UIC measurements, weaned infants had a lower median iodine intake (25 µg/day) than exclusively breastfed (66 µg/day) and partially breastfed infants (57 µg/day). Further, 51% (95% CI: 42–60) of the infants had a 24-hour iodine intake below the RI from the NNR2012 of 50 µg/day. Of note, the reference intake (AI) for this age group was raised to 90 µg/day in the NNR2023. Using the NNR2023, the

proportion of infants with a 24-hour iodine intake below the AI would increase to 78% (95% CI: 70–85).

- Estimations of usual iodine intake were only performed for partially breastfed and weaned infants, showing median (P25, P75) intakes of 21 µg/day (6, 37) and 34 µg/day (14, 87), respectively. Of them, 85% (95% CI: 75–92) had a usual iodine intake below the AI from the NNR2023 of 90 µg/day, and 84% (95% CI: 73–91) had a suboptimal usual iodine intake (below the proposed EAR of 72 µg/day). None of the infants had an excessive usual iodine intake (above the UL from EFSA of 200 µg/day).
- There was a linear relationship between infant UIC and BMIC. The median (P25, P75) BMIC was 71 µg/L (45, 127), as presented in a former publication of the current project (122). A linear regression analysis showed that for the exclusively breastfed infants, almost half of the variation in UIC was explained by maternal BMIC (adjusted R2 = 0.45). There was no significant correlation between UIC and estimated 24-hour iodine intake in the infants (Spearman's rank correlation coefficient (*r*) = 0.122, *P* = 0.166).

In conclusion, the results suggest that the iodine status in the infants was adequate on a population level, as shown by a median UIC above the current cut-off of 100 µg/L. Breastfed infants had substantially lower UIC compared with weaned infants, highlighting the importance of sufficient iodine in breast milk until the infant can derive iodine from other sources. The dietary assessment did not seem to adequately capture the infants' iodine intake and did not align with the UIC data.

4.2 Paper II

Specific objective: Describe iodine intake (not status) in mothers of young children (0–2 years of age) in Innlandet County, Norway.

4.2.1 Main results

In this paper, iodine intake was described in 300 women in Innlandet County, Norway, who had children between 0–27 months of age. The main dietary assessment method chosen for this purpose was repeated 24-HRs, and iodine intakes were expressed as usual intake. Iodine intake was also estimated by FFQ. Usual iodine intake was presented in three ways:

- *For all women* (n = 300). Based on the repeated 24-HRs, the median (P25, P75) usual iodine intake from food was 124 µg/day (93, 167), and the median (P25, P75) usual iodine intake from food and supplements (total iodine intake) was 151 µg/day (103, 216). In total, 62% (95% CI: 57–68) had a total usual iodine intake below the RI from the NNR2012 (150 µg/day in non-lactating women and 200 µg/day in lacating women). Further, 23% (95% CI: 18–28) had a total usual iodine intake below the AR of 100 µg/day (suboptimal intake). Notably, in the NNR2023, the AR for women was raised to 160 µg/day in lactating women and 120 µg/day in non-lactating (provisional ARs). Using the updated thresholds, the proportion of women with a suboptimal iodine intake in our study would increase to 48% (95% CI: 42–54). Further, none of the women had a total usual iodine intake above the UL of 600 µg/day (excessive intake).

- *Stratified by lactation status*. The median (P25, P75) usual iodine intake from food alone was 129 µg/day (95, 176) in lactating women (n = 197) and 117 µg/day (88, 153) in non-lactating women (n = 103). The median (P25, P75) usual iodine intake from food and supplements in the same groups was 153 µg/day (107, 227) and 141 µg/day (97, 185), respectively.
- *Stratified by supplement use*. In regular supplement users (n = 63), supplements contributed to an average of 172 µg/day of iodine. Among regular iodine supplement users, none (0%, 95% CI: 0–6) had a suboptimal usual iodine intake (below the AR from the NNR2012), compared with 29% (95% CI: 23–35) among non-supplement users (n = 237).

Among the women with FFQ data (n = 195), 55% reported to drink 1–2 glasses of cow's milk daily or more frequently (sweet, sour, skimmed, or flavored), and 14% reported to drink 3–4 glasses a day or more. Further, 29% reported to eat lean fish or products of lean fish once a week or more frequently, while 11% reported eating it twice a week or more.

In conclusion, the iodine intake in mothers of young children in Innlandet County was inadequate. The study confirms the need for action to improve iodine intake among lactating and postpartum women Norway.

4.3 Paper III

Specific objective: Describe iodine nutrition in a representative sample of young children (0–2 years of age) in Innlandet County and relate it to maternal iodine nutrition.

4.3.1 Main results

In this paper, usual iodine intake was estimated in children 0–27 months of age by repeated 24-HRs and FFQ. The main method chosen for dietary assessment was 24-HRs. Further, the associations between children's iodine intake and measured UIC with maternal measures of iodine nutrition (iodine intake, UIC, and BMIC) were assessed. Iodine nutrition was described in the whole group of children, in separate age groups (<6 months, 6–11.9 months, and ≥12 months), and in feeding status groups (breastfed, formula-fed, mixed milk-fed, and weaned). The main results are summarized below:

- *In the whole group of children* (n = 333), the median (P25, P75) usual iodine intake was 83 µg/day (64, 113) based on the 24-HRs. Further, 56% (95% CI: 51–62) had a usual iodine intake below the AI from the NNR2023 (90–100 µg/day), 35% (95% CI: 30–41) had a suboptimal usual iodine intake (below the EAR of 72 µg/day), and 0.6% (95% CI: 0.0–2.2) had a usual excessive iodine intake (above the UL of 200 µg/day). None of the children were reported to consume iodine-containing supplements. The median (P25, P75) UIC was 145 µg/L (85, 226), indicating an adequate iodine status according to the current WHO cut-off of 100 µg/L.
- *Categorized by age:* The proportion of children with a suboptimal usual iodine intake was 48%, 26%, and 29%, respectively, in children <6 months (n = 132), 6–11.9 months (n = 117), and ≥12 months of age (n = 84). The proportion of children with an excessive usual iodine intake was <1% in all age groups. Further, the median UIC was above the current recommended cut-off in all age groups (130, 143, and 163 µg/L, respectively).
- *Categorized by feeding practice*: In the youngest two age groups (<6 and 6–11.9 months), breastfed infants had significantly lower usual iodine intakes than formula-fed and mixed-milk fed infants [(<6 months: 67 µg/day vs. 119 and 109 µg/day, respectively, p <0.001); (6–11.9 months: 82 µg/day vs. 103 and 115 µg/day, respectively, p <0.001)]. For children ≥12 months of age, there were no notable differences in iodine intake between different feeding practices (P = 0.6148). Further, the lowest UIC was among the breastfed children, regardless of age.
- There was a positive correlation between the children's usual iodine intake and BMIC [Spearman's rank correlation coefficient (r) = 0.67, p <0.001]. Also, there was a positive correlation between the children's UIC and BMIC (r = 0.43, p <0.001), child

and maternal UIC (r = 0.23, P = 0.001), and the children's UIC and maternal usual iodine intake (r = 0.20, P = 0.004).

- Among the children one year of age and older with FFQ data (n = 57), 53% were reported to drink cow's milk daily or more frequently (sweet, sour, skimmed or flavored), and 37% were reported to drink it twice a day or more. Furthermore, among the same children, 40% were reported to eat yoghurt daily or more frequently. From six months of age, 28% were reported to eat lean fish or lean fish products at least once a week, while 9% were reported to consume them twice a week or more.

In conclusion, although the median UIC was above the current WHO cut-off for iodine sufficiency (100 μg/L), the dietary data indicate that more than a third of the children had a suboptimal usual iodine intake, as shown by intakes below the EAR. Moreover, the results suggest that the risk of iodine excess in young children was low.

5. Discussion

In this thesis, iodine nutrition was assessed in children 0–2 years of age and their mothers using data from the cross-sectional study "Iodine in Early Life" conducted in Innlandet County, Norway. We used UIC, which is the recommended biomarker for the assessment of population iodine status, BMIC, and dietary assessment methods. With few dietary sources of iodine in Norway and a low iodine concentration in salt, dietary data can be useful to identify at-risk groups of low and excessive iodine intakes and provide an insight into key dietary iodine sources. This information is valuable when considering measures for improving iodine intake in the population. As highlighted in the introduction section, few studies have reported on iodine nutrition in young children before. Relevant methodological considerations are discussed in section 5.1. An overall discussion of the main findings can be found in section 5.2.

5.1 Methodological considerations

5.1.1 Study design

All the papers in this thesis were primary analyses of cross-sectional data from the "Iodine in Early Life" study. Cross-sectional studies are frequently used to provide estimates of iodine nutrition for a population (45). This study design allows for the collection of data from a relatively large population group over a short period of time. Also, cross-sectional designs generally demand a shorter time commitment and fewer resources compared with longitudinal and experimental designs.

In contrast to longitudinal studies, cross-sectional studies can be performed without the need for follow-up assessments. Nevertheless, as with all study designs, the methods and tools used in our study, such as phone interviews, questionnaires, and home sampling, carried a risk of non-delivery and low response rates. In our study, the participants were approached and recruited during consultations at the healthcare clinic and requested to collect urine and breast milk samples at home. Following this, they were required to visit the clinic to deliver the collected samples. The rationale for home sampling was to lessen the workload on the personnel at the healthcare clinics and provide the mothers with sufficient time to complete the sampling. Additionally, home sampling helped to minimize the duration the mother-child pairs had to spend at the clinics during the COVID-19 pandemic. In phase I, the mothers were asked to return to the healthcare clinic the day following recruitment to return the samples and to fill out the dietary assessment forms, and 91% of those who signed the informed consent did so. In phase II, the mothers were asked to return the samples to their local healthcare clinic within two weeks after sampling and to conduct the dietary assessment by phone (24-HR), and digitally (FFQ). Of the women who signed the informed consent, ~91% completed at least one 24-HR and ~90% delivered biological samples for iodine analysis. Efforts to maximize response rates included reminders (telephone/message/mail) and gift cards for participation (300 NOK). Also, in phase II, the study team offered a pick-up service to mothers who lived far from the healthcare clinics and faced challenges in personally delivering the samples.

Cross-sectional studies and other observational designs are useful for identifying associations and generating hypotheses but cannot be used to establish causal relationships between exposures and outcomes (135). For instance, in Paper III, the children's iodine intake and UIC were positively associated with all markers of maternal iodine nutrition. While these associations do not necessarily prove causal relationships, the influence of maternal iodine status on the iodine intake of breastfed children is well established due to the transmission of iodine through breast milk. Like all study designs, cross-sectional studies are susceptible to errors. Random errors and bias will be discussed in the upcoming sections; related to the study population (section 5.1.2), to the measurement of iodine in urine and breast milk (section 5.1.3), and to the dietary assessment (section 5.1.4). Random errors decrease the precision of the effect measures, while bias decreases the accuracy of the results (136). They can both impact a study's internal validity, referring to the extent to which the observed results represent the true findings in the study population, and the external validity, which concerns the generalizability of these findings to broader populations or settings (137).

Confounders are third factors that are associated with both the exposure and the outcome of interest and can confuse the interpretation of the association between them. In the current study, we did not designate specific exposure and outcome variables but instead explored child and maternal iodine nutrition as equally important outcomes. Thus, in the papers included in this thesis, there were no adjustment of potential confounders. Confounding variables are typically more relevant in studies that aim to establish causality or temporal relationships, where controlling for confounders is necessary to reduce confounding bias (138).

5.1.2 Study population

The target population in this study was mother-child pairs in Innlandet County, Norway. Norway was divided into 18 counties during phase I of the study (2018) and 11 counties during phase II (2020–2021) (139). Innlandet is the largest county in Norway in terms of area and has a population of 375.356 as of 2023 (140). The study population in phase I was not representative of the target population since only 2 out of 46 municipalities were invited. Upon receiving additional funding after phase I was completed, we could ensure a representative sample in phase II by inviting more municipalities randomly. In total, 44 municipalities were invited to the study, of which 30 accepted. Phase II was, however, substantially delayed, in part due to the COVID-19 pandemic.

Selection of the study population in phase II involved a random process and this sample was accordingly considered representative of the target population (141). There are, however, possible sources of selection bias that should be acknowledged. Selection bias occurs when individuals or groups who participate in a study differ systematically from those who do not participate. For instance, participation in a study might be more likely for highly educated subjects (known as volunteer bias), which can further result in a distribution of the exposure or outcome of interest that differs from the target population (137). In phase II, mean (SD) maternal age was 31 (4.4) years and 20.3% of the women were classified as highly educated (≥4 years of college/university). This proportion is similar to the percentage of highly educated women in the general female population in Norway within the 30–34 age group (20.2% in 2022). However, it is somewhat higher than the proportion of highly educated women in Innlandet County among the 30–39 age group (14.8% in 2022) (142). In Norway, one study found higher UIC in women with the highest education (≥4 years of college/university) and income (≥450.000 NOK) compared with women with lower education and income (143), while another study found no such association (55). In phase II, we did not document the total number of individuals invited to the study, preventing the calculation of the exact participation rate. However, we used a random sampling approach to reduce selection bias and to obtain a sample as representative as possible of the target population. Based on the above, we cannot remove the possibility of selection bias in our data. External validity will be discussed in section 5.1.6.

5.1.3 Measurement of iodine in urine and breast milk

In the current study, spot urine samples were used to measure UIC in the children and their mothers. Spot UIC has a high day-to-day and within-day variability depending on iodine intake and hydration status. Thus, spot UIC is not reflective of individual iodine status, and it has been suggested that up to 10 spot urine samples are needed from the same subject to measure individual iodine status (90, 91). These random variations are considered to even out in large population settings and thus, spot UIC is recommended as a population marker of iodine status (45). In a study population, adjustment for within-person variation in UIC can be done by collecting two or more repeated spot urine samples from a subgroup of the participants (84). In phase I of our study, 2 spot urine samples from the same day were collected from 27 infants (out of 130), as well as 2 spot samples of breast milk from 25 mothers. For these individuals, we used the mean iodine concentration of the two spot samples to calculate the UIC and BMIC. This limited some of the variation in UIC and BMIC, although the spot samples should have been from two different days to reduce day-to-day variability. Also, instead of using the mean UIC and BMIC of the repeat samples, we could have applied methods similar to the MSM to reduce population variability. Due to large variability in UIC, median UIC should only be used to define population iodine status and not to quantify the proportion of the population with iodine deficiency or iodine excess (144), although this is often seen in the literature. For instance, in Paper I, we reported that 33.6% of the infants had a UIC within the suggested optimal range of 100–199 μg/L. This information should be interpreted with caution due to the substantial day-to-day variation in UIC. In phase II, UIC measurements were carried out only once per participant and only used to describe the population median UIC and not the proportion of individuals with UIC above and below the cut-off. To calculate the proportion of individuals with inadequate and excessive iodine intakes in phase II, we predominantly used the iodine intake estimations by the repeated 24-HRs.

UIC is also often adjusted for hydration status using urinary creatinine concentration. Creatinine is a byproduct of muscle metabolism which is excreted in urine at a fairly constant rate (145). However, excretion is variable between individuals depending on age, sex, muscle mass (119), and protein intake (45). Thus, adjusting for creatinine concentrations is not recommended by the WHO when assessing iodine status in a population. In infants, a low protein intake may result in low creatinine excretion and unreliable urinary iodine/creatinine ratios (45).

Urine sampling in infants can be challenging, and sources to measurement error vary with the method used. We used the diaper-pad collection method in our study, which may lead to loss or contamination of the sample and thus affect the reliability and the accuracy of the UIC measurement. A reliability study used the repeated infant urine samples from phase I of this study (n = 27) to assess the intraindividual variability of iodine concentration measured in two spot samples of diaper-retrieved urine (146). This study concluded that the diaper-pad approach can be considered a feasible and reliable method for measuring infant UIC. Further, UIC and BMIC in our study was analyzed with ICP-MS, which is considered the gold standard method for measuring urinary and breast milk iodine concentrations due to its high level of accuracy and low detection limits (147).

5.1.4 Dietary intake assessment

The methodology of iodine intake assessment differed between the two phases of the study due to the mentioned time constraints and restricted resources in phase I. While the focus in phase I was primarily on iodine-rich sources, a more general assessment of the diet was performed in phase II, although iodine was the nutrient of interest. The quality of the dietary data and the potential for measurement errors will be discussed in the following sections.

24-hour iodine intake, FFQ, and repeated 24-HRs

In phase I, we developed a 24-hour questionnaire and a FFQ to assess recent and long-term intake of iodine-rich foods, respectively. These questionnaires were not validated, which limits the validity of the findings. In phase II, we used repeated short-term measurements (24-HRs) to estimate the usual iodine intake. In addition, usual iodine intake was assessed by FFQ, which was also not validated for the purpose of estimating iodine intake. The main method chosen for dietary assessment in phase II was the repeated 24-HRs. This choice was made since research indicates that repeated short-term measurements tend to provide less-biased data than tools that examine long-term intake directly, such as FFQs (103). FFQs were mainly used in our study as a supplement to the 24-HRs to capture the intake of iodine-rich sources that are episodically consumed (e.g., fish and eggs) and to examine dietary habits. Thus, in the included papers from phase II, most of the focus is put on the usual intake estimates from the repeated 24-HRs.

All dietary data based on self-reports are subject to measurement errors, which can be random or systematic (bias). Random errors can stem from day-to-day variations in food intake and can be reduced by including repeated measurements of the dietary assessment method used (148). Bias occurs when measurements consistently deviate from the true value in the same direction, potentially leading to incorrect estimates and conclusions (103). FFQs are not affected by day-to-day variability such as 24-HRs. However, they tend to be more biased than 24-HRs as it is generally more challenging to memorize and report food intake and portion sizes over a longer time perspective (149). **Table 8** provides some of the strengths and limitations associated with 24-HRs and FFQs. Like all dietary assessment methods, both are prone to recall bias and misreporting of food intake, which may be affected by characteristics such as memory, age, weight, perceptions of body image, and knowledge (150). Other sources of measurement error in dietary assessment for young children include leftovers and spillages, rapidly changing dietary patterns, and multiple caregivers throughout the day (for instance, due to attendance in the kindergarten).

Table 8. Strengths and limitations of 24-hour dietary recalls and food frequency questionnaires.

Method	Strengths	Limitations
24-HR	Enables detailed data collection on all consumed foods and drinks, including portion size, brand, and preparation details[1]. Can provide estimates of usual dietary intake (provided that repeated recalls are conducted)[1]. Appropriate for all eating patterns due to open-ended format[2]. Does not affect eating behavior due to the retrospective approach[2].	Requires substantial time from the study team for interviews and data processing[2]. May not capture the intake of episodically consumed foods[1]. Does not cover day-to-day variations unless repeated recalls are conducted[1]. Relies on respondent's memory[2]. Subject to recall bias as respondents may selectively report foods and misreport portion sizes[2].
FFQ	Can capture the intake of episodically consumed foods[1]. Can capture portion size estimates (if semi-quantitative or quantitative)[2]. Assess long-term usual intake[2]. Easy to administer and cost-effective in large population settings[2]. Does not affect eating behavior due to the retrospective approach[2].	Do not cover all foods consumed[2]. May not give precise information on the consumed portion size[2]. Relies largely on respondent's memory[2]. Subject to recall bias and misreporting of frequency and portion sizes (if semi-quantitative or quantitative)[2]. Not suitable for a population where people have distinctly different dietary patterns[2].

[1]Reference: Food and Agriculture Organization of the United Nations, 2018 (150)
[2]Reference: National Cancer Institute, 2015 (103)
24-HR, 24-hour dietary recall; FFQ, food frequency questionnaire.

Use of food composition data

Measurement errors in dietary assessment can also be introduced with the use of food composition data. For the assessment of iodine intake, an up-to-date food composition database (FCD) with data on iodine content in foods and dietary supplements is needed. The database should be specific to the country or to local eating habits (150). Not all countries have their own FCD and not all national databases include iodine. The Norwegian Food Composition Table is updated regularly with iodine concentrations in foods (the last update in

2023). However, producers may alter their production and recipes, and it is not feasible to update the database with all new products. Also, FCDs often have limited coverage of processed and packaged products, including products made for infants and young children. In the current study, many reported products were not registered in the FCD and had to be replaced with similar products that may vary in nutritional composition from the originally reported product. Additionally, the food composition data does not cover natural or seasonal variations in foods as only one concentration is given per nutrient. For instance, a Norwegian study found that the iodine concentration in cow's milk varied between 12–19 µg/100 g, the concentration in eggs between 23–43 µg/100 g, and the concentration in different fish species between 18–1210 µg/100 g (151). As a result, at the individual level, the estimated iodine intake from these foods, particularly fish, may differ substantially from the actual amount of iodine ingested. Consequently, the estimated iodine intake from fish is prone to random errors. Such errors will make our estimates less precise.

Assignment of breast milk volumes

In both phases of the study, for the estimation of breast milk intake, we used reference values for breast milk intake since measurement of breast milk intake directly is comprehensive and time-consuming. Such measurement usually involves weighing the mother or the child before and after multiple feeding occasions (131), which was not prioritized owing to the burden for the participants. In phase II, such estimation would not have been feasible since the 24-HR was unannounced (the mothers would have needed to know the day of the 24-HR if they were to estimate their child's breast milk intake from the day before). As explained in the methods section, we used different sets of breast milk reference volumes in the two phases because of the publication of new reference volumes in 2023. They were both based on available published studies from different regions across the world that reported breast milk intake. Generally, the WHO references (129) that we used in phase I were higher than the references by Rios-Leyvraz et al. (131) used in phase II. For exclusively breastfed infants, the difference in breast milk intake between the two sets of references ranged from 12 mL/day at three months of age to 125 mL/day at six months of age (**Table 7**, section 3.3.3). The authors of each of the reference sets pointed at considerable uncertainties behind the reference volumes, such as limited information available from the included studies (only study-level and not individual data). Therefore, there are uncertainties related to the iodine contribution from breast milk in our study. Rios-Leyvraz et al. provided 95% confidence intervals together with the reference values, but for simplicity, we only used the mean estimates in our calculations of iodine intake.

Classification of lactation status and feeding practice

Since we conducted two 24-HRs per mother-child pair in phase II, some of the children could be breastfed when we did the first 24-HR, but not at the second, or be exclusively breastfed at the first 24-HR but partially breastfed at the second. Thus, for children in phase II (Paper III), we did not distinguish between the degree of breastfeeding, like we did in phase I (Paper I), where dietary intake was only assessed once per child. In phase II, we based children's feeding status and women's lactation status on information given in the first 24-HR. This may have introduced some misclassification bias, with some children potentially being classified as breastfed although they were only breastfed in the first 24-HR (137). Similarly, some women may have been classified as lactating although they were only lactating in the first 24-HR. Consequently, since the reference intake is higher for lactating than non-lactating women, the reported proportion of mothers with iodine intakes below the recommendations in Paper II may have been somewhat overestimated. However, this did not affect the percentage of women with suboptimal iodine intakes (intakes below the AR), as the same AR cut-off of 100 µg/day from the NNR2012 applies to both lactating and non-lactating women.

Classification of maternal iodine-supplement use

In Paper II, we classified women as either regular iodine-supplement users or non-regular users. As explained in the methods section, women were classified as regular supplement users if they: (1) reported taking iodine-containing supplements in both 24-HRs, or (2) reported taking iodine-containing supplements in one of two 24-HRs plus multivitamin and mineral supplements a minimum two to three times weekly in the FFQ. There is potential for information bias in this approach, as iodine-supplement use in two random recall days does not necessarily imply regular use (137). In the literature, there is a large variability in which how dietary supplement users are defined, which can hinder the comparability of results and limit the generalizability of the findings. For instance, a study among pregnant women in Norway classified iodine supplement users as women taking iodine-containing supplements at least five times a week (143), and, in many studies, it is not defined how the classification has been made. In our study, 21% of the women were classified as regular iodine-supplement users, according to the definition we made. This seem compatible with other Norwegian studies among postpartum and lactating women where 12–32% have been reported to use iodine-containing supplements (116, 152, 153).

Cut-off values for suboptimal iodine intake

In phase II, suboptimal iodine intake in the children was defined as a usual iodine intake below the EAR of 72 µg/day. This EAR was based on the results from a Swiss randomized, double-blind, dose-response crossover study from 2016, showing that iodine balance in the first 6 months of life was achieved at a minimum daily iodine intake of 11 µg/kg, corresponding to 72 µg/day (18). The threshold was established as a provisional AR in the NNR2023 for infants <1 year of age, though as a range of 64–72 µg/day (77). Using the lower threshold of 64 µg/day for children <1 year of age in our study, a smaller proportion would have been classified as having a suboptimal iodine intake (27% vs. 37%). Further, the NNR2023 established a provisional AR of 80 µg/day for children 1–3 years of age, which we unfortunately did not use in our study as we used the same EAR of 72 µg/day for all the children. Using the provisional AR of 80 µg/day for children ≥1 year of age in our study, an even larger proportion would have been classified as having a suboptimal iodine intake (43% vs. 29%). It should be noted that there are uncertainties related to the provisional ARs. Also, as demonstrated above, the proportion with suboptimal iodine intake in the whole group of children would not have been substantially altered using the age specific ARs, since fewer of the youngest children would have been classified as having a suboptimal iodine intake, while more of the oldest children would fall into this category. As seen in **Table 3** (methods section), not all authorities have set an EAR/AR for iodine due to insufficient evidence (46). The threshold of 72 µg/day that we used closely aligns with the EAR from the Institute of Medicine of 65 µg/day (154).

Among the women in our study, however, the proportion with a suboptimal usual iodine intake was considerably increased when we applied the provisional ARs available from the NNR2023 (77). Using the updated thresholds (120 µg/day for adults and 160 µg/day for lactating women), the proportion with a suboptimal intake increased from 23% (as reported in paper II, using the AR from the NNR2012 of 100 µg/day) to 48%. The NNR2023 report was published after the publication of Paper II, and the large proportion with intake below the AR underscores the need for measures to improve iodine intake in postpartum and lactating women.

5.1.5 Statistical considerations

Adjustment of cluster sampling

The cluster sampling approach that was used to recruit mother-child pairs in phase II of the study introduces the concept of cluster effects, where individuals within the same cluster (such as municipalities or schools) tend to exhibit greater similarity in characteristics compared with those from different clusters. For instance, geographical variations, driven by factors such as local food availability or cultural norms, could potentially influence dietary habits and, thereby, iodine intake. The determination of whether to adjust for cluster effects can be based on the intra-cluster correlation (ICC) coefficient, which reflects the degree of similarity among individuals within clusters with respect to the study outcome. The ICC ranges from −1 to 1, where values closer to 0 indicate low within-cluster similarity, and values closer to 1 indicate high-within cluster-similarity (155). Our analyses revealed the ICC for the following variables: children's usual iodine intake (ICC: 0.07, 95% CI: 0–0.15), children's UIC (ICC: 0.004, 95% CI: 0–0.06), maternal usual iodine intake (ICC: 0.10, 95% CI: 0–0.21), maternal UIC (ICC: 0.12, 95% CI: 0.01–0.22), and BMIC (ICC: 0.11, 95% CI: 0–0.24). This indicated some, but not substantial similarity among individuals within municipalities regarding iodine intake and status. In Papers II and III**,** we chose not to adjust for cluster effects in our analyses of usual iodine intakes, but adjustment was made for the purpose of this thesis. **Table 9** presents the unadjusted and adjusted proportions (95% CI) of children and mothers with iodine intakes below and above the reference values (below the RI/AI, below the AR/EAR, and above the UL). As seen from the table, adjustment of cluster effects generally resulted in somewhat wider confidence intervals of the calculated proportions with inadequate and excessive iodine intakes but did not alter the proportions. Adjustment for cluster effects would most likely also have resulted in higher p-values for the associations between child and maternal iodine nutrition given in Paper III, but not have altered the correlation coefficients.

Table 9. Proportion of individuals below the RI/AI, below the AR/EAR, and above the UL, both unadjusted and adjusted for cluster effects.

	Mother[1] **n = 300**		**Child**[1] **n = 333**	
	Unadjusted (From Paper II)	**Adjusted**	**Unadjusted** (From Paper III)	**Adjusted**
% below RI[2]/AI[3] (95% CI)	62 (57, 68)	62 (56, 68)	56 (51, 62)	56 (49, 63)
% below AR[4]/EAR[5] (95% CI)	23 (18, 28)	23 (17, 30)	35 (30–41)	35 (28–43)
% above UL[6] (95% CI)	0 (0, 0)	0 (0, 0)	0.6 (0.1, 2.3)	0.6 (0.2–2.3)

[1]Proportions are based on total usual iodine intakes estimated by 2 x 24-HRs using the MSM (132). Unadjusted proportions were presented in Paper II (mothers) and Paper III (children).
[2]Recommended intake for adults from the NNR2012 (200 µg/day in lactating women and 150 µg/day in nonlactating women).[3]Adequate intake from the NNR2023 (90 µg/day for infants <12 months of age and 100 µg/day for children ≥12 months of age.
[4]Average requirement for adults from the NNR2012 (600 µg/day).[5]Estimated average requirement for children <2 years of age from a Swiss dose-response crossover balance study (72 µg/day) (18).
[6]Upper limit for adults from the NNR2012 (600 µg/day) and for 1–3-year-olds from the European Food Safety Authority (200 µg/day).
RI, recommended intake; AI, adequate intake, AR, average requirement; EAR, estimated average requirement; UL, upper limit; MSM, Multiple Source Method.

Subgroup analyses

In Paper III, iodine intake and status were presented for all the children and for the three age subgroups: <6 months (n = 132), 6–11.9 months (n = 117), and ≥12 months (n = 84). Splitting up in subgroup analyses lead to a smaller sample size and consequently loss of precision of the estimates. We further divided the children into groups of feeding status (breastfed, formula-fed, mixed milk-fed, and weaned), leading to very small sample sizes in certain groups. For instance, in the box plot presenting UIC in Paper III, there were only two children in the group of mixed milk-fed children in the age group ≥12 months. The same applies to Paper I, where infant iodine intake and status were presented for three feeding groups (exclusively breastfed, partially breastfed, and weaned). Thus, the stratified analyses comparing iodine nutrition between the feeding groups is subject to some uncertainty and should be interpreted with caution. A disparity in the number of individuals in feeding groups is difficult to avoid. In the first six months of life, for instance, a higher proportion of breastfed children is expected due to a high breastfeeding rate, particularly in Norway (156).

Use of the Multiple Source Method (MSM)

In phase II of the study, we used the MSM to adjust for intra-subject variability and estimate usual iodine intakes based on short-term dietary measurements. To use this tool, only a random sub-sample of respondents must have repeated intake data to predict the usual intake for all respondents in the sample. However, in Paper II (maternal iodine intake), we restricted the MSM analysis to women with 2 x 24-HRs, unnecessarily excluding 30 women who only had one day of 24-HR data. An updated analysis has been conducted, now also including women with only one day of 24-HR. Notably, this adjustment did not substantially alter the iodine intake distribution (see **Table 10**).

Table 10. Distribution of usual iodine intake (µg/day) in women with two days of 24-HR data (as presented in Paper II) and in all women (at least one day of 24-HR data).

Study population	***n***	**P50**[1]	**P25, P75**[1]
Women with 2 x 24-HRs (from Paper II)	300	151	103, 216
All women with 24-HR data	330	153	102, 220

[1]Estimated using the Multiple Source Method.

Further, in Paper II, before the MSM adjustment, we excluded three women with an estimated energy intake outside the range of 500–3500 kcal/day based on the mean of two 24-HRs. These cut-offs for implausible energy intake have been used for women in other epidemiological studies, such as the Nurses' Health Study (157). In hindsight, a better approach would have been to have included all women in the MSM analysis and rather to have excluded potential women with a usual energy intake outside of the range. A single day's intake could easily be lower than 500 kcal and higher than 3500 kcal. Hence, these limits for implausible intakes are more relevant to usual intakes. A subsequent analysis showed that the usual energy intake in all women with 24-HR data ranged from 1016–2870 kcal/day, thus, none of the women would have been excluded using this approach. However, our decision to exclude these three women had a minimal impact on the population distribution, as shown in **Table 10**. We did not adjust for usual energy intake in the children, which ranged from 381–1647 kcal/day after MSM adjustment. In young children, adjusting for energy intake is a complex task due to factors such as rapid growth and varying nutritional needs. Therefore, it was not prioritized in this study.

5.1.6 External validity

As explained in section 5.1.1, external validity is the extent to which results are applicable to a larger study population than the one examined (137). Our cross-sectional study was a county-level investigation, and we cannot rule out the possibility that iodine status in young children and their mothers in other parts of Norway is different. Before the addition of iodine to cow fodder in the 1950s, iodine intake was unevenly distributed across the country as people who lived near the coast had access to saltwater fish, in contrast to those who lived in inland areas (111). Today, there is limited evidence to suggest that iodine intake differs substantially by geographical area in Norway. For instance, a study in 18-month-old children from all four health regions in Norway found no significant or substantial differences in UIC between different geographical regions (158). Among women, one study reported significantly lower UIC in pregnant women in mid-Norway compared with those living in the north, west, and east (143), while a study in young Norwegian women found no differences in UIC between those living in the west and east of Norway (159). Based on this, we believe our results can be applied to other parts of Norway. Furthermore, we also think our results are relevant for other populations sharing similarities with Norway in terms of iodine sources, iodine status, and iodine concentration in salt.

5.2 Discussion of main findings

To our knowledge, the "Iodine in Early Life" study is the first to present data on iodine nutrition in young children in Norway, including both UIC, estimated iodine intake, and associations with maternal iodine nutrition. Also, it is the first study to provide estimates of iodine intake in breastfed children using analyzed iodine concentrations in breast milk. Iodine intake estimates in this age group have mainly focused on formula-fed and weaned children due to the challenges related to estimating nutrient consumption from breast milk. Thus, our data provide new insights into this relatively sparse literature on iodine intake in children <2 years of age. The findings are highly relevant since the Norwegian health authorities are currently considering encouraging the industry to increase the iodine concentration in salt production (from currently 5 μg/g salt to 20 μg/g salt) and salt used in industrially baked bread and bakery products, in line with the recommendations by the National Council of Nutrition. The council has highlighted the importance of monitoring UIC and iodine intake in population groups vulnerable to deficient and excess intakes, particularly 2-year-olds (120). Thus, our findings offer valuable baseline data before possible alterations and may also be used to predict iodine intakes if the proposed iodization adjustments are implemented. Below is a summary and discussion of the key findings in our study and their further implications.

5.2.1 Children's iodine nutrition (Papers I and III)

In Paper I, iodine status was assessed in 130 infants (0–12 months of age) using UIC, which is the recommended indicator for the assessment of iodine status in a population (45). Also, we estimated the 24-hour intake of iodine-rich foods (for all infants), and usual intake of iodine-rich foods (by FFQ) for partially breastfed and weaned infants. We found a median UIC of 146 µg/L, indicating sufficient iodine status in the infants according to the current WHO cut-off of 100 µg/L. Further, the dietary assessment for the whole group of infants showed a median 24-hour iodine intake of 50 µg/day, which was just within the available RI range at that time of 50–70 µg/day (NNR2012) (78). Accordingly, we concluded that the iodine status of the infants in Paper I was adequate. From a later perspective, although there was no measure of usual iodine intake for the whole group of infants, the 24-hour median iodine intake is below the updated reference intake (AI) from the NNR2023 of 90 µg/day (77). Additionally, the UIC cut-offs are currently under revision by the WHO (see section 1.4), and it has been argued that 100 µg/L to define iodine sufficiency in infants is too low (18, 22, 160). The reason for this is that the urine volume is lower in infants compared with older children, resulting in a higher UIC that might not reflect iodine adequacy. In infants, a UIC of 100 µg/L would translate to an iodine intake of 55 µg/day, assuming 92% bioavailability and a daily urine volume of 0.5 L (161). This is far below the RI from the WHO of 90 µg/day (45). To better align with the iodine intake recommendations, it has been suggested that the UIC cut-off for iodine sufficiency in infants and toddlers should be closer to 200 µg/L (22). Thus, insufficient iodine intake in the infants of Paper I cannot be excluded.

In Paper III, we assessed iodine nutrition in 0–2-year-old children using UIC and dietary assessment (repeated 24-HRs and FFQ). We found a median UIC of 145 µg/L, which is above the current cut-off of 100 µg/L and similar to the median UIC in Paper I of 146 µg/L. However, our comprehensive dietary data indicated that about one-third (35%) of the children had a usual iodine intake below the proposed EAR of 72 µg/day, which was defined as a suboptimal iodine intake in the paper. Interestingly, among those with a suboptimal usual iodine intake (n = 117), approximately 79% were breastfed and 50% were breastfed children in the youngest age group (<6 months). This further suggests that for many infants, breast milk may not provide adequate iodine to meet the requirements in the first months of life, most likely due to low BMIC. In the oldest age group (≥12 months), there were no prominent differences in iodine intake between different feeding practices, however, a notable 29% had a suboptimal iodine intake. This further suggests that even as children transition to a diet with a higher percentage of energy from complementary foods, a substantial proportion still falls short in meeting their recommended iodine intake. Furthermore, we found that the proportion of children with an excessive iodine intake in our study was low (<1%). Our findings highlight the importance of improving iodine levels in breast milk and raise awareness regarding iodine-rich sources in the diets of infants and young children.

Besides breast milk and formula, the main sources of iodine in the children's diets were industrial porridge and cow's milk, contributing 14.7% and 7.3% to the iodine intake, respectively. This was based on the repeated 24-HRs since the FFQ data did not provide the children's consumption quantities of individual foods or foods groups. Nevertheless, the FFQ provided a valuable insight into the dietary habits and the consumption frequency of iodine-rich foods (given in section 4.3.1, main results). For instance, among children one year of age and older, 45% and 60% respectively were reported to not drink cow's milk (sweet, sour, skimmed, or flavored) or consume yoghurt daily. Furthermore, from six months of age, 72% were reported to not have lean fish or products of lean fish as part of their weekly diet. This suggests that a considerable proportion of young children do not have a regular consumption of key dietary sources of iodine in the Norwegian diet, potentially leading to a suboptimal iodine intake.

Despite the critical role of THs in brain development during the first two years of life, data on iodine nutrition in this age group is scarce. One of the reasons is likely that in population monitoring of iodine status, UIC in school-age children serves as a proxy for the general population (47). However, the dietary patterns of school-age children may differ substantially from those in earlier and later life stages (46). Thus, in addition to school children, iodine nutrition should be assessed directly in vulnerable population groups, such as younger children, pregnant, and lactating women (46, 119). An overview of the published papers on iodine nutrition in children 0–2 years of age globally since 2000 can be found in **Table 11**. Most of the published studies have presented data on UIC and not iodine intake from dietary assessment methods. This is reasonable, since UIC is the recommended indicator to assess iodine status (45), and since estimating iodine intake in young children is challenging, especially in breastfed children. Except for two papers, all have reported a median UIC above the current WHO cut-off for iodine sufficiency. Næss et al. (Norway) found a median UIC of 82 μg/L in 3-month-old infants (n = 108) (152), and Anderson et al. (Switzerland) found a median UIC of 91 μg/day in 3–4 day-old infants (n = 368) and in 6-month-old infants (n = 279) (20). They both pointed to low maternal UIC and BMIC as possible explanations for iodine insufficiency in the infants, which was also discussed in Paper III of the current thesis.

In Norway, two studies besides ours have reported data on iodine intake (**Table 11)**. Based on FFQs, these studies reported a median usual iodine intake of 109 μg/day (age 18 months, n = 416) (158) and 138 μg/day (age 2 years, n = 1413) (162), which is similar to the median iodine intake estimated by the FFQ in phase II of the current study (101 μg/day, n = 137) (Paper III). These estimates by FFQ are somewhat higher than the median usual iodine intake we estimated using repeated 24-HRs (83 μg/day, n = 333). FFQs tend to overestimate the intake of energy and correlated nutrients (127, 163), although the extent may vary with the length of the FFQ and the food items in focus (164). Some studies have found a higher iodine intake by FFQ compared with other dietary assessment methods (165-168), whereas others have not (169, 170). To the best of our knowledge, only one study conducted outside of Norway has provided estimates of usual iodine intake in children 0–2 years of age (171). The study was conducted in Iceland and was in good agreement with our findings (n = 124, median intake of 88 μg/day based on a 3-day food record). However, all the children in the Icelandic study were two years old, and studies on younger, breastfed children, such as ours, have been lacking.

Table 11. Overview of available studies on iodine nutrition in children 0–2 years of age.

Authors, year, country	**Age (y/mo/wk/d)**	**n**	**Infant UIC (median, µg/L)**	**Infant iodine intake (median, µg/day)**	**Maternal biomarkers of iodine status (median, µg/L)**
Aarsland 2023, Norway (Paper III) (172)	0–2 y	333	145	83 (2 x 24-HRs) 101 (FFQ)	UIC: 92 BMIC: 74
Groufh-Jacobsen 2023, Norway (173)	2 y	55	123	N/A	UIC: 83
Hlako 2023, South Africa (174)	0–6 mo	300	217	N/A	BMIC: 102 UIC: 96.3
Gunnardsdóttir 2023, Iceland (171)	2 y	124	N/A	Average: 88 (3-day food record)	N/A
Næss 2023, Norway(152)	3, 6, 11 mo	108, 90, 91	82, 110, 110	N/A	BMIC, 3M: 77 UIC, 3M: 74 UIC, 6M: 84
Bakken 2021, Norway (Paper I) (117, 161)	Median 5.5 mo, range 1–12	130	146	50 (24-HR) PB, FFQ: 21 W, FFQ: 34	UIC: 80 BMIC: 71
Prpić 2021, Croatia (175)	2–26, 27–96	133, 101	234, 209	N/A	UIC: 75 BMIC: 121
Astrup, 2020, Norway (162)	2 y	1413	N/A	138 (FFQ)	N/A
Aakre 2018, Norway (158)	18 mo	416	129	109 (FFQ)	N/A
Thomassen 2017, Norway (126)	Median 9 mo, range 0–23	57	159	3-d food record FFQ, but estimates not presented	N/A
Andersson 2010, Switzerland (20)	3-4 d, 6 mo, 12 mo	368, 279, 228	91, 91, 103	N/A	UIC: 75 BMIC: 49

N/A, not available; PB, partially breastfed; W, weaned.

5.2.2 Maternal iodine nutrition (Papers II and III)

Maternal UIC and BMIC and its correlation with children's iodine nutrition was presented in Paper III, but not discussed in detail as the main aim was to assess iodine nutrition among the children. Furthermore, maternal iodine intake (not status) was presented in Paper II. As explained before, maternal iodine nutrition from phase I was not part of this thesis and has been described in a previous publication from the current study (122). Among the women in phase II, the median UIC was 92 µg/L (n = 330), indicating an inadequate iodine intake according to the WHO (88). When assessing lactating women and non-lactating women separately, there was a slight but not significant difference in UIC between the groups (median 85 vs. 98 µg/L, respectively, $P = 0.182$). For non-lactating women, a median UIC between 50–99 µg/L is defined as mild iodine deficiency by the WHO (45). This cut-off does not apply to lactating women, yet it is widely used in the literature for both lactating and pregnant women with inadequate iodine intake. For transparency, this definition has been used in this thesis and the included papers. **Figure 3** shows the UIC in lactating and nonlactating women in phase II of this study.

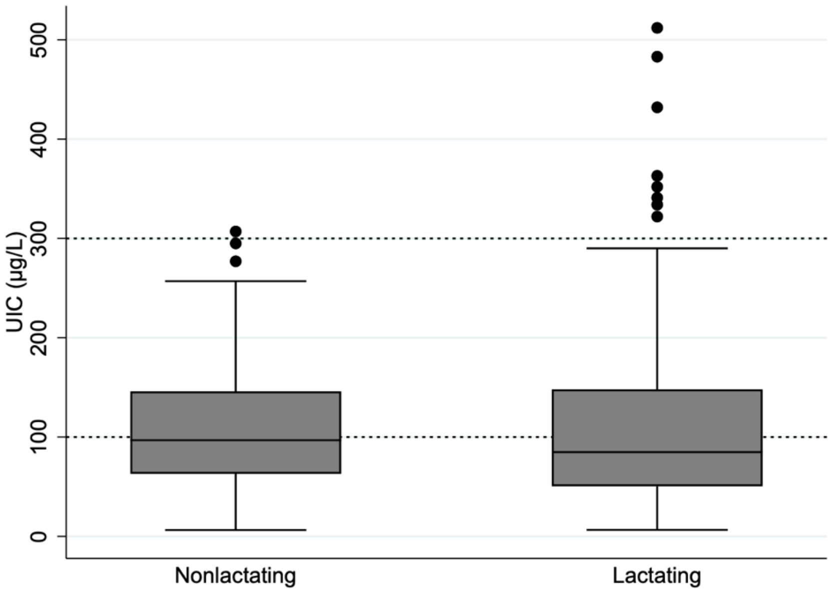

Figure 3. Box plot of maternal UIC in nonlactating (n = 96) and lactating women (n = 234). The reference lines indicate the thresholds for iodine sufficiency (100 µg/L) and iodine excess (300 µg/L, not applicable to lactating women), according to the WHO (88). UIC > 800 µg/L, n = 2.
UIC, urinary iodine concentration.

Since iodine is also excreted in breast milk, BMIC has been proposed as a biomarker of iodine nutrition in lactating women (95). However, as mentioned in the methods section, there is not yet scientific consensus on the optimal ranges of BMIC considered to provide adequate iodine in infancy. Additionally, the fractional iodine excretion in breast milk and urine may vary with iodine intake and status (22). Hence, an evaluation of iodine status using both UIC and BMIC is recommended (95, 98). The median BMIC among the women in our study was 74 μg/L. Some authors have proposed that a BMIC of 100–200 μg/L generally indicates iodine sufficiency (22, 96, 97). Based on this proposed cut-off and considering the large proportion of breastfed infants with suboptimal iodine intake in our study, our findings suggest that the lactating women had less than optimal BMIC to support recommended iodine intake. For instance, with a BMIC equal to the median BMIC in our study, a 1-month-old fully breastfed infant will be provided with 46 μg/day of iodine (assuming a consumption amount of 624 mL per day as given by the reference intakes of Rios-Leyvraz et al.). Similar, a 4-month-old infant will be provided with 55 μg/day of iodine (74 μg/L * 743 mL). These iodine intakes are lower than the EAR we used in this study of 72 μg/day and may lead to a suboptimal infant iodine intake over time.

According to the estimations of iodine intake from the repeated 24-HRs, the main iodine sources in the women's diets were dairy products, iodine-containing supplements, and fish, contributing 30.2, 22.7, and 16.0% to the total iodine intakes, respectively. Despite dairy products and fish being the main dietary iodine sources, a large proportion of the women reported seldom consuming these foods. For instance, while the Norwegian Directorate of Health recommend three daily portions of dairy products (176), 45% of the women reported that cow's milk (sweet, sour, skimmed, or flavored) was not part of their daily diet. Moreover, less than 3% reported consuming yoghurt daily. Additionally, 71% of the women reported consuming lean fish or products of lean fish less than once a week. As outlined in **Table 5** (section 1.5, introduction section), individuals in Norway with a low intake of cow's milk and/or lean fish are recommended to use iodine-containing supplements (68). Based on the above, a considerable proportion of the women in our study should have used iodine-containing supplements considering the reported low consumption of cow's milk and lean fish. These findings indicate low adherence to iodine-specific dietary guidelines and a high risk of insufficient iodine intake. As emphasized in the 2016 report by the National Council of Nutrition, healthcare personnel are crucial in raising public awareness about iodine (111). However, according to a recent study among midwives and public healthcare nurses in northern Norway, there was lack of knowledge and little focus on iodine in conversation with pregnant and postpartum women (177). While improving iodine knowledge may not ensure sufficient intake alone, it may improve intake and affect behaviour around iodine-containing supplements (178).

In Paper II, we reported that 23% of the women in this study had a suboptimal usual iodine intake (below the AR of 100 µg/day based on the repeated 24-HRs). The proportion with a suboptimal iodine intake was particularly high among women who were not classified as regular iodine-supplement users. Women who used iodine-containing supplements regularly (n = 237) had a significantly higher BMIC and estimated usual iodine intake, but not UIC, than women who did not (n = 63, **Table 12**). The reason why the women's BMIC was higher but not the UIC remains unclear. It might be attributed to an increased fractional uptake of circulating iodine into the mammary glands, possibly resulting from a low maternal iodine intake. Although there is limited knowledge in this field, such an observation was made in a study from New Zealand that determined partitioning of iodine excretion between urine and breast milk at three months postpartum (179). As elaborated by the authors, this may be seen as a protective effect to ensure an adequate iodine supply for breastfed infants. In our study, lactating women who regularly used iodine-containing supplements tended to have children with a higher UIC and higher estimated iodine intakes, although these differences were not statistically significant.

Table 12. Markers of iodine nutrition in mothers who were regular users of iodine-containing supplements vs. non-regular users.

	Regular iodine-supplement users (n = 237)		Non-regular iodine-supplement users (n = 63)		*p*[1]
	n	Median (P25–P75)	n	Median (P25–P75)	
Maternal UIC, μg/L	235	97 (51–151)	62	92 (54–152)	0.995
BMIC, μg/L	149	94 (57–172)	51	68 (44–102)	**<0.001**
Maternal usual iodine intake, μg/day	237	275 (220–328)	63	134 (94–179)	**<0.001**
Children's UIC, μg/L (breastfed children only)	53	148 (88–214)	160	122 (75–197)	0.069
Children's usual iodine intake, μg/day (breastfed children only)	53	91 (64–118)	163	77 (60–106)	0.082

[1]*P*-values from a Wilcoxon rank-sum test.

The effect of iodine-containing supplements on mildly-to-moderately iodine deficient populations remains unclear. The few available RCTs and systematic reviews addressing this topic have evaluated that evidence is lacking to support iodine supplementation during pregnancy (48, 180-182), but also pre- and post-conception (181), with regards to thyroid function and/or child development. Nevertheless, many countries have public recommendations for iodine-supplementation to all pregnant and lactating women, which makes experimental studies within this field ethically challenging. In a recent cohort study from Australia, Sullivan et al. stressed that there is an urgent need to reexamine the widespread recommendation for universal iodine supplementation during pregnancy in iodine-deficient populations. Further, they suggested that targeted, not blanket iodine supplementation may be needed (183). The authors evaluated the relationship between iodine intake during pregnancy and neurodevelopment at 18 months of age (n = 699 mother-child pairs) and found that higher iodine intakes (≥350 μg/day), driven by maternal supplement use, was associated with poorer child neurodevelopmental scores, similar to lower iodine intakes (<185 μg/day). As discussed by the authors, the negative effects of higher iodine intakes could be related to a possible protecting mechanism in the infant thyroid gland, involving transient inhibition of TH production and release to prevent iodine overload, known as the Wolff-Chaikoff mechanism.

Other studies have also suggested that a sudden increase in iodine intake during pregnancy, e.g., through initiation of iodine-containing supplements, may result in transient inhibition of TH release (184, 185). More studies, including high-quality data, are needed to investigate the relationship between iodine-supplementation and health outcomes.

Not surprisingly, our findings in postpartum and lactating women in Innlandet County align with previous studies in Norway and elsewhere showing mild-to-moderate iodine deficiency and inadequate iodine intake in women of childbearing age (113-117). This is highly concerning given the importance of adequate iodine intake prior to pregnancy and during lactation to ensure optimal health outcomes for both mothers and infants. A considerable proportion of the women in our study reported to never or seldom consume cow's milk and/or lean fish, suggesting a high risk of low iodine intakes. The declining intake of milk and fish over the past decades highlights the need for additional sources of iodine in the diet, particularly among women of childbearing age. In the next section, salt iodization will be discussed, which is the preferred strategy globally to prevent iodine deficiency (104).

5.2.3 Iodization of household salt and salt used in bread

The recommendation by the National Council of Nutrition to iodize household salt with 20 µg/g (up from 5 µg/g), as well as salt in bread, aims to increase the iodine intake in the population, specifically in young women, with 40–50 µg/day (120). As detailed in the introduction section (section 1.6), a comprehensive evaluation of the risks and benefits associated with salt iodization was conducted by VKM in 2020 (119). VKM assessed that increasing the iodine concentration in salt to 15–20 µg/g would enhance iodine intake in young women and women of childbearing age, but also pose a risk of excess iodine intake in certain population groups, particularly 1- and 2-year-olds. The estimated iodine exposures by VKM were based on FFQ data and indicated that an addition of 15 µg/g iodine to household salt and salt in bread would result in intakes above the UL in 18% of 2-year-olds, compared with 8% without the enrichment. In 2021, one year after the report from VKM was published, the National Council of Nutrition argued that the energy and nutrient estimates used by the VKM to predict iodine intakes in children were overestimated by 25–30%, likely also resulting in an overestimation of the proportion of children with excessive iodine intakes (120). Also, the council emphasized that according to the proposed UIC cut-off of 200 µg/L in young children, nearly half of the children in a survey of 18-month-olds (n = 416) had iodine intakes below the recommendations, with a high likelihood that a significant proportion was also below the

EAR (120, 158). Along with a strong recommendation for salt iodization, the National Council of Nutrition concluded that the likelihood of children or other population groups exceeding the UL following the suggested iodine enrichment is low (120).

In 2023, iodization of household salt with 20 µg/day was permitted in Norway with a law change (121). So far, the industry has not yet implemented the increase in their production, and they have not been encouraged to do so. In the next section, we have used the estimated usual iodine intakes from Papers II and III in this thesis to predict usual iodine intakes following the iodization of household salt and salt in bread in line with the recommendations by the National Council of Nutrition and the current permitted level.

Risk of iodine excess – exposure estimates using data from the "Iodine in Early Life" study

In the following section, we have assessed the effect of increasing the iodization level in household salt and salt in bread on the iodine intake of children between 0–2 years of age and their mothers in the "Iodine in Early Life" study. The intake estimates are compared with the established dietary reference values AI, EAR, and UL. For the children, we applied the EAR of 65 µg/day from the IOM (80), since this threshold was used in the risk-benefit assessment by the VKM (119). Furthermore, we used the dietary data from the repeated 24-HRs in phase II as the basis for our calculations.

To all single 24-HRs, we added iodine from household salt and bread (not crisp bread, bread rolls, etc.) before we used the MSM to adjust for day-to-day variations and estimate usual iodine intakes. Akin to the VKM approach, we assumed that the daily intake of household salt was 0.8 g/day in women and 0.5 g/day in 2-year-olds. These were approximations from the Tromsø 7 study (Norway), carried out in 2015–2016 (119, 186). One-year-olds consume less salt than older children and adults, thus, iodine from household salt was only added to 24-HRs of children aged two years and above (n = 8). Further, for bread, we assumed a salt concentration of 1.1 g per 100 g bread. For instance, a slice of bread (40 g) was assumed to contribute 0.44 g salt and 8.8 µg iodine. For breastfed children, we also accounted for a potential increase in BMIC following increased maternal iodine intake. On average, maternal usual iodine intake increased with 23% after addition of iodine from household salt and bread. Thus, for each measured BMIC in phase II, we increased the iodine concentration by 23% to calculate the children's iodine consumption from breast milk. This approach is considered conservative, as when maternal iodine intake is increased, not all additional iodine will be partitioned into breast milk and ingested by the child. Thus, our estimates of iodine intake in the breastfed children are likely slightly overestimated. The iodine exposure estimates from our calculations are presented in **Table 13**.

Briefly, our findings suggest that iodizing both household salt and salt used in bread at the permitted level of 20 μg/g could lead to a reduction in the proportion of children with usual iodine intakes below the EAR, from 35 to 20%. Also, the median iodine intake is estimated to increase from 83 to 91 μg/day, which is above the AI for infants <1 year of age but below the AI for older children. The proportion of children above the UL seem to remain low, with an increase from 0.6 to 2%. As explained above, our estimates are likely also slightly right-skewed due to a possible overestimated iodine contribution from breast milk.

Among the women, our crude estimates suggest that the proposed iodization would reduce the proportion with usual iodine intakes below the EAR from 24 to 9%. Proportionally, this is the same reduction as estimated in the children. Furthermore, the proportion of women with intakes above the UL is estimated to increase from 0 to 0.6%, which is a low proportion and a minor shift when compared to the 15% of women transitioning from suboptimal intakes to intakes above the EAR.

Table 13. Iodine exposure estimates in participants from the "Iodine in Early Life study" if iodine is added to household salt (20 μg/g) and salt used in bread (1.1 g salt/100 g).

	Mothers[1, 2] (n = 330)		**Children[1,2] (n = 333)**	
	Before iodization (from paper II)	**After iodization**	**Before iodization** (from paper III)	**After iodization**
μg/day, P50 (P25, P75)	153 (102, 220)	181 (133, 249)	83 (64, 113)	91 (70, 121)
% below RI[3]/AI[4], (95% CI)	63 (58, 69)	51 (46, 57)	56 (51, 62)	51 (46, 57)
% below AR[5]/EAR[6] (95% CI)	24 (19, 29)	9 (6, 13)	35 (30, 41)	20 (16, 25)
% above UL[7] (95% CI)	0 (0, 4.6)	0.6 (0.1, 2)	0.6 (0.0, 2.2)	2 (0.8, 4)

[1]Total usual iodine intakes (from foods and supplements) estimated by 2 x 24-HRs using the MSM (132).
[2]Numbers of participants and data deviate slightly from those given in Paper II. In Paper II, mothers with only one day of 24-HR data were excluded. In the current table, all mothers with 24-HR data were included, except three, due to usual energy intake outside the range of 500–3500 kcal/day.
[3]Recommended intake for adults from the NNR2012 (200 μg/day in lactating women and 150 μg/day in nonlactating women).[4]Adequate intake from the NNR2023 (90 μg/day for infants <12 months of age and 100 μg/day for children ≥12 months of age.
[5]Estimated average requirement for adults from the NNR2012 (100 μg/day).[6]Estimated average requirement for children <2 years of age from the IOM (72 μg/day) (18).
[7]Upper intake level for adults from the NNR2012 (600 μg/day) and for 1–3-year-olds from the EFSA (200 μg /day).
AI, Adequate intake; EAR, estimated average requirement, UL, Upper limit; IOM, Institute of Medicine, EFSA; European Food Safety Authority: NNR, Nordic Nutrition Recommendations.

Based on the above, our crude estimates support the recommendations by the National Council of Nutrition to enrich household salt and salt used in bread with 20 μg/g iodine (120), in line with the recent law change. The enrichment appears to reduce the percentage of individuals with suboptimal iodine intakes, while concurrently maintaining a low proportion with excessive iodine intakes. However, as mentioned, the optimal level of iodine intake is narrow, particularly for young children. Thus, as emphasized by both the WHO and the National Council of Nutrition, it is crucial to monitor iodine status and iodine intake in vulnerable population groups following the potential enrichment to prevent both iodine deficiency and excess (45, 120).

Conclusion

The work presented in this thesis suggests that children between 0–2 years of age in Innlandet County, Norway, have adequate iodine status on a population level, as indicated by a median UIC above the current cut-off of 100 µg/L. However, the UIC cut-off for young children is debated, and there might be a need to revaluate the UIC data when updated guidance on indicators and thresholds for iodine status assessment becomes available. This is supported by our extensive dietary data, indicating that more than a third of the children had a suboptimal usual iodine intake as shown by intakes below the EAR. Further, our results indicate that the proportion of children with an excessive usual iodine intake was low.

The highest proportion with suboptimal iodine intakes were among the breastfed children, particularly among children below six months of age. A suboptimal iodine intake was also prominent in older children, who had a higher intake of complementary foods. These findings support the need for improving iodine status in lactating women, but also to raise awareness regarding iodine-rich sources as infants are introduced to complementary foods and eventually weaned. Furthermore, our results align with earlier findings in Norway and elsewhere of mild-to-moderate iodine deficiency and inadequate iodine intake in postpartum and lactating women. Maternal UIC, BMIC, and iodine intake were positively associated with children's iodine intake and UIC, underlining the importance of an adequate maternal iodine intake in providing a sufficient iodine intake in infants and young children.

This thesis provides valuable data to inform and support public health policies aimed at optimizing iodine nutrition, particularly in vulnerable population groups such as children under two years of age and women of childbearing age. Young children are the most susceptible to both excessive and low iodine intakes, and it is crucial to regularly monitor iodine nutrition in this age group. The National Council of Nutrition strongly recommends an immediate increase in the iodization level of household salt and salt used in bread. The findings presented in this thesis offer important baseline data for comparing and assessing the effectiveness of potential iodization measures.

6. Future perspectives

- **Consensus on UIC cut-offs for infants and young children**

  As mentioned in the current thesis, various organizations and researchers have stressed that there is insufficient evidence for the current cut-off to define iodine adequacy in children under two years of age. Since the UIC cut-offs are based on school-age children, and infants and young children generally have lower urine volumes, their UIC will be higher despite a lower iodine intake. The UIC-cut offs are currently undergoing revision by an expert group on behalf of the WHO, and current available literature on iodine status in young children should be evaluated considering potential adjusted thresholds.

- **Monitoring of iodine status in children 0–2 years of age**

  The crude iodine exposure estimates from this PhD thesis suggest that the proposed and permitted iodization level of 20 μg/g salt would lead to a decreased, but still notable proportion of young children having a suboptimal usual iodine intake (from 35 to 20%). Thus, a focus on iodine-rich sources, both for young children and for women of childbearing age, is important to ensure adequate iodine intake in this age group. Even after the proposed enrichment is implemented, there might be a need for recommending iodine-containing supplements to women of childbearing age, pregnant women, and lactating women with a low intake of milk and/or lean fish.

  Further, our estimates suggest that the proportion of children with an excessive iodine intake will remain low with the proposed iodization level. Given the narrow optimal range of iodine intake in young children, regular monitoring of iodine status is important. This is also emphasized by the WHO and provides opportunities for adjustments to mitigate both iodine deficiency and excess. In a proposal for a national monitoring program in Norway on behalf of the Ministry of Health and Care Services, it was suggested that iodine status should be measured every five years in 2-year-olds and their mothers (n = 400 pairs) by urinary collection and dietary questionnaires (67).

- **Investigation of the role of mild-to-moderate iodine deficiency and iodine excess on thyroid function**

  The only known role of iodine in the human body is being a constituent of the THs. While the consequences of severe iodine deficiency are well established, it is not clearly understood whether and how mild-to-moderate iodine deficiency affects thyroid function. A meta-analysis was recently conducted in pregnant women, concluding that mild iodine deficiency may increase the risk of thyroid dysfunction (187). Future studies need to address this association also in population groups such as lactating women and young children. Further, while iodine excess also results in altered thyroid functioning, it is not clear at which level of iodine intake adverse effects occur. Thus, more research is needed to assess the prevalence of excessive iodine intakes in the population and the association with thyroid disorders.

- **Investigation of the possible benefits and harms of maternal iodine supplementation during pregnancy and lactation**

  In Norway, iodine-containing supplements are recommended to pregnant and lactating women with a low intake of milk and/or lean fish, but many expert bodies and other health authorities recommend iodine-containing supplements to all pregnant and lactating women regardless of intake. As mentioned, there is insufficient good quality evidence to support these recommendations, and observational studies have linked both low and high iodine intakes in pregnancy to poorer neurodevelopmental outcomes in children. Therefore, future experimental studies should assess the potential harms and benefits of iodine supplements. RCTs are ongoing in Australia (the PoppiE trial) (188) and in Sweden (189), with the aim of investigating the effects of iodine supplementation to iodine-sufficient pregnant women (Australia) and mildly-to-moderately deficient women (Sweden) on child neurodevelopmental outcomes. The results from such studies will provide valuable insights into whether the current standard practices of iodine supplementation during pregnancy should persist or, as in Norway, a more targeted approach based on individual iodine intake is warranted.

Erratum

- In Paper I, we reported that 57.5% of the infants had an iodine intake below the Nordic recommendations (50 μg/day for infants aged 6–11 months). The correct proportion is 51%, which is the proportion given in the results section (4.1.1).
- In Paper II, we reported that 29 municipalities took part in the study. However, the accurate count is 30 municipalities, which is the number given in Paper III and further used in the current thesis.

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Paper I

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Article

Adequate Urinary Iodine Concentration among Infants in the Inland Area of Norway

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Abstract: Considering the importance of iodine to support optimal growth and neurological development of the brain and central nervous system, this study aimed to assess and evaluate iodine status in Norwegian infants. We collected data on dietary intake of iodine, iodine knowledge in mothers, and assessed iodine concentration in mother's breast milk and in infant's urine in a cross-sectional study at two public healthcare clinics in the inland area of Norway. In the 130 mother–infant pairs, the estimated infant 24-h median iodine intake was 50 (IQR 31, 78) µg/day. The median infant urinary iodine concentration (UIC) was 146 (IQR 93, 250) µg/L and within the recommended median defined by the World Health Organization for this age group. Weaned infants had a higher UIC [210 (IQR 130, 330) µg/L] than exclusively breastfed infants [130 (IQR 78, 210) µg/L] and partially breastfed infants [135 (IQR 89, 250) µg/L], which suggest that the dietary data obtained in this study did not capture the accurate iodine intake of the included infants. The iodine status of infants in the inland area of Norway seemed adequate. Weaned infants had higher UIC compared to breastfed infants, suggesting early access and consumption of other sources of iodine in addition to breast milk.

Keywords: infants; iodine; knowledge; urinary iodine concentration; UIC; iodine intake; inland area; Norway

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1. Introduction

Iodine is an essential mineral required for the synthesis of thyroid hormones (THs). In the first phases of life, optimal levels of THs are critical for normal growth and neurological development of the brain and central nervous system [1]. Iodine excess may also result in thyroid dysfunction, but the evidence for health effects of excess is more limited than of deficiency [2]. Iodine deficiency (ID) in the fetus and infant is the most common cause of preventable brain damage globally [3]. A systematic review from 2013 on the effect of ID on mental development in children 5 years and younger showed that even mild ID could influence school performance, intellectual ability, and work capacity of children [4]. However, a recent review concluded that there is insufficient evidence to support recommendations for iodine supplementation in areas of mild- or moderate deficiency of iodine [5]. Despite the role of iodine in growth and development, we have little knowledge of infant's iodine status in Norway.

Infant sources of iodine come exclusively from breast milk or formula during the first 4–6 months of life and thereafter from breast milk, formula, and complementary foods. The iodine concentration in breast milk reflects maternal iodine intake and probably status, which in turn is affected by the maternal intake of dietary iodine and/or supplements. The main sources of iodine in the Norwegian diet are milk and seafood, mainly lean fish such as cod, saithe, and haddock, constituting approximately 55 and 20% of the dietary iodine intake, respectively [6]. Severe ID was widespread in Norway 100 years ago, especially in the inland area where the seafood intake was low [7]. In the 1950s, iodine was added to cow fodder to improve animal health [8]. Due to the high transfer of iodine to milk and high consumption of milk and dairy products, the iodine intake in the population increased. However, a decline in the intake of these foods over the last decade has contributed to inadequate iodine intake in several groups of the population, especially among women of childbearing age [9–12]. Iodine is excreted in breast milk during lactation, and breastfed infants rely on an adequate supply through the breast milk to cover their production of thyroid hormones [13]. As the breastfeeding prevalence in Norway is high, a large proportion of infants may be at increased risk of not reaching their iodine needs due to inadequate maternal iodine intake. The World Health Organization (WHO) recommends a daily iodine intake of 90 μg/day for children younger than two years of age [14], while in the Nordic countries a daily iodine intake of 50–70 μg/day is recommended [15].

As severe ID is no longer seen in Norway, the primary concern is the consequences of mild-to-moderate ID. Globally, the main strategy to eliminate ID is iodization of salt, which is not implemented in Norway. A risk-benefit analysis by the Norwegian Scientific Committee for Food and Environment on the health consequences of iodization of household salt and salt used in bread was published recently. This report concluded that these measures could benefit groups such as youths and women of childbearing age but simultaneously put one- and two-year-old's at risk of excess iodine intake [16]. The report highlights the need for more data on small children's iodine status in Norway. A recent study confirmed inadequate iodine intake and insufficient iodine status among lactating women in the inland area of Norway [17]. This study aimed to assess and evaluate iodine status in infants resident in the same area.

2. Materials and Methods

2.1. Study Population

During October–December 2018, mother-infant pairs were recruited at two public healthcare clinics, in the cities Lillehammer and Gjøvik. Mothers and infants aged 0–12 months with appointments at the healthcare clinics were all invited to participate in the study. The inclusion criteria were (1) mothers were able to read and write in Norwegian, (2) healthy infant, no known metabolic or congenital chronically illness in the infant that could affect cognitive development, and (3) possibility to collect urine and blood sample of the infant.

A total of 204 mothers were invited to participate, and of these 151 (74%) mother–infant pairs signed informed consent at the public healthcare clinics. Eleven participants withdraw from the study and four were lost to follow-up (Figure 1). In addition, six mother-infant pairs were excluded from this analysis due to use of thyroid medication. Completed questionnaires and urine samples were available for 130 infants. Figure 1 shows the study recruitment.

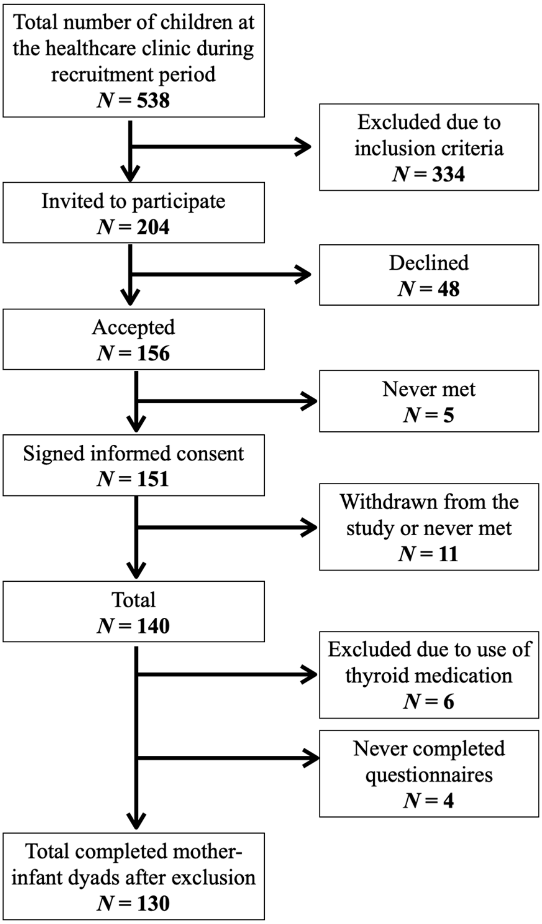

Figure 1. Flowchart of study recruitment and completion.

2.2. Ethical Considerations

The Regional Committee for Medical and Health Research Ethics approved the study (2018/1230/REC South East). All women provided written informed consent. All materials were handled de-identified.

2.3. Collection of Breast Milk and Urine Samples

Every mother was informed about the study purpose, and the ones that consent to participate were instructed to collect one spot breast milk sample (5 mL) in the morning before breastfeeding and a second spot breast milk sample (5 mL) in the afternoon after breastfeeding. Both breast milk samples were obtained by manual expression into the same labelled 50 mL polypropylene (pp) centrifuge tube (Sarstedt, Nümbrecht, Germany). Moreover, the mothers were instructed to collect one spot urine sample (5 mL) from the infant in the morning using Sterisets Urine collection packs 310,019 (Sterisets International BV, Oss The Netherlands) containing one syringe (5 mL), one specimen container (20 mL), two uricol collection pads (21 cm $\times$ 7 cm), and an instruction leaflet. To collect the baby's urine, a pad was placed inside the disposable diaper and checked every 5 min until the pad was wet with urine but not soiled by feces. Then, the pad was placed on a flat surface, and the urine was transferred into the sterile container. An alternative method to extract the urine was to cut the pad open, put the wet cotton into the opened syringe and press the urine into the container. In summary, once during the study period, each mother donated a repeated spot breast milk sample in one container (10 mL) and one spot infant urine sample (5 mL), all samples collected on the same day. The containers were kept refrigerated until the sample was transferred to a −70 °C freezer and later transported on dry ice for analysis.

2.4. Chemical Analyses

The analysis of the mother's breast milk and the infant urine to determine the concentration of iodine was performed at the Norwegian University of Life Sciences, Faculty of Environmental Sciences and Natural Resource management. The frozen urine was thawed and aliquoted into 15 mL pp centrifuge tubes (Sarstedt, Nümbrecht, Germany) using a 100–5000 µL electronic pipette (Biohit, Helsinki, Finland). In detail, an aliquot of 1.00 mL of urine was diluted to 10.0 mL with an alkaline mixture (BENT), containing 4% (weight (w)/volume (V)) 1-Butanol, 0.1% (*w/v*) H4EDTA, 2% (*w/v*) NH4OH, and 0.1% (*w/v*) TritonTM X-100 (Millipore, Burlington, MA, USA). To avoid precipitation of struvite (MgNH4PO4 × 6H2O) in the urine, the concentration of NH4OH in BENT was set to 2%.

The breast milk samples were thawed and heated to 37 °C in a heating cabinet, homogenized, and then prepared by dilution in an alkaline solution (BENT), following the same procedure as the one used for the urine samples, except that the concentration of NH4OH in BENT was increased to 5% (*w/v*). A conformance test between weight and volume of breast milk limited the concentration of iodine to two significant figures.

Standard Reference Materials (SRM) and method blank samples were prepared in the same manner as the respective sample matrices. Deionized water (>18 MΩ) and reagents of analytical grade or better were used throughout. The quantification of iodine in urine and breastmilk was performed by means of an Agilent 8900 ICP-QQQ (Triple Quadrupole Inductively Coupled Plasma Mass Spectrometer; Agilent Technologies, Hachioji, Japan) using oxygen reaction mode. Iodine was quantified on mass 127. To correct for non-spectral interferences, ^{129}I was used.

In breast milk, the limit of detection (LOD) was 0.04 µg/L and the limit of quantification (LOQ) was 0.14 µg/L. With regard to the infant urine, LOD was 0.1 µg/L and LOQ was 0.44 µg/L. The LOD and LOQ were calculated by multiplying the standard deviation of five method blank samples that followed each treatment by three and ten, respectively. The measurement repeatability was 1.6% with respect to both urine and breast milk. To ensure methodological traceability and to check for accuracy, SRM were analyzed concurrently with the sample matrices. Allowing for a coverage factor k = 2, corresponding to a level of confidence of about 95%, our results were within the recommended values issued for the Seronorm™ (Oslo, Norway) Trace Elements Urine L-1, SeronormTM Trace Elements Urine L-2, and the European Reference Materials ERM®-BD 150 (Geel, Belgium) and ERM®-BD 151 Skimmed milk powders.

A performance test of the sampling method of infant urine showed no significant change in analyte; thus, the sampling method is considered reliable [18].

2.5. Infant Iodine Intake from Food and Supplements

To calculate the 24-h iodine intake in exclusively breastfed infants, reference values for human milk intakes by infants age in high-income countries [19] were multiplied with the mother's individual breast milk iodine concentration (BMIC). For example, the breast milk intake of exclusively breastfed 1-month-olds is 0.699 L per 24 h. The estimated intake for a particular 1-month-old baby is accordingly 0.699 × BMIC µg/L. The BMIC data can only be used to estimate one 24-h iodine intake in breastfed infants as the mothers provided breast milk samples from one single day. Similarly, for partially breastfed infants, the 24-h iodine intake was calculated by combining the calculated iodine intake from breast milk (the intake of partially breastfed infants at 1 month is 0.611 L) with the calculated iodine intake from foods as estimated by the on-site 24-h recall.

The 24-h recall captured the infant's intake of iodine-containing food items, reported by the mothers. The iodine intakes of partially breastfed- and weaned infants were calculated by using the 24-h recall data and the applicable iodine concentration according to the Norwegian Food Composition Table [20].

Habitual iodine intake in the infants who eat solid food was calculated based on a food frequency questionnaire (FFQ) assessing infant's food intake the past two weeks. The questionnaire was developed based on a modified version used in previous studies [21]. The infant FFQ assessed the intake of bread, yoghurt, fatty fish, lean fish, fish products, iodine enriched smoothies, processed baby foods (dinner), eggs, cheese, water, and industrially produced porridge. The frequency alternatives ranged from never/rarely, more rarely than weakly, 1–3 times a week, 4–6 times a week, 1–2 times a day, 3–4 times a day, to 5 times a day or more. The reported daily consumption frequencies for each food item in the infant FFQ were multiplied with portion sizes and iodine concentrations applicable for each food item using The Norwegian Food Composition Table [20]. The habitual intake among partially breastfed infants only covers calculations from food, not the additional amount of iodine they get from breast milk.

2.6. Participant Characteristics and Independent Variables

We recorded the participants' age, both maternal (in years) and infant (in weeks). We also recorded maternal educational level (in categories; <12 years, 12 years, 1–4 years college/university, and >4 years college/university), maternal height and weight, and calculated body mass index (BMI, kg/m^2, categorized into; underweight [<18.5], normal weight [18.5–24.9], overweight [25–29.9] and obese [>30]), infant gender (boy or girl) and infant breastfeeding status (categorized into; weaned, partially, and exclusively). Information on maternal use of iodine-containing supplements were collected from the 24-h recall and reflects maternal use of the supplement at the time of breast milk collection.

The maternal iodine knowledge score was calculated using a validated questionnaire including six questions [22]. In the current study, we used three of the questions to calculate a total iodine knowledge score. These questions were: (1) What are the most important dietary sources of iodine? (2) Why is iodine important? and (3) What do you know about the current iodine status among pregnant women in Norway. The questions had multiple answer alternatives, whereas some were correct, and some were incorrect. A correct answer gave 2 points, if they correctly identified an incorrect answer they got 1 point, and a wrong answer gave 0 points. Those who answered "I don't know" did not get 1 point, even if they "correctly identify an incorrect answer". The total knowledge score ranged from 0–26 points and was categorized into four categories of knowledge scores: poor (0–5 points), low (6–11 points), medium (12–19 points) and high (20–26 points).

2.7. Statistical Analyses

Statistical analyses were performed using Stata/SE 16.1 (StataCorp, College Station, TX, USA). Skewness and kurtosis test for normality was used to test whether the dependent variable UIC was normally distributed. The correlation between variables were evaluated using Spearman correlation matrix. We used kernel regression to assess the univariate associations between the dependent variable infant UIC and the independent variables. We computed bootstrap standard errors and percentile confidence intervals with 100 replications by the npregress kernel command (non-parametric kernel regression).

3. Results

3.1. General Characteristics

Table 1 summarizes the background information of the infants and their mothers. Only three mothers reported to be either vegetarian or vegan, and only two mothers had never breastfed their infant. None of the infants consumed iodine-containing supplements; however, 23% of the mothers used iodine-containing supplements during the last 24 h.

Table 1. Characteristics of mother–infant dyads (*n* = 130).

Characteristic	Categories	*n* (%) [a]
Maternal age, mean (SD)		31.5 (4.6)
Maternal educational level	<12 years	6 (5)
	12 years	17 (13)
	1–4 years college/university	52 (40)
	>4 years college/university	55 (42)
Maternal BMI, kg/m^2	<18.5 (Underweight)	4 (3)
	18.5–24.9 (Normal weight)	81 (62)
	25–29.9 (Overweight)	30 (23)
	>30 (Obese)	15 (12)
Maternal iodine knowledge score	Poor (0–5)	10 (8)
	Low (6–11)	17 (13)
	Medium (12–19)	69 (53)
	High (20–26)	34 (26)
Maternal use of iodine-containing supplement last 24-h	Yes	30 (23)
Infant age in weeks, median (min–max)		22 (1–5)
Infant gender	Boy	69 (53)
Breastfeeding status [b]	Weaned	28 (22)
	Partially	46 (35)
	Exclusively	56 (43)

[a] Numbers are presented as *n* (%) if not indicated otherwise. [b] Exclusively breastfed infants were defined as infants who received breast milk (including milk expressed) only, and no other liquids, solid foods or water was given, except drops of vitamins or minerals.

3.2. Dietary Iodine Intake

The habitual, as well as the recent 24-h dietary iodine intakes are given in Table 2. In total, the estimated 24-h median (IQR) iodine intake was 50 (31, 78) µg/day. Eighty-eight (57.5%) of the infants had an iodine intake below the Nordic recommendations (50 µg/day for infants aged 6–11 months). The weaned infants seemed to have a lower dietary iodine intake compared to the breastfed infants (Table 2). Only 4.7% of these weaned infants were estimated to reach the intake recommendation of 50 µg iodine a day, whereas 54.7% of the exclusively breastfed infants had an estimated iodine intake above this recommendation. Seventeen (15.5%) of the weaned infants had a habitual iodine intake below the Nordic recommendations. Habitual iodine intake was not calculated for the exclusively breastfed infants, as two spot samples of breastmilk collected on the same day do not cover the day-to-day variation in breast milk iodine content.

Table 2. Urinary iodine concentration (µg/L) and calculated iodine intake (µg/day) for the infants (*n* = 130). Numbers are presented as median (IQR).

	Total *n* **= 130**	**Exclusively Breastfed** *n* **= 56**	**Partially Breastfed** *n* **= 46**	**Weaned** *n* **= 28**
Infant urinary iodine concentration, µg/L	146 (93, 250)	130 (78, 210)	135 (89, 250)	210 (130, 330)
Total habitual iodine intake, µg/day	-	-	21 (6, 37) [a]	34 (14, 87)
Total 24-h iodine intake, µg/day	50 (31, 78)	66 (44, 107)	57 (35, 77)	25 (13, 39)

[a] Includes iodine intake from solid food only, not breastmilk. Habitual intake in exclusively and partially breastfed infants are not calculated due to insufficient data (only one single spot sample of breast milk).

3.3. Urinary Iodine Concentration

The median UIC (IQR) was 146 (93, 250) µg/L. A total of 44 (33.6%) of the infants had a UIC within the suggested optimal UIC range (100–199 µg/L). The exclusively breastfed and partially breastfed infants had a median UIC within the range, while the weaned infants had a median UIC slightly above (Table 2 and Figure 2). The association between breastfeeding status and UIC was significant (Table 3). Infants who were exclusively and partially breastfed had on average 79.6 µg/L (p = 0.006) and 70.2 µg/L (p = 0.014) lower UIC, respectively, compared to weaned infants. We did not identify other maternal or infant characteristics associated with the UIC (Table 3).

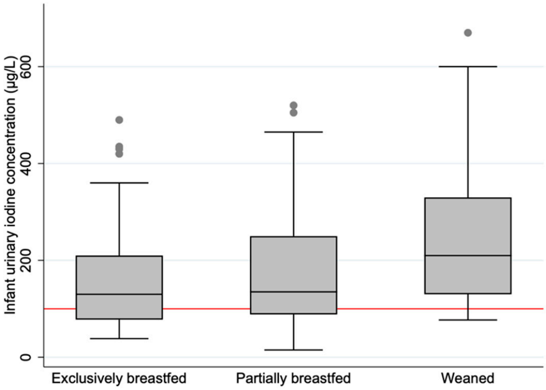

Figure 2. Boxplot displaying infant urinary iodine concentration (µg/L) in the three categories of breastfeeding status. The horizontal black line indicates the median; the boxes indicate the interquartile range (IQR); the whiskers represent observations within 1.5 times the IQR. The red line shows the recommended median value for sufficient iodine concentration in urine (≥100 µg/L).

Table 3. Non-parametric regression model of the univariate association between maternal and infant characteristics and infant urinary iodine concentration (µg/L) (n = 130). Numbers are presented as β with 95% confidence interval.

Independent Variables	ß and 95% CI [a]	
Maternal age in Years	3.7	−1.2, 9.3
Maternal educational level		
<12 years	Reference	
12 years	0.0	−1.3, 0.9
1–4 years college/university	0.2	−1.9, 2.4
>4 years college/university	0.3	−1.6, 2.1
Maternal BMI, kg/m^2		
18.5–24.9 (Normal weight)	Reference	
<18.5 (Underweight)	3.6	−2.1, 9.4
25–29.9 (Overweight)	−1.2	−10.4, 7.8
>30 (Obese)	1.9	−3.7, 6.8
Maternal iodine knowledge score		
Poor (0–5)	Reference	
Low (6–11)	4.7	−2.1, 13.8
Medium (12–19)	−3.2	−10.2, 5.4
High (20–26)	4.7	−2.1, 10.8
Maternal use of supplement last 24 h, yes	−0.3	−7.7, 6.9
Infant age in weeks	1.4	−0.2, 2.7
Infant gender, boy	3.1	−7.7, 13.2
Breastfeeding status		
Weaned	Reference	
Partially	−70.2	−121.8, −24.5
Exclusively	−79.6	−141.6, −36.5

[a] CI = Confidence interval.

For the exclusively breastfed infants, almost half of the variation in UIC was explained by the maternal BMIC (adjusted R2 = 0.45). We found a linear relationship between infant UIC and BMIC (Figure 3). However, there was no significant correlation between infant UIC and the estimated 24-h dietary iodine intake (rs = 0.122, p = 0.166), which may be evidence of inaccuracies in the estimation of the dietary iodine intake.

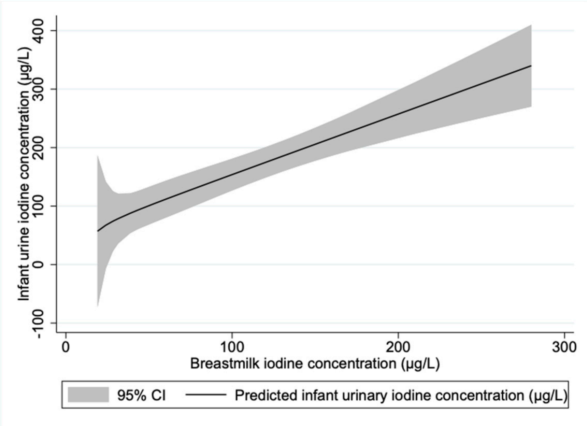

Figure 3. Prediction plot of infant urinary iodine concentration by maternal breastmilk iodine concentration for exclusively breastfed infants. n = 56.

4. Discussion

This is the first study to present data on iodine status and iodine intake in infants in the inland area of Norway. We found that the median UIC (146 μg/L) was indicative of sufficient iodine status according to the current WHO median of 100 μg/L in children under two years of age [14]. The median assumes a daily urine volume of 500 mL and 92% iodine bioavailability. A median UIC of 100 μg/L would extrapolate to a mean daily iodine intake of 55 μg, lower than the WHO recommendation of 90 μg/day iodine [23]. The disagreement in recommendations by the WHO makes evaluation of iodine status in infants difficult. There may therefore be a need for a review of the UIC recommendations by the WHO in small children using associations with biomarkers of iodine status, as the current one may not reflect the true metabolic iodine status in infants and young children. The thyroid-derived protein thyroglobulin (Tg) is increasingly being used as an index of iodine status in the population. In school-aged children, Tg is a sensitive indicator of both low and excess iodine intake [24]. However, validated reference ranges are needed for the determination of iodine sufficiency in infants and young children.

The infant median iodine intake based on 24-h recalls was 50 μg/day, which is below the WHO intake recommendation [14] but in accordance with the Nordic recommendation of 50–70 μg/day [15]. Since there are many challenges related to dietary assessment, our iodine intake estimations may be more accurate for exclusively breastfed infants than for partially breastfed and weaned infants.

Despite significant improvements over the past decades in the global iodine status through salt iodization, ID remains a concern in several countries, particularly in Europe. However, there is limited information on UIC in infants in European countries. Iodine status in infants is usually not monitored in countries with established salt iodization programs where the general population has adequate iodine intake. Breastfed infants may benefit from iodized salt through breastmilk, but the salt content in complementary foods and industrial baby foods is generally low [25]. It is estimated that up to half of all newborns in Europe may be at risk of restrictions to their cognitive potential due to ID [26]. Studies from other areas of Norway have been conducted, but most previous studies have assessed iodine status in subpopulations or in children at an older age. A study carried out in children with cow´s milk protein allergy, two years and younger, showed a median UIC of 159 µg/L [27]. The Little in Norway study (LiN) undertaken between 2011–2014, which included 18 months old infants from all health regions in Norway, found a median UIC of 129 µg/L, and the authors concluded that 59% had an adequate iodine status [28]. The iodine exposure in two-year-olds was estimated from the study Småbarnskost 3 conducted in 2019, which found a mean iodine intake of 138 µg/day and 128 µg/day respectively with and without iodine supplementation [29]. Småbarnskost 3 was based on semi-quantitative FFQs; providing a better estimate of the individual iodine intake than the UIC, but may overestimate the food intake and the intake of energy-related nutrients [30]. A validation study confirmed that the FFQ used in the nationwide survey overestimated the intake of energy and most nutrients [31].

Only one of the variables we tested, breastfeeding status, were associated with infant UIC. We did not find that increased maternal iodine knowledge score was associated with increased infant UIC. Few other studies have explored this. However, another Norwegian study among pregnant and lactating women found no association between the participants' knowledge scores and iodine status [22]. In contrast, a study among young female students in Norway found that UIC was lower in women with high iodine knowledge compared to those with low knowledge score [12]. The majority of mothers in the current study (79%) had medium to high knowledge score, but the relationship between iodine knowledge score and UIC remains unclear.

We found significant differences in UIC according to breastfeeding status. All three groups had a median UIC above the median of 100 µg/L. There was a significantly higher prevalence of UIC values below the median among the exclusively and partially breastfed infants compared to the weaned infants. These variations may be explained by different urinary volumes between the breastfed and the weaned infants. It is therefore unfortunate that we did not measure creatinine in the urine samples. However, we believe that most of the differences in UIC between the groups can be explained by dietary factors related to breast milk, as there were negligible differences in UIC between the exclusively breastfed and partially breastfed infants. It is reasonable to believe that urine volume is also altered when going from being exclusively breastfed to being partially breastfed. A former publication from the present study confirmed mild to moderate ID and inadequate iodine intake among lactating women [17]. Since infants have limited iodine stores, an adequate BMIC is required to ensure adequate intake of the infant [32]. We also found that the BMIC explained almost half of the variation in UIC of the breastfed infants. The highest median UIC was among the weaned infants. However, this group seemed to have the lowest estimated iodine intake based on 24-h recall, less than half the intake compared to both the partially breastfed and the exclusively breastfed infants. The median UIC of 146 µg/L extrapolates to a median iodine intake of 67 µg/day, assuming the aforementioned conditions of urinary volume and iodine bioavailability. The low calculated iodine intake and the satisfactory UIC suggest that the dietary data did not capture the accurate iodine intake of the included infants. This was supported by the poor correlation between UIC and estimated iodine intake from the 24-h dietary intake.

As mentioned, there are many challenges related to dietary assessment, particularly in infants and young children. Dietary assessment methods comprise both under- and over-reporting [33] and thus introduce substantial errors into the calculation of both energy and specific nutrients such as iodine. The quality of dietary data is highly dependent on the caregiver´s ability to report the type and amount of food the young child has eaten. In this study, the infant food intake was reported by the mothers, although some of the children were with their fathers in the daytime. Obtaining accurate data may be further complicated if persons other than the parents are responsible for feeding. Some of the oldest infants in this study had daytime care and thus knowledge of the foods consumed was limited. Other challenges in dietary assessment in this age group are estimating the proportion of food spillage and wastage, particularly during and after the shift to self-feeding. These are possible explanations for the low estimated iodine intake in this study, particularly in the weaned infants. The estimated median habitual iodine intake in the weaned infants was 34 µg/day. On the other hand, calculating the 24-h iodine intake from breast milk may have led to an overestimation of the iodine intake in partially and exclusively breastfed infants. The reference values of breast milk intake used in this study may deviate from the volume consumed, and using these standards may thus have under- or overreported the iodine intake in the breastfed infants. Since the habitual intake among breastfed infants did not cover the iodine contribution from breast milk, this calculation may be underestimated.

Since only two maternal spot samples of breast milk were collected during the same day, the BMIC data could not be used to estimate the habitual iodine intake in the breastfed infants. Questions covering habitual use of caviar and whey cheese spread in infants were not included in the FFQ. However, the 24-h recall showed a low consumption of these foods. An additional challenge in calculating the iodine intake is the variability in the iodine concentration of many foods, particularly seafood. A study assessing the iodine content of six fish species in Norway found the iodine concentration in cod to range between 22–720 µg [6]. This may have under- or overestimated our iodine intake estimates as food composition tables do not account for natural variations in food.

An important strength of this study is the use of two spot samples of breast milk from the same day to estimate the iodine intake in exclusively breastfed infants. As BMIC vary throughout the day in response to recent iodine intake, two samples per mother provide a more accurate level of the BMIC. In addition to the already mentioned limitations related to dietary assessment, we had a relatively small sample size, particularly in the group of weaned infants. This can be partly explained by the age of our study group (0–12 months) and the recommendation to breastfeed for the entire first year. Another limitation is that the participants are not representative of the Norwegian population as they were recruited from only two public healthcare clinics in the inland area of Norway.

The National Council of Nutrition strongly advice national authorities to introduce mandatory iodization of 20 µg/g household salt and salt used in bread and bakery products [30]. They consider a low risk of excessive iodine intake in children and other groups of the population with the proposed enrichment. That report was not based on a systematic review or meta-analyses such as the risk-benefit report by The Norwegian Scientific Committee for Food and Environment, which considers all the relevant studies on iodine status in the population in Norway [16]. However, this study was a contribution to the knowledge need on iodine status in this population group.

5. Conclusions

The infants in the inland area of Norway had adequate iodine status evident by the median UIC. Weaned infants had higher UIC compared to breastfed infants, suggesting early access and consumption of other sources of iodine in addition to breastmilk. Breastfed infants had lower UIC compared to weaned infants. The results of this study add important information to the sparse literature on UIC and iodine intake in infants in Norway.

Author Contributions: All authors have contributed substantially to the work reported in this paper. Conceptualization, T.A.S. and S.H.; methodology, T.A.S., S.H., E.L.F.G. and K.S.B.; data collection, S.G.-J., B.S.S. and K.S.B.; chemical analysis, E.L.F.G.; statistical analysis, K.S.B., T.E.A. and T.A.S.; writing—original draft preparation, K.S.B. and T.E.A.; writing—review and editing, S.G.-J., B.S.S., S.H., T.A.S., E.L.F.G., T.E.A. and K.S.B.; visualization, T.A.S. and K.S.B.; supervision, T.A.S.; project administration, T.A.S.; funding acquisition, T.A.S., S.H. and K.S.B. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and The Regional Committee for Medical and Health Research Ethics approved the study (2018/1230/REC South East). All women provided written informed consent. All materials were handled de-identified.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. In order to meet ethical requirements for the use of confidential patient data, requests must be approved by the Regional Committee for Medical and Health Research Ethics in Norway.

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Conflicts of Interest: The authors declare no conflict of interest.

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Paper II

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Original Research

Inadequate Iodine Intake in Mothers of Young Children in Innlandet County, Norway

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A B S T R A C T

Background: Iodine has an essential role in child growth and brain development. Thus, sufficient iodine intake is particularly important in women of childbearing age and lactating women.

Objectives: This cross-sectional study aimed to describe iodine intake in a large random sample of mothers of young children (aged ≤2 y) living in Innlandet County, Norway.

Methods: From November 2020 to October 2021, 355 mother–child pairs were recruited from public health care centers. Dietary data were obtained using two 24-h dietary recalls (24-HRs) per woman and an electronic FFQ. The Multiple Source Method was used to estimate the usual iodine intake from the 24-HR assessment.

Results: Based on the 24-HRs, the median (P25, P75) usual iodine intake from food was 117 μg/d (88, 153) in nonlactating women and 129 μg/d (95, 176) in lactating women. The median (P25, P75) total usual iodine intake (from food combined with supplements) was 141 μg/d (97, 185) in nonlactating women and 153 μg/d (107, 227) in lactating women. Based on the 24-HRs, 62% of the women had a total iodine intake below the recommendations (150 μg/d in nonlactating women and 200 μg/d in lactating women), and 23% of them had an iodine intake below the average requirement (100 μg/d). The reported use of iodine-containing supplements was 21.4% in nonlactating women and 28.9% in lactating women. In regular users of iodine-containing supplements ($n = 63$), supplements contributed to an average of 172 μg/d of iodine. Among regular iodine supplement users, 81% reached the recommendations compared with 26% of nonsupplement users ($n = 237$). The iodine intake estimated by FFQ was substantially higher than that estimated by 24-HRs.

Conclusions: Maternal iodine intake in Innlandet County was inadequate. This study confirms the need for action to improve iodine intake in Norway, particularly among women of childbearing age.

Keywords: iodine intake, women of childbearing age, lactating women, 24-h dietary recall, Multiple Source Method

Introduction

In 2020, Norway was considered as one of the 21 countries with deficient iodine intake [1]. Severe iodine deficiency (ID) is no longer prevalent in Norway, but in a few, recent studies, mild-to-moderate ID was reported in specific population groups, such as pregnant and lactating women and women of childbearing age [2–7]. These groups are particularly vulnerable to ID because iodine is essential for proper growth and brain development in the fetus and infant [8].

Iodine is required to produce the thyroid hormones triiodothyronine and thyroxine [9]. Adequate iodine supply is extremely important during the first 1000 d of life [10], which is the time from conception to 2 y of age. The source of iodine for the fetus and the fully breastfed infant is maternal iodine [8,11]. Suboptimal intake of iodine reported in young women is thus of major concern. Severe ID in early life can cause irreversible brain

Abbreviations used: 24-HR, 24-h dietary recall; ID, iodine deficiency; MSM, Multiple Source Method; NNR, Nordic Nutrition Recommendations; UIC, urinary iodine concentration.

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damage, whereas the consequences of mild-to-moderate ID are not fully understood [8]. Observational studies suggest that mild-to-moderate ID during pregnancy is associated with suboptimal neurological development in the offspring [12–14]. Historically, women from inland Norway were more severely affected by ID than those from coastal areas due to the low availability of fish [15]. A study of 130 lactating women in 2018 revealed that mild-to-moderate ID was common in the inland area of Norway [7].

In Norway, dietary iodine intake is highly dependent on the consumption of lean fish and milk because these are the primary iodine sources [16]. However, dietary patterns have changed over the last decades toward lower intake of milk and fish [17]. Changes in food habits and low salt iodization may explain the low iodine intake in groups of the population. Salt iodization has been implemented in most Nordic countries [18] but is neither yet sufficient nor mandatory in Norway, despite recommendations from the WHO [19] and the National Council of Nutrition in Norway [15,20]. Although the WHO recommends fortifying salt with 15–40 μg of iodine per gram of salt, the current Norwegian legislation allows only 5 μg of iodine per gram of table salt (salt for household consumption) [21]. A benefit and risk assessment from the Norwegian Scientific Committee for Food and Environment in 2020 concluded that adding more iodine to salt can compensate for low iodine intake in adolescents and women of childbearing age but could lead to iodine excess in toddlers [22]. In 2021, the National Council of Nutrition in Norway advised that the iodine concentration in table salt and salt used in industry bread and bakery products should be increased from 5 μg/g to 20 μg/g [20].

In the Nordic countries, a daily iodine intake of 150 μg/d is recommended for nonpregnant adults and adolescents. For lactating women, an additional 50 μg/d of iodine is recommended to maintain maternal thyroid gland function and provide sufficient iodine in breastmilk [23]. Practically, the recommendations can be met by consuming one portion of lean fish weekly and 5 dL of milk/yogurt daily (8 dL for lactating women). With little or no lean fish in the diet, a large daily intake of dairy products is required (1–1.4 L of milk/yogurt), and thus, supplements may be needed. The Norwegian Directorate of Health recommends iodine-containing supplements to individuals who do not meet their iodine needs through food sources [24]. Some studies indicate that a sudden increase in iodine intake may lead to a transient "stunning effect" with temporary inhibition of maternal thyroid hormone synthesis, particularly in individuals with poor iodine status [22]. Therefore, iodine nutrition should be optimized before entering pregnancy.

The WHO recommends UIC to assess iodine status in a population [9]. However, because there are few dietary iodine sources in Norway and low iodine concentration in salt, iodine intake can easily be estimated by assessing the diet. In the estimation of the usual or long-term average dietary intake, the use of repeated short-term measures such as 24-h dietary recalls (24-HRs) is the preferred method [25]. Based on the above information, this study aimed to describe iodine intake in a large random sample of mothers of young children in Innlandet County, Norway.

Methods

Study design and study population

In this cross-sectional multicenter study, we aimed to include 500 mother–child pairs, of which 130 were recruited in a pilot phase in 2018 and are not part of this article. Data from the pilot are described elsewhere [7,26]. From November 2020 to October 2021, 355 mother–child pairs (2 y of age or younger at the time of recruitment) were recruited from 29 municipalities in Innlandet County, Norway. First, municipalities were selected at random from a list of all municipalities in the county. In this list, we included each municipality 1–10 times according to the birth rate in 2019, meaning that a municipality with a high birth rate was listed more often than that with a low birth rate. For each time a municipality was listed, we attempted to recruit four mother–child pairs from the corresponding health care center. Second, the participating health care centers were provided with necessary study material (participant consent forms and participant information sheets), and the nurses at the health care centers were instructed on how to approach the mothers for recruitment. Mothers who could read and write in Norwegian and had a healthy child aged ≤2 y at the time of recruitment were invited to participate.

Collection of dietary data and estimation of iodine intake from food and supplements

The main method for the collection of dietary data was two 24-HRs per woman. Dietary data were also obtained using a self-administered electronic FFQ.

The 24-HRs were performed as telephone interviews by three certified dietitians. For each mother–child pair, we aimed for two interviews with varying time intervals (3 d–2 wk) and on various days of the week. The women were reminded a maximum of three times for each of the two 24-HRs. For each unanswered call, a text message was sent with a request to return the call or reply with what time would be best for a conversation. Women who did not respond to our request to participate in the first 24-HR were not contacted later. In short, the 24-HR was conducted as a three-step sequence. First, the participants described as freely as possible what they consumed the day before the call, that is, from the time when they woke up and the following 24 h. Second, the interviewer repeated all items that were reported and asked detailed questions about portion sizes, preparation methods, and ingredients. Finally, the interviewer asked for commonly forgotten items (such as snacks, in-between meals, milk or cream in the coffee/tea, and nighttime snacks) and dietary supplements. Furthermore, the iodine intake (μg/d) was estimated using the Norwegian dietary estimation tool "Kostholdsplanleggeren" [27], which multiplies the consumption amount of each food item with its iodine concentration registered in the Norwegian Food Composition Table [28]. For items not registered in this system, similar items were chosen when appropriate, or nutritional values were obtained from the producers of the food items. The total energy intake was estimated, and women with a mean energy intake based on two 24-HRs outside the range of 500–3500 kcal/d (regarded as implausible intake) were excluded from further analyses.

The electronic FFQ was developed at the University of Oslo [29] and included questions on 279 different foods and beverages. The women were asked to answer the questions based on their food habits over the past 6 mo or after pregnancy if they had given birth <6 mo ago. Frequencies of intake varied with the food item in question and ranged from never, seldom, per week, and per month to several times a day. Portion sizes were estimated from pictures of common food items and/or from general household measures. The food composition database and calculation system "Kostberegningssystem" (KBS, version AE-18) from the University of Oslo was used to calculate energy and nutrient intake. Each participant received a maximum of three written reminders (text messages or emails) to answer the FFQ.

Definitions of iodine intake and supplement use

Iodine intake from food alone and the total iodine intake (from food combined with supplements) were estimated. In this article, adequate iodine intake was defined as an iodine intake of 150 μg/d in nonlactating women and 200 μg/d in lactating women, which is in accordance with the Nordic Nutrition Recommendations (NNR) 2012. Intakes above the upper intake level of 600 μg/d were defined as excessive [23].

Women were classified as regular supplement users if they reported taking iodine-containing supplements in two 24-HRs or reported taking iodine-containing supplements in one 24-HR plus minimum two to three times weekly in the FFQ.

Statistics

Descriptive results are reported as *n* (%) for categorical variables and mean (SD) for continuous variables. Data processing and analysis were performed using STATA/SE 16.1 (StataCorp). Intake distributions from the 24-HRs were estimated using the statistical package in the Multiple Source Program. The Multiple Source Method (MSM) is a statistical method for estimating the usual dietary intake from repeated short-term dietary instruments. FFQ information does not appear to substantially alter estimates of usual intakes from 24-HRs [25], and was not used in the MSM analysis. Estimated iodine intakes were expressed as medians with 25th and 75th percentiles because the distribution of the data was skewed. Spearman correlation coefficients were calculated to compare the estimated iodine intakes from the 24-HRs and the FFQ.

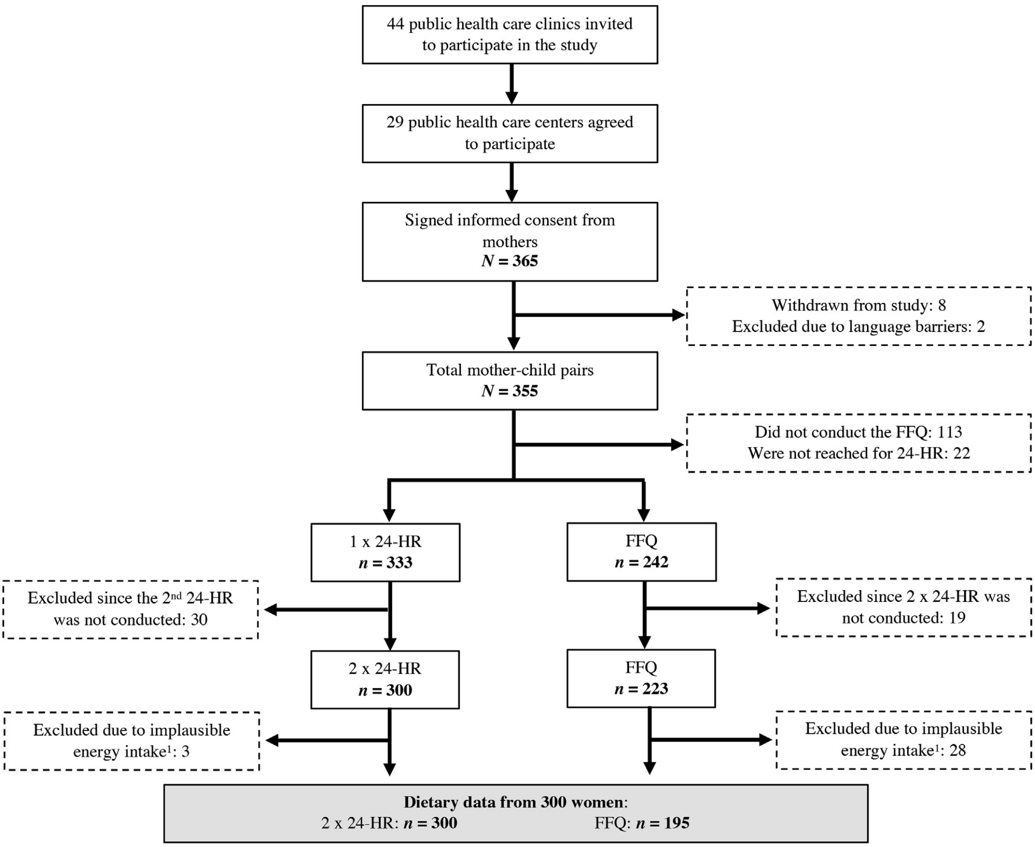

FIGURE 1. Flow chart of the study population and collection of dietary data (24-HRs and FFQ). [1]Estimated energy intake outside the range of 500–3500 kcal/d based on the mean of two 24-HRs. 24-HR, 24-h dietary recall.

Ethics

All women gave written informed consent before participation. The study was approved by the Regional Committee for Medical and Health Research Ethics (2018/1230/REC South East).

Results

Study population

An overview of the study population and the collected dietary data are given in Figure 1. Of the 46 municipalities in the county, 44 were contacted at least once, and 29 accepted the invitation. Written informed consent was given by 365 women, of which 300 provided dietary data and were included in the final estimations of iodine intake. In total, 66% (197/300) of the women were lactating and 34% (103/300) did not lactate/had ceased lactating. Regular use of iodine-containing supplements according to our definition was reported by 21% (63/300) of the women. More characteristics of the study population are given in Table 1.

TABLE 1
Characteristics of mother–child pairs enrolled in the study

Characteristic	*n*	*n* (%) or mean (SD)
Maternal age, mean (SD)	295	31.0 (4.4)
Maternal BMI (kg/m^2), *n* (%)	288	
<18.5 (underweight)		1 (0.3)
18.5–24.9 (normal weight)		151 (52.4)
25–29.9 (overweight)		81 (28.1)
>30 (obese)		55 (19.1)
Prepregnancy BMI (kg/m^2), *n* (%)	290	
<18.5 (underweight)		3 (1.0)
18.5–24.9 (normal weight)		171 (59.0)
25–29.9 (overweight)		74 (25.5)
>30 (obese)		42 (14.5)
Lactation status, *n* (%)	300	
Yes		197 (65.7)
No		103 (34.3)
Marital status, *n* (%)	295	
Single		9 (3.1)
Cohabitant		195 (66.1)
Married		90 (30.5)
Other		1 (0.3)
Maternal education level, *n* (%)	295	
<12 y		3 (1.0)
12 y		71 (24.1)
1–4 y college/university		161 (54.6)
>4 y college/university		60 (20.3)
Country of birth, Norway, *n* (%)	295	261 (88.5)
Smoking status, *n* (%)	295	
Daily		7 (2.4)
No		263 (89.2)
Previous smoker		25 (8.5)
Use of snuff, *n* (%)	295	
Daily		22 (7.5)
Sometimes		4 (1.4)
No		248 (84.1)
Previous		21 (7.1)
Previous or current thyroid disease, *n* (%)	295	15 (4.6)
Hyperthyroidism		6 (2.0)
Hypothyroidism		9 (3.1)
Current use of thyroid medication		8 (2.7)
Child characteristics		
Age (wk), mean (SD)	296	39.8 (27.1)
Sex, boy, *n* (%)	295	142 (48.1)

Iodine intake from food and supplements

Estimated iodine intakes by the 24-HRs and the FFQ, stratified by lactation status, are shown in Tables 2 and 3, respectively. The correlation between the usual iodine intakes estimated by the two methods was moderate (Spearman rank correlation coefficient $r = 0.49$, $P < 0.001$, $n = 195$).

The iodine contribution from different food groups was calculated based on the 24-HRs because these generated more detailed data on specific food items than the FFQ. The main sources of iodine in this population were dairy products, iodine-containing supplements, and fish, contributing ~70% to the total iodine intake. The iodine content of the supplements was 75–225 μg. The mean daily intake of different food groups and their contribution to the iodine intake from food are given in Table 4. Supplemental Table 1shows the iodine contribution from different food groups when iodine intakes from supplements were also included.

Estimated intake based on 24-HRs using the MSM

The median usual iodine intake based on the 24-HRs was below the NNR in both lactating and nonlactating women, with and without the inclusion of iodine-containing supplements (Table 2). The median (P25, P75) usual iodine intake from food was 117 μg/d (88, 153) in nonlactating women and 129 μg/d (95, 176) in lactating women. The median (P25, P75) usual total iodine intake (from food combined with supplements) was 141 μg/d (97, 185) in nonlactating women and 153 μg/d (107, 227) in lactating women. Among women who reported regular use of iodine-containing supplements ($n = 63$), 81% reached their daily iodine recommendations compared with 26% of nonsupplement users ($n = 237$, Supplemental Table 2). None of the women had a usual total iodine intake above the safe upper level of 600 ug/d (excessive intake).

Estimated intake based on FFQ

The total iodine intake estimated by FFQ was substantially higher than that estimated by 24-HRs, with a mean absolute difference of 53 μg/d (data not shown). The median iodine intake estimated by FFQ was within the adequate range when iodine from supplements was included, but not from food alone. The median (P25, P75) iodine intake from food was 133 μg/d (106, 210) in nonlactating women and 188 μg/d (122, 247) in lactating women. The median (P25, P75) total iodine intake was 193 μg/d (114, 272) in nonlactating women and 227 μg/d (161, 326) in lactating women. Four percent of the women had excessive total iodine intake.

Discussion

The present study assessed maternal iodine intake in a large random sample of mothers of young children in Innlandet County. Our results suggest that inadequate iodine intake was prevalent among the women. Based on the repeated 24-HRs, which was the main dietary assessment method chosen for this study, the majority (62%) of the women had a usual total iodine intake below the NNR and 23% had an iodine intake of below the average requirement of 100 μg/d. The proportion of women with inadequate iodine intake was particularly high among women who did not report regular use of iodine-containing supplements (Supplemental Table 2**)**. The iodine intake estimated by FFQ

TABLE 2

Maternal intakes of iodine (µg/d) estimated using two 24-HRs per woman ($N = 300$). Presented for all women and for two categories of lactation

Study population	n	P50[1]	P25, P75[1]	% below NNR[2] (95% CI)	% below AR[3] (95% CI)	% above UL[4] (95% CI)
All women, food only	300	124	93, 167	82 (77–86)	33 (27–38)	0 (0–1)
All women, total intake	300	151	103, 216	62 (57–68)	23 (18–28)	0 (0–1)
Lactating, food only	197	129	95, 176	86 (81–91)	29 (23–36)	0 (0–2)
Lactating, total intake	197	153	107, 227	67 (60–74)	20 (15–26)	0 (0–2)
Nonlactating, food only	103	117	88, 153	73 (63–81)	40 (30–50)	0 (0–4)
Nonlactating and total intake	103	141	97, 185	53 (43–63)	29 (21–39)	0 (0–4)

24-HR, 24-h dietary recall; AR, average requirement; NNR, Nordic Nutrition Recommendations; UL, upper intake level.

[1] Estimated usual intakes were calculated using the Multiple Source Method [25].

[2] Recommended intakes from the NNR from 2012 (200 µg/d in lactating women and 150 µg/d in nonlactating women).

[3] Average requirement from the Nordic Nutrition Recommendations from 2012 (100 µg/d).

[4] Upper intake level from the Nordic Nutrition Recommendations from 2012 (600 µg/d).

TABLE 3

Maternal intakes of iodine (µg/d) estimated using FFQ ($N = 300$). Presented for all women and for two categories of lactation

Study population	n	P50[1]	P25, P75[1]	% below NNR[2] (95% CI)	% below AR[3] (95% CI)	% above UL[4] (95% CI)
All women, food only	195	174	115, 244	57 (50–64)	16 (11–22)	0 (0–2)
All women, total intake	195	211	131, 314	42 (34–49)	12 (1–18)	4 (2–8)
Lactating, food only	129	188	122, 247	56 (47–65)	13 (1–20)	0 (0–3)
Lactating, total intake	129	227	161, 326	42 (33–51)	11 (1–17)	5 (2–11)
Nonlactating, food only	66	133	106, 210	59 (46–71)	21 (12–33)	0 (0–5)
Nonlactating and total intake	66	193	114, 272	41 (29–54)	15 (1–26)	2 (0–8)

AR, average requirement; NNR, Nordic Nutrition Recommendations; UL, upper intake level.

[1] Estimated using the food composition database and calculation system "Kostberegningssystem" (KBS, version Ae-18) from the University of Oslo.

[2] Recommended intakes from the NNR from 2012 (200 µg/d in lactating women and 150 µg/d in nonlactating women).

[3] Average requirement from the Nordic Nutrition Recommendations from 2012 (100 µg/d).

[4] Upper intake level from the Nordic Nutrition Recommendations from 2012 (600 µg/d).

showed inadequate iodine intake from food alone, but not from food combined with supplements. Excessive iodine intake was indicated only by the FFQ.

The total iodine intake estimated by FFQ was much higher than that estimated by 24HRs. Although FFQ is a feasible method for assessing dietary intake in large groups, it often tends to overestimate food and nutrient intakes compared to 24-HR [30–32]. To account for this, FFQ answers from 28 women were excluded due to energy intakes of >3500 kcal/d. These women had a median 24-h energy intake of 3958 kcal/d (range: 3515–6856) and a median total 24-h iodine intake of 405 µg/d (range: 191–992). Certain foods may contribute to excessive amounts of iodine, such as seaweed or seaweed products, but none of the women in this study reported the use of such products. Both the FFQ and the 24-HR method pose challenges related to the estimation of portion sizes, misreporting of food intake, and the bias caused by poor memory and social desirability [32]. However, repeated short-term instruments, such as 24-HR, tend to provide more accurate estimates of dietary intake than tools that examine usual intake directly, such as FFQs [25].

Our findings support previous findings of low iodine intake in women of childbearing age and lactating women in Norway [2, 4–7]. Poor iodine nutrition in these groups, as well as in pregnant women, has also been documented in other countries where dairy products and fish are the main dietary sources of iodine, such as Finland [33], Iceland [34], UK [35–37], USA [38], and New Zealand [39]. Although fish is a rich source of iodine, our results indicate, with support from national consumption data [16,40], that fish intake among young women is low. Furthermore, in recent years, there has been a growing interest in plant-based alternatives to animal products, such as cow milk and yogurt. These are, in general, poor sources of iodine, and few are fortified with iodine on the Norwegian marked [41]. Data on the actual consumption of plant-based dairy alternatives in Norway is lacking, but in the UK, it has been suggested that young women are driving this trend and that one-third of 16–34-y olds prefer such alternatives to cow milk [42]. In a survey among adults in Norway in 2019, 40% of young women reported to never or rarely drink cow milk [43]. In the current study, 57% of the women had an estimated cow milk intake of below one glass (200 mL) daily, based on the mean value of two 24-HRs (all types of liquid cow milk, as drink or in mixed dishes, excluding yogurt). Of them, 28% did not report any intake of cow milk at all. With a few good sources of iodine in the diet, young women are poorly equipped to meet the increased demands of iodine as they enter pregnancy and lactation.

The estimated iodine intake in the current study was substantially higher than that in our pilot among lactating women from 2018 ($N = 133$, median total intake of 32 µg/d estimated by 24-HR and 42 µg/d estimated by FFQ) [7]. In the pilot study, we only had 1 d of 24-HR data per woman, which does not take into account the variability in intake from day to day for a single individual (within-subject variability). In the current study, we applied a second day of 24-HR per woman to provide an estimate of usual iodine intake. Hence, the estimated iodine intakes by 24-HR in the two studies are not fully comparable. However, we suppose that the discrepancy in iodine intake in the two studies is mainly explained by different approaches in dietary

TABLE 4
Mean intake (g/d, SD) and contribution (%) from different food groups to the iodine intake (food only) based on data from two 24-HRs per woman ($N = 300$)

Food group	Mean intake (g/d, SD), all women	Contribution of food group to the iodine intake (%)		
		All women ($n = 300$)	Nonregular supplement users[1] ($n = 63$)	Regular supplement users[2] ($n = 237$)
Dairy products	263.9 (196.3)	39.1	40.6	33.9
Milk	174.8 (179.1)	19.9	20.7	17.3
Yogurt, cottage cheese, and quark	29.4 (53.8)	2.9	3.1	2.4
White-colored cheese[3]	38.9 (45.3)	7.6	8.1	6.0
Whey cheese	6.3 (10.4)	7.6	7.6	7.4
Other dairy products[4]	14.5 (23.9)	1.0	1.0	0.9
Fish and seafood	44.4 (65.8)	20.7	19.7	24.0
Lean/semifat fish and related products	7.8 (32.5)	9.6	9.1	11.3
Fatty fish	13.3 (42.3)	0.5	0.5	0.5
Other fish products	23.2 (308.7)	10.6	10.1	12.2
Nondairy beverages	531.9 (30)	14.4	13.8	16.3
Coffee and coffee products	186.0 (75.0)	5.5	5.7	4.7
Carbonated mineral water	22.7 (75.0)	6.7	5.5	10.7
Milk alternative drinks	12.8 (48.4)	0.1	0.1	0.1
Other beverages[5]	310.4 (250.1)	2.1	2.5	0.8
Eggs	22.7 (32.7)	6.0	5.5	7.7
Bread, cereals, seeds, and nuts	233.9 (104.0)	4.0	3.9	4.2
Vegetables, fruits, and berries	221.8 (143.4)	2.7	2.7	2.9
Poultry, meat, and meat products	94.7 (75.4)	1.4	1.4	1.3
Butter, margarine, and oils	16.1 (13.5)	1.3	1.3	1.2
Mixed dishes and other products	232.6 (157.5)	10.4	11.0	8.6

24-HR, 24-h dietary recall.
[1] No reported use of iodine-containing supplements or use in one 24-HR only.
[2] Reported taking iodine-containing supplements in both 24-HRs or in one recall plus minimum two to three times weekly in the FFQ.
[3] Solid and cream cheese.
[4] Cream milk, crème fraiche, sour cream, and ice cream.
[5] Juice, soda, tea, energy drink, and alcoholic beverages.

assessment. In the pilot, the 24-HR was structured around typically iodine-rich foods (iodine-specific 24-HR), and a fixed amount of iodine (15 μg) was added to each recall to account for iodine in other foods. In the current study, the 24-HR had equal focus on all nutrients and intended to capture information on all foods and beverages consumed the previous day. Thus, in the current study, we captured a wider range of foods contributing to the iodine intake compared to the pilot study. Regarding the iodine intakes estimated by FFQ, we used different FFQs in the pilot and current study. The FFQ in the pilot was relatively short (addressing 32 foods and beverages), nonquantitative, and iodine-specific, whereas the FFQ in the current study was semi-quantitative and more comprehensive (addressing 279 foods and beverages). The FFQ used in the pilot had not been validated to estimate the iodine intake. It should also be noted that in the pilot study, we used convenience sampling and the participants were accordingly not a random selection of the population.

One might also speculate that the higher iodine intake estimated in the current study may in part be related to the increased awareness about iodine in recent years among health professionals and the general public. For instance, in 2018, the Directorate of Health specifically recommended iodine supplementation to women of childbearing age and pregnant and lactating women with low intake of milk and/or lean fish [24]. In the current study, 21% of the women regularly used iodine-containing supplements according to the definition we made (use in two 24-HRs or in one recall plus minimum two to three times weekly in the FFQ). It is not clear how many of the women used iodine-containing supplements regularly in the pilot study, although 23% reported use in the past 24 h. In 2018, iodine was also implemented in antenatal care as a nutrient that should be paid special attention to, similar to nutrients such as folic acid, vitamin D, and iron [44]. Since then, health professionals providing antenatal care have been encouraged to provide women with basic information on iodine at the first consultation during pregnancy. Based on this, it is reasonable to believe that more women are aware of their iodine intake today than in 2018 when we conducted the pilot study.

Strengths and limitations

A major strength of this study was the large sample based on the random selection of health care centers in the county. Another strength was that we used the MSM to adjust for within-subject variability and provide estimates of usual iodine intake. Furthermore, it was a strength that we used a comprehensive FFQ in addition to the 24-HRs, although the correlation with estimates by 24-HRs was moderate. The discrepancy in iodine intake between the two methods underline the importance of carefully choosing the method of dietary assessment.

A limitation of this study is that we did not include any biomarkers of iodine status or thyroid function. Future studies should aim to include both dietary and biochemical data to give a more complete picture of iodine nutrition in this population group. Another limitation is that we did not calculate the participation rate due to the large number of healthcare workers involved in recruitment. Furthermore, we did not obtain detailed data on the types and producers of plant-based dairy alternatives consumed by the women, so the iodine contribution from these might be underestimated. However, most of these contain negligible amount of iodine.

In conclusion, the present study adds to the growing evidence of a low iodine intake in women of childbearing age and lactating women in Norway. The potential consequences of these findings need to be further studied. Our results highlight the need to monitor and improve iodine intake among young women, so that they are equipped to provide sufficient iodine to support child growth and neurodevelopment. Such improvement should commence before conception due to the importance of thyroid hormones in early pregnancy.

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Data Availability

Requests for data can be made to the corresponding author. To meet the ethical requirements for the use of confidential patient data, sharing of data must be approved by the Regional Committee for Medical and Health Research Ethics in Norway.

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Author disclosures

The authors report no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cdnut.2023.100047.

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Supplementary Table 1 Contribution (%) from different food groups and supplements to the total iodine intake, based on data from two 24-HRs per woman (N = 300). Presented for all women and for regular and non-regular users of iodine-containing supplements.

Food group	**Contribution of food group to the total iodine intake (%)**		
	All women (n = 300)	Non-regular supplement users[1] (n = 63)	Regular supplement-users[2] (n = 237)
Dairy products	30.2	38.9	16.1
Milk	15.4	19.8	8.3
Yoghurt, cottage cheese and quark	2.3	3.0	1.1
White-colored cheese[3]	5.9	7.8	2.8
Whey cheese	5.8	7.3	3.5
Other dairy products[4]	0.8	1.0	0.4
Fish and seafood	16.0	18.8	11.4
Lean/semi-fat fish and related products	7.4	8.7	5.4
Fatty fish	0.4	0.5	0.2
Other fish products	8.2	9.6	5.8
Non-dairy beverages	11.1	13.2	7.8
Coffee and coffee products	4.2	5.4	2.3
Carbonated mineral water	5.2	5.3	5.1
Milk alternative drinks	0.1	0.1	<1
Other beverages[5]	1.6	2.4	0.4
Eggs	4.6	5.3	3.6
Bread, cereals, seeds and nuts	3.1	3.8	2.0
Vegetables, fruits and berries	2.1	2.6	1.4
Poultry, meat and meat products	1.1	1.3	0.6
Butter, margarine and oils	1.0	1.2	0.6
Mixed dishes and other products	8.1	10.5	4.1
Supplements	22.7	4.6	52.4

[1] No reported use of iodine-containing supplements or use in one 24-HR only.
[2] Reported taking iodine-containing supplements in both 24-HRs, or in one recall plus minimum 2–3 times weekly in the FFQ.
[3] Solid and cream cheese.
[4] Cream milk, crème fraiche, sour cream and ice cream.
[5] Juice, soda, tea, energy drink and alcoholic beverages.
24-HR, 24-hour dietary recall.

Supplementary Table 2 Maternal intakes of iodine (µg/day) estimated using two 24-HRs per woman (*N* = 300). Presented for regular and non-regular users of iodine-containing supplements, and for two levels of cow´s milk consumption.

Study population	*n*	P50[1]	P25, P75[1]	% below NNR[2] (95 % CI)	% below AR[3] (95 % CI)	% above UL[4] (95 % CI)
All women, regular supplement-users[5], total intake	63	274	220, 328	19 (10–31)	0 (0–6)	0 (0–6)
All women, non-regular supplement users[6], total intake	237	135	94, 179	74 (68–79)	29 (23–35)	0 (0–2)
Women with a daily intake of cow´s milk[7] < 200 mL, food only	170	101	80, 139	88 (82–93)	49 (42–57)	0 (0–0)
Women with a daily intake of cow´s milk[7] ≥ 200 mL, food only	130	151	121, 190	73 (65–80)	11 (1–17)	0 (0–0)

[1]Estimated usual intakes calculated using the Multiple Source Method (MSM) [25].
[2] Recommended intakes from the Nordic Nutrition Recommendations (NNR) from 2012 (200 µg/day in lactating women and 150 µg/day in non-lactating women).
[3] Average requirement from the Nordic Nutrition Recommendations from 2012 (100 µg/day).
[4] Upper intake level from the Nordic Nutrition Recommendations from 2012 (600 µg/day).
[5] Reported taking iodine-containing supplements in both 24-HRs, or in one recall plus minimum 2–3 times weekly in the FFQ.
[6] No reported use of iodine-containing supplements or use in one 24-HR only.
[7]All types of liquid cow´s milk, as drink or in mixed dishes, not including yoghurt.
24-HR, 24-hour dietary recall.

Paper III

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Nutrient Requirements and Optimal Nutrition

Iodine Nutrition in Children ≤2 years of Age in Norway

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A B S T R A C T

Background: As a component of the thyroid hormones (THs), iodine is vital for normal neurodevelopment during early life. However, both deficient and excess iodine may affect TH production, and data on iodine status in young children are scarce.
Objectives: To describe iodine nutrition (iodine status and intake) in children ≤2 y of age in Innlandet County (Norway) and to describe the associations with maternal iodine nutrition.
Methods: A cross-sectional study was performed in a representative sample of mother–child pairs selected from 30 municipalities from November 2020 until October 2021. Iodine status [child urinary iodine concentration (UIC), maternal UIC, and breast milk iodine concentration (BMIC)] was measured. Child's iodine intake was estimated using 2 24-h dietary recalls (24-HR) and a food frequency questionnaire. The Multiple Source Method was used to estimate the usual iodine intake distributions from the 24-HR assessments.
Results: The median UIC in 333 children was 145 μg/L, indicating adequate iodine status according to the WHO cutoff (100 μg/L). The median usual iodine intake was 83 μg/d. Furthermore, 35% had suboptimal usual iodine intakes [below the proposed Estimated average requirement (72 μg/d)], whereas <1% had excessive usual iodine intakes [above the Upper intake level (200 μg/d)]. There was a positive correlation between children's iodine intake and BMIC (Spearman rank correlation coefficient $r = 0.67$, $P < 0.001$), and between children's UIC and BMIC ($r = 0.43$, $P < 0.001$), maternal UIC ($r = 0.23$, $P = 0.001$), and maternal iodine intake ($r = 0.20$, $P = 0.004$).
Conclusion: Despite a median UIC above the cutoff for iodine sufficiency, more than a third of the children had suboptimal usual iodine intakes. Our findings suggest that many children will benefit from iodine fortification and that risk of iodine excess in this age group is low.

Keywords: urinary iodine concentration, breast milk iodine concentration, iodine status, iodine intake, 24-h dietary recall, Multiple Source Method, females of childbearing age, lactating females, infants, toddlers

Introduction

Several recent studies in Norway and elsewhere have documented poor iodine intake and iodine deficiency (ID) in females of childbearing age, including pregnant and lactating females [1–9]. In addition, estimates have proposed that ≤50% of newborns in Europe are exposed to ID [10]. These findings have raised concerns regarding the iodine status of infants and young children, given the importance of thyroid hormones (THs) in the development of the central nervous system [11].

Iodine is an essential micronutrient required in the production of the THs, triiodothyronine and thyroxine [12]. From the fetal stage into postnatal life, THs are crucial for neural and cognitive development and regulate many vital processes in the

Abbreviations: 24-HR, 24-h dietary recall; AI, adequate intake; AR, Average requirement; BMIC, breast milk iodine concentration; EAR, Estimated average requirement; FFQ, food frequency questionnaire; ID, iodine deficiency; LOD, limits of detection; LOQ, limits of quantification; MSM, Multiple Source Method; NNR, Nordic Nutrition Recommendations; SRM, standard reference material; TH, thyroid hormones; UIC, urinary iodine concentration; UL, Upper intake level; V, volume; w, weight.

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body [13]. In early life, the production rate of THs per kg bodyweight is particularly high as the body undergoes rapid growth, leading to an increased turnover of intrathyroidal iodine stores [14]. Hence, infancy and early childhood are particularly critical periods for ID. Suboptimal iodine intakes in this period may lead to iodine depletion, diminish TH synthesis, and thereby affect physical, neurological, and cognitive development [15]. During the first 4–6 mo of life, adequate iodine intake for TH production must be provided through human breast milk and/or formula. The iodine concentration in breast milk reflects maternal iodine intake in the past hours before breastfeeding, and thus, the iodine intake of exclusively breastfed infants relies entirely on maternal iodine status and intake [16]. Furthermore, with the introduction of complementary foods, iodine is also obtained from iodine-rich food sources, such as enriched infant porridge, lean fish, eggs, and cow's milk [17,18].

Globally, there has been a remarkable improvement of iodine intake over the past decades, mainly because of salt iodization programs. Yet, ID remains a threat in countries where efficient salt iodization programs are not established, such as Norway [19]. As part of a strategy to improve iodine intake in Norway, the government decided in 2023 to increase the permitted level of iodine in table salt and salt used in industry bread and bakery products from 5 μg/g to 20 μg/g [20]. However, the food industry has not yet implemented the increase in their production, and so far, they have not received any explicit encouragement from the health authorities to do so. Because both ID and iodine excess may impair TH synthesis [21], it is important to monitor the population's iodine status, particularly vulnerable population groups such as young children and lactating females. Several studies have documented ID among lactating females in Norway [3–5,22]; however, studies reporting on iodine nutrition in early childhood are rather scarce. In most previous studies, iodine intake has been estimated in older children or breastfed children have been excluded from estimates of iodine intake because of limited knowledge of consumption volumes.

On the basis of the above, the aim of this study was to examine iodine nutrition (iodine status and intake) in a representative sample of children $\leq$2 y of age in Innlandet County (Norway). Furthermore, we aimed to assess the associations between the iodine nutrition of children and their mothers, and to describe the main dietary sources of iodine in young children.

Methods

Study design and study population

In this cross-sectional study, mother–child pairs from public health care centers were recruited from 30 randomly selected municipalities in Innlandet County in Norway from November 2020 until October 2021. During consultations at the health care centers, nurses approached and recruited females who could communicate in Norwegian and had a child between 0 and 2 y of age with no known ongoing, congenital, or chronical illness. The selection and recruitment process has been described in more detail previously [23].

Collection of urine samples and human breast milk

As recommended by the WHO/UNICEF/ICCIDD, iodine status was measured by urinary iodine concentration (UIC) in spot urine samples of children and their mothers [12]. Iodine status in lactating mothers was also measured by breast milk iodine concentration (BMIC). Females who agreed to participate were instructed to collect a urine sample from herself and her child, and a breast milk sample (if applicable). Oral and written instructions and a bag of equipment were provided by trained nurses at the health care centers.

A spot urine sample from the child (1–5 mL) was collected using a urine collection pad placed in the diaper (Sterisets Urine collection packs, Sterisets International BV), checking the diaper every 10 min to retrieve the urine before possible feces contamination. If the pad was soiled, then a second attempt was made using a clean pad. Once the pad was wet with urine, it was placed with the wet side up and the urine was transferred into a sterile urine specimen container using a syringe. In case of difficulty extracting the urine using the syringe, an alternative method was to open the pad and squeeze the urine from the wet cotton directly into the container. A reliability study showed that compared with standard methods of collecting urine for measuring UIC, the diaper-pad collection method did not substantially affect the reliability of the measurements [24].

A spot urine sample from the mother was collected using a 100 mL Vacuette® urine beaker (Greiner Bio-one) and a 9.5 mL Vacuette® Urine tube (Greiner Bio-One). Lactating mothers also provided a spot breast milk sample (20 mL, or any volume below she was able to provide) by manual or mechanic expression into a 50 mL polypropylene centrifuge tube (Sarstedt). For compliance and convenience, the mothers could sample the urine and breast milk at any given time point during the day. The samples were collected at home, marked with unique ID numbers, kept in the fridge, and delivered to the health care center within 1 wk after sampling. All samples were kept in the fridge (4°C) until picked up by the study team.

The samples were aliquoted into vials (5 and 10 mL for breast milk and 2 or 5 mL for urine) before long-time storage at −80°C. All samples were thawed at 4°C overnight or at room temperature the same day. To homogenize the samples, they were incubated at 38°C for 1 min in an ultrasonic bath. Eppendorf Xplorer® 0.2–5 mL (VWR 613-1408) was used to transfer 1 mL sample to 10 mL falcon tubes (SARSTEDT 62.554.502) using Eppedorf epT.I.P.S.® (VWR 613-6934). The falcon tubes were measured (Sartorius MSE125P-100-DU) before and after sampling for optimal weight measurement. Samples were frozen at −80°C until they were transported to the laboratory (Faculty of Environmental Sciences and Natural Resource Management at the Norwegian University of Life Sciences, Norway) for analyses.

Determination of iodine in urine and human breast milk

The 1.00-mL aliquot of breast milk was diluted to 10.0 mL with an alkaline solution (BENT), containing 4% [weight (*w*)/volume (*V*)] 1-**b**utanol, 0.1% (*w/V*) H_4**E**DTA, 5% (*w/V*) **N**H_4OH, and 0.1% (*w/V*) **T**riton™ X-100. Method blank samples and samples of standard reference material (SRM) were prepared following the same procedures. The samples were analyzed for iodine by means of an Agilent 8800 ICP-QQQ (Triple Quadruple Inductively Coupled Plasma Mass Spectrometer, Agilent Technologies) using oxygen as a reaction gas. Iodine was determined at mass 127. ^{129}I was used as an internal standard for ^{127}I. The quantification of iodine in spot urine followed the same procedure, except that the urine was thawed, but not heated before the alkaline dilution, and the concentration of NH_4OH in BENT was decreased to 2% to limit precipitation of struvite ($MgNH_4PO_4 \cdot 6H_2O$) in urine. Reagents of analytical grade or better and deionized water (>18 MΩ) were used throughout.

The limits of detection (LOD) and limits of quantification (LOQ) were calculated by multiplying the standard deviation of the method blank samples ($n = 18$) by 3 and 10, respectively. The obtained LOD and LOQ for iodine were 0.20 and 0.79 μg/L, respectively. To ensure methodological traceability and to check for accuracy, SRM were analyzed concurrently with the sample matrices. Accuracy in the determination of iodine in breast milk was checked by analysis of the European Reference Material ERM®-BD150 Skimmed milk powders. Considering urine, Seronorm™ Trace Elements Urine L-1 and Seronorm™ Trace Elements Urine L-2 (Sero AS) were analyzed; each with value assignment established in accordance with International Organization for Standardization 17511. Allowing for experimental error, that is, a coverage factor $k = 2$, corresponding to a level of confidence ~95%, our results were within the recommended values issued. Intermediate precision (within-laboratory reproducibility) in the analysis of urine for iodine was 3.9% ($n = 11$).

Collection of dietary data and estimation of iodine intake

To estimate usual iodine intake, short-term measurements such as 24-h dietary recalls (24-HRs) are the preferred method [25]. Thus, the main method for the collection of dietary data in this study was 2 24-HRs per child. The children's mothers reported the dietary data by phone to 1 of the 3 certified dietitians in the study team. To capture iodine-rich food sources that are irregularly consumed, dietary data were also obtained using an electronic food frequency questionnaire (FFQ) [17,18].

We aimed to conduct 2 24-HRs for each child, with different time intervals (3 d–3 wk) and on different days of the week. Nonresponding females were contacted and reminded a maximum of 3 times. The structure of the interview varied with the complexity of the child's diet; however, all interviews were initiated with questions about the intake of breast milk and/or formula. If formula was consumed, then the type of formula and the total volume ingested were reported. Iodine intake from the formula was calculated by multiplying the iodine concentration of the given formula (retrieved from the product declaration) with the reported consumption volume. The volume of ingested breast milk was only reported if the milk was bottle-fed. For breastfed children, the volume consumed was derived from recently published global age-specific breast milk intake estimates by Rios-Leyvras et al. [26]. Furthermore, to calculate the iodine contribution from breast milk, the consumption volume was multiplied by the BMIC of the corresponding mother, if measured. If the BMIC was not measured, then the iodine concentration from the Norwegian Food Composition Table of 70 μg/L was used [27]. If intake of other kinds of milk in addition to breast milk was reported (formula, cow's milk, or plant-based milk replacements), then the volume of consumed breast milk was reduced by the corresponding volume for these. For instance, the mean daily intake of breast milk for an 8-mo-old infant is 694 mL/d [26]. If an infant of this age received 200 mL of formula in addition to breast milk, 200 mL was subtracted from 694 mL. If the volume of other kinds of milk than breast milk exceeded the age-specific estimate, then

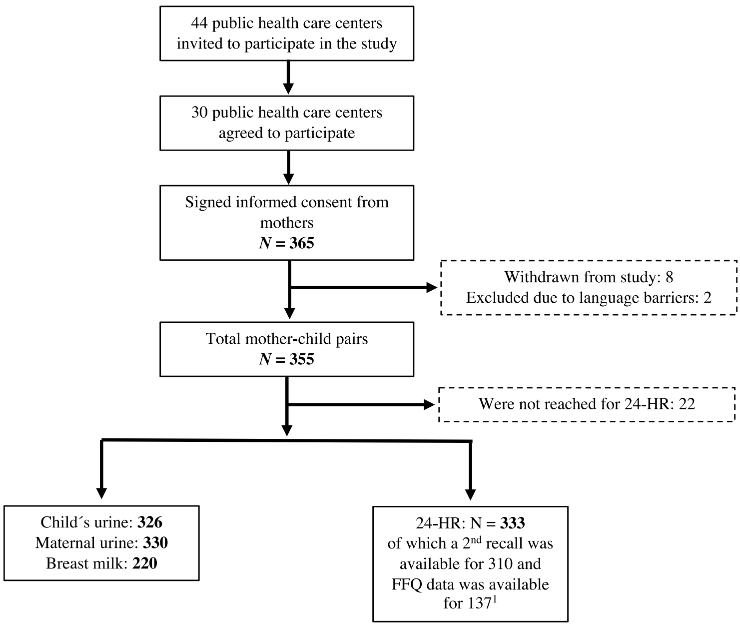

FIGURE 1. Flowchart of the study population and the collection of urine, breast milk, and dietary data (24-HRs and FFQ). 24-HR, 24-h dietary recall; FFQ, food frequency questionnaire. [1]FFQ data were available for 251 children, but calculations of energy and iodine intakes were only computed for children ≥6 mo of age.

the volume of breast milk consumption was set to 0 (unless the breast milk was bottle-fed). For children who were weaned or received complementary foods, the mother was further asked to describe as freely as possible what her child consumed the day before the call, from when the child woke up and the following 24 h. Next, the mother was asked to provide details on portion sizes, ingredients, and preparation methods of home-cooked meals. Finally, the interviewer ensured that nothing was missed using a list of easily forgotten foods (for example, butter/oil in cooking, snacks between meals, dietary supplements, and foods eaten while outside the home). The Norwegian dietary estimation tool "Kostholdsplanleggeren" [28] was used to compute total daily intakes of iodine and energy. This tool multiplies the consumption amount of each food item with the concentration of the corresponding nutrient registered in the Norwegian Food Composition Table [27]. For items not found within this system, we chose similar items when appropriate, or obtained nutritional values from the producers of the food items.

Two different semi-quantitative FFQs were applied, one for children <6 mo of age and the other for older children. Depending on the child's age, one of these was answered online by either of the child's parents. The FFQs were originally developed for the third national dietary survey among infants in Norway conducted in 2018 and 2019 among 6- and 12-mo-old infants, respectively ("Spedkost 3") [17,18]. Respondents were asked to report the child's habitual diet with the last 2 wk in mind. Both FFQs included questions about breastfeeding, formula, and dietary supplements. For some foods, picture series were included to help aid in estimating portion sizes. Frequencies of intake varied with the food item in question and ranged from never/seldom to ≥5 times per wk or per mo. The food composition database and calculation system "Kostberegningssystem" (KBS, version AE-18) from the University of Oslo was used to calculate energy and nutrient intake. Non-responders were sent a maximum of 3 reminders (by text message) to answer.

Maternal iodine intake was also assessed using 2 24-HRs. These data have been described earlier [23] and are not further discussed in this paper, apart from its correlation with children's iodine nutrition.

Definitions of iodine status, iodine intake, and feeding practice

In children, we used the cutoff of a median UIC >100 μg/L for iodine sufficiency, which is the proposed cutoff from WHO for children <2 y of age [29]. The same UIC cutoff was applied for maternal iodine sufficiency [29]. Furthermore, for assessment of dietary iodine intake, an adequate intake was defined as an intake above or equal to the Adequate intake (AI) from the Nordic Nutrition Recommendations (NNR) 2023 of 90 μg/d for infants <12 mo of age and 100 μg/d for children ≥ 12 mo of age [30]. The NNR has not defined an Upper intake level (UL) or Average requirement (AR) of iodine for young children. Thus, we used the UL from the European Food Safety Authority of 200 μg/d for children 1–3 y of age to define excessive iodine intake [31]. Furthermore, we used the proposed Estimated average requirement (EAR) of 72 μg/d from a Swiss dose-response crossover balance study [32] to define suboptimal iodine intake.

The children were divided into the following 4 groups of feeding practice: breastfed (exclusively, or in combination with complementary foods, no use of formula); formula-fed (exclusively, or in combination with complementary foods, no breast milk); mixed milk-fed (breast milk and formula, with or without complementary foods); and weaned (only solid foods, no breast milk or formula). The current paper focuses on iodine nutrition in 3 age subgroups: <6, 6–11.9, and ≥12 mo.

Statistics

The estimated sample size was based on the absolute precision of the estimated proportion with low iodine intake or deficiency. The calculated sample size for the project ensured a margin of error of 4% and a 95% confidence interval.

The proportion of children with usual iodine intakes below the AI, below the EAR (suboptimal intake), and above the UL (excessive intake) were estimated for all children and for the 3 age groups separately. Data processing and analyses was performed using STATA/SE 16.1 (StataCorp). To estimate the intake distributions from the 24-HR assessments, the Multiple Source Method (MSM) was used through the online interface accessible at https://msm.dife.de. The MSM is a statistical method that

TABLE 1
Characteristics of mother–child pairs enrolled in the study

Characteristic	*n*	*n* (%) or mean (SD)
Child		
Age, in mo	333	
All children		8 (6.0)
<6		132 (39.7)
6–11.9		117 (35.1)
≥12		84 (25.2)
Sex, boy	328	58 (48.2)
Feeding practice	333	
Breastfed		196 (58.9)
Formula-fed		65 (19.5)
Mixed milk-fed		30 (9.0)
Weaned		42 (12.6)
Mother		
Maternal age, (y)	295	31.0 (4.4)
Maternal BMI (kg/m^2)	288	
<18.5 (underweight)		1 (0.3)
18.5–24.9 (normal weight)		151 (52.4)
25–29.9 (overweight)		81 (28.1)
>30 (obese)		55 (19.1)
Marital status	295	
Single/other		10 (3.4)
Cohabitant		195 (66.1)
Married		90 (30.5)
Maternal education level	295	
<12 y		3 (1.0)
12 y		71 (24.1)
1–4 y college/university		161 (54.6)
>4 y college/university		60 (20.3)
Maternal country of birth, Norway	295	261 (88.5)
Maternal smoking status	295	
Daily		7 (2.4)
Previous smoker		25 (8.5)
No		263 (89.2)
Use of snuff	295	
Daily		22 (7.5)
Sometimes		4 (1.4)
Previous		21 (7.1)
No		248 (84.1)
Previous or current thyroid disease	295	15 (4.6)
Hyperthyroidism		6 (2.0)
Hypothyroidism		9 (3.1)
Current use of thyroid medication		8 (2.7)

enables the estimation of usual dietary intake from repeated short-term measurements. The FFQ data were not used in the MSM analyses because the inclusion of such data is found to have minimal impact on the estimates of usual intakes from 24-HRs [25]. The results were calculated as μg/L iodine (UIC and BMIC), and μg/d (iodine intake), and were expressed as median (P25 and P75) because the data were skewed. We calculated the Spearman's rank correlation coefficient *r* between children's UIC and iodine intake and maternal variables of iodine nutrition (iodine intake, BMIC, and UIC). The strength of the correlation was considered poor if $r < 0.20$, moderate if 0.20–0.49, and strong if ≥0.50 [33]. The non-parametric Kruskal–Wallis test was used to assess whether the UIC and iodine intake differed across different child age groups (<6, 6–11.9, and ≥ 12 mo of age) and feeding practices (breastfed, formula-fed, mixed milk-fed, and weaned). A *P* value <0.05 was considered statistically significant.

Ethics

Written informed consent was given by the mothers on behalf of their children. The study was approved by the Regional Committee for Medical and Health Research Ethics (2018/1230/REC South East).

Results

A total of 333 children were included in the estimations of iodine intake, of which urine samples for analyzation of iodine were available from 326. An overview of the study population and the collected data is given in Figure 1. More characteristics of the study population are given in Table 1. At the time point of the first 24-HR, the mean (SD) age of the children was 8 (6.0) mo. Furthermore, 3% had never been breastfed, 29% were previously breastfed, and 68% were still breastfed.

Children's iodine nutrition

Data on children's UIC and estimated iodine intake by the 24-HRs and FFQ, stratified by the 3 age groups (<6, 6–11.9, and ≥12 mo), are provided in Table 2. The iodine sources and their contribution (in %) to the iodine intake are presented in Table 3. None of the children were reported to consume iodine-containing supplements.

The median UIC was 145 μg/L and above the current recommended cutoff of 100 μg/L in all age groups (Table 2). The lowest UIC was among the breastfed children regardless of age (Figure 2). However, within the age groups, there were no significant differences in UIC between different feeding practices, except for infants aged 6–11.9 mo, where formula-fed infants had substantially higher UIC (202 μg/L) compared with breastfed (123 μg/L) and mixed milk-fed infants (129 μg/L) ($P = 0.0045$).

For all children, the median usual iodine intake based on the 24-HRs was 83 μg/d. A total of 56% ($n = 188$) had usual iodine intakes below the AI, 35% ($n = 117$) had iodine intakes below the EAR of 72 μg/d (suboptimal intake), whereas <1% ($n = 2$) exceeded the UL of 200 μg/d (excessive intake). For infants aged 6–11.9 mo, the median iodine intake was just within the AI of 90 μg/d, whereas for the other 2 age groups (<6 and ≥12 mo), the median iodine intakes were below the AIs of 90 and 100 μg/d, respectively (Table 2). Furthermore, in the youngest 2 age groups, breastfed infants had significantly lower iodine intakes than formula-fed and mixed milk-fed infants (<6 mo: 67 μg/d compared with 119 and 109 μg/d, respectively, $P < 0.001$, and 6–11.9 mo: 82 μg/d compared with 103 and 115 μg/d, respectively,

TABLE 2
UIC among the children and intakes of iodine estimated using 24-HR and FFQ

	All children		<6 mo		6–11.9 mo		≥12 mo	
	N	Value	*n*	Value	*n*	Value	*n*	Value
UIC								
P50 (P25 and P75)	326	145 (85, 226)	131	130 (81, 199)	114	143 (83, 235)	81	163 (113, 258)
Iodine intake, 24-h[1]								
P50 (P25 and P75)	333	83 (64, 113)	132	75 (57, 114)	117	90 (70, 113)	84	86 (67, 113)
% below AI[2] (95% CI)	188	56 (51, 62)	79	60 (51, 68)	57	49 (39, 58)	52	62 (51, 72)
% below EAR[3] (95% CI)	117	35 (30, 41)	63	48 (39, 57)	30	26 (18, 35)	24	29 (19, 39)
% above UL[4] (95% CI)	2	0.6 (0.0, 2.2)	1	0.7 (0.0, 4.1)	1	0.8 (0.2, 4.6)	0	0 (0.0, 4.2)
Iodine intake, FFQ[5]								
P50 (P25 and P75)	137	101 (52, 145)	—	—	80	66 (37, 126)	57	127 (88, 164)
% below AI[2] (95% CI)	66	48 (40, 57)			47	59 (47, 70)	19	33 (21, 47)
% below EAR[3] (95% CI)	44	32 (24, 41)			39	49 (37, 60)	5	9 (3, 19)
% above UL[4] (95% CI)	20	15 (9, 22)			9	11 (5, 20)	11	19 (10, 32)

Presented for all children ($N = 333$) and for 3 age group categories.
Abbreviations: UIC, urinary iodine concentration; 24-HR, 24-h dietary recall; FFQ, food frequency questionnaire; EAR, Estimated average requirement; UL, Upper intake level, AI, Adequate intake, CI, confidence interval.
[1] Estimated usual iodine intakes (μg/d) calculated using the Multiple Source Method [25].
[2] Adequate intake from the Nordic Nutrition Recommendations 2023 (90 μg/d for infants <12 mo of age and 100 μg/d for children ≥ 12 mo of age [30].
[3] Estimated average requirement of 72 μg/d for children <2 y of age [32].
[4] Upper intake level of 200 μg/d from the European Food Safety Authority [31].
[5] FFQ data was available for 251 children, but calculations of energy and iodine intakes were only computed for children ≥ 6 mo of age.

TABLE 3
Spearman's rank correlation coefficient between children's UIC and children's iodine intake, BMIC, maternal UIC and maternal iodine intake

	Children's UIC	Children's iodine intake[1]	BMIC	Maternal UIC	Maternal iodine intake[1]
Children's UIC	1.00				
Children's iodine intake[1]	0.408 ($P < 0.001$)	1.00			
BMIC	0.431 ($P < 0.001$)	0.669 ($P < 0.001$)	1.00		
Maternal UIC	0.231 ($P = 0.001$)	0.342 ($P < 0.001$)	0.325 ($P < 0.001$)	1.00	
Maternal iodine intake[1]	0.203 ($P = 0.004$)	0.216 ($P = 0.002$)	0.337 ($P < 0.001$)	0.170 ($P = 0.017$)	1.00

Abbreviations: UIC, urinary iodine concentration; 24-HR, 24-h dietary recall; BMIC; breast milk iodine concentration, MSM, Multiple Source Method.

Estimated usual iodine intakes (μg/d) calculated using 24-HRs and the MSM [25].

[1] Estimated usual iodine intakes (μg/d) from Aarsland et al. [23] using 24-HRs and the MSM [25]. The median (P25 and P75) iodine intake was 151 μg/d (103 and 216) in all females ($N = 300$), including iodine from food and supplements [23].

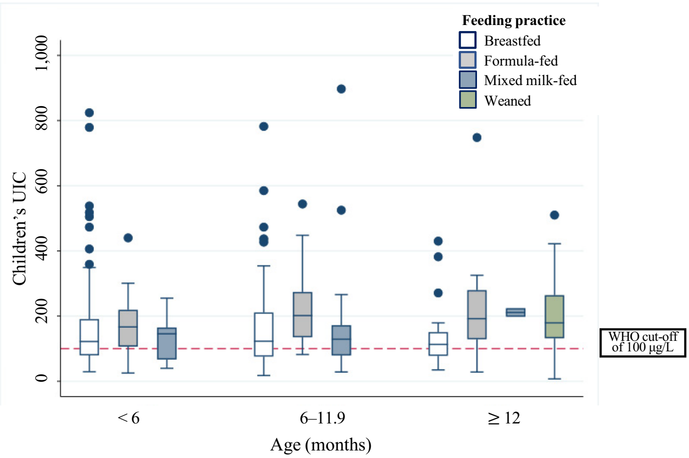

FIGURE 2. Box plot of children's urinary iodine concentration (UIC), stratified by 3 age groups. The horizontal line in the box indicates the median UIC, the box indicates the interquartile range (IQR) (P25–P75), the whiskers represent observations within 1.5 times the IQR, and the filled circles are outliers (defined as a value >1.5 length of the box). Sample sizes in the age groups were as follows: <6 mo ($n = 131$): breastfed ($n = 101$), formula fed ($n = 16$), mixed milk-fed ($n = 14$); 6–11.9 mo ($n = 114$): breastfed ($n = 71$), formula fed ($n = 30$), mixed milk-fed ($n = 13$); ≥12 mo ($n = 81$): breastfed ($n = 21$), formula fed ($n = 17$), mixed milk-fed ($n = 2$), and weaned ($n = 41$).

$P < 0.001$). For children ≥12 mo of age, there were no notable differences in iodine intake between different feeding practices ($P = 0.6148$). Besides breast milk and formula, the main dietary iodine sources were industrial infant porridge and cow's milk, contributing 14.7% and 7.3% to the iodine intake, respectively (Table 4).

Calculation of iodine intake from the FFQ was only computed for children >6 mo of age, because the FFQ used for the younger children only quantified the consumption amount of certain food items. As indicated by Table 2, 48% ($n = 66$) of the children had iodine intakes below the AI, 32% ($n = 44$) had intakes below the EAR, and 15% ($n = 20$) had intakes above the UL.

Correlation between children's UIC, children's iodine intake, and maternal iodine nutrition

The correlation coefficients between children's UIC and children's iodine intake, BMIC, maternal UIC, and maternal iodine intake are presented in Table 3. In the lactating females who provided breast milk samples ($n = 220$), the median (P25 and P75) BMIC was 74 μg/L (48 and 110). The median (P25 and P75) UIC in all mothers ($N = 330$) was 92 μg/L (54 and 148), indicating inadequate maternal iodine status. There was a high and statistically significant correlation between children's iodine intake and BMIC, whereas a moderate correlation was found between children's UIC and BMIC, maternal UIC, and maternal iodine intake.

TABLE 4
Contribution (%) from different food groups to the iodine intake, based on 24-HRs from 333 children (2 × 24-HRs from 310 children)

Food group	Contribution of food group to the total iodine intake (%)			
	All children (N = 333)	<6 mo (n = 132)	6–11.9 mo (n = 117)	≥12 mo (n = 84)
Dairy products	12.6	<0.1	2.7	45.5
Milk	7.3		0.8	27.2
Yogurt, cottage cheese, and quark	3.0		0.8	10.4
White-colored cheese[1]	0.8		0.3	2.8
Whey cheese	1.4		0.7	4.6
Other dairy products[2]	0.1		<0.1	0.5
Fish and seafood	4.9	0.2	5.5	11.1
Lean/semi-fat fish and related products	2.2	0.2	4.5	2.0
Fatty fish	0.1	0.0	0.1	0.2
Other fish products	2.6	0.0	0.9	8.9
Eggs	1.2	0.1	1.1	3.2
Bread, cereals, seeds, and nuts	15.9	6.4	27.8	12.6
Industrial infant porridge	14.7	6.1	27.1	9.3
Other products	1.2	0.3	0.7	3.3
Vegetables, fruits, and berries	1.1	0.2	1.1	2.2
Poultry, meat, and meat products	0.3	<0.1	0.2	0.7
Butter, margarine, and oils	0.2	<0.1	0.2	0.6
Non-dairy beverages[3]	0.2	<0.1	0.1	0.7
Supplements	0.0	0.0	0.0	0.0
Mixed dishes and other products	1.9	<0.1	1.9	4.8
Breast milk	40.5	67.3	36.5	7.0
Formula	21.2	25.9	22.9	11.6

Presented for all children and for the 3 age group categories.
Abbreviation: 24-HR, 24-h dietary recall.
[1] Solid and cream cheese.
[2] Cream milk, crème fraiche, sour cream and ice cream.
[3] Juice, soda and plant-based milk replacements.

Discussion

To our knowledge, this is the first study to present data on iodine nutrition in young children in Norway, including both UIC, estimated iodine intake, and associations with maternal iodine nutrition.

In the present study, the median UIC in all children was 145 μg/L, which indicates adequate iodine status according to the current WHO cutoff of 100 μg/L for children <2 y of age. However, this UIC cutoff for infants and toddlers has been questioned as it does not align with the WHO dietary intake recommendations for this age group. The UIC cutoff is based on goiter prevalence in school-aged children, and it does not consider that younger children have lower urine volumes compared with school-aged children [16]. The WHO is currently reviewing their cutoffs for ID, and a cutoff of a median UIC >200 μg/L has been proposed by others [16]. Using the proposed cutoff of >200 μg/L, the median UIC among the children in our study would be defined as insufficient in all age groups. In addition, the dietary assessment of the same children indicated that a large proportion had usual iodine intakes below the EAR.

The lowest median UIC was among the breastfed children in all age groups. Another recent study in Norway (N = 113) found lower UIC in breastfed infants compared with mixed milk-fed and weaned infants at 3 and 6 mo of age, but not at 9 mo of age [34]. Also, other studies in Norway and elsewhere have reported lower UIC among breastfed children compared with other feeding practices [6,35,36]. Of the few previous studies from Norway reporting data on UIC in children 0–2 y of age, a median UIC in the range of 82–210 μg/L has been reported [34–38]. In these Norwegian studies, the lowest levels have been reported in breastfed infants aged 3 mo (median UIC 82 μg/L) [34], and the highest levels have been reported in weaned infants ≤1 y of age (median UIC 210 μg/L and median age ~5 mo) [35].

On the basis of the repeated 24-HRs in this study, which was the main method chosen for dietary assessment, 35% of the children had suboptimal usual iodine intakes (below the proposed EAR of 72 μg/d). Similar to the UIC, the iodine intake differed between age groups and feeding practice (Figure 3), with the highest proportion of children with suboptimal iodine intakes among breastfed children in the youngest age group (59 out of 102; 58%). The iodine intake of exclusively breastfed infants is largely determined by the BMIC. For instance, with a BMIC equal to the median BMIC of 74 μg/L in this study, a 1-mo-old fully breastfed infant will be provided with 46 μg iodine/d (74 μg/L × 0.624 L), which is far below the EAR of 72 μg/d. Conversely, a fully formula-fed infant receiving the same daily volume of 0.624 L will receive 87 μg/d, assuming an iodine concentration in formula equal to the median iodine concentration of the formulas in this study of 140 μg/L. There is currently no established BMIC cutoff to categorize iodine sufficiency in lactating females, but to maintain positive iodine balance in infants, a BMIC of 100–200 μg/L has been suggested [16]. The median BMIC of 74 μg/L in this study falls short of this proposed range and suggests that infants having breast milk as their primary food source are likely to have suboptimal intakes of iodine. In our study, both children's UIC and iodine intake were positively associated with all markers of maternal iodine

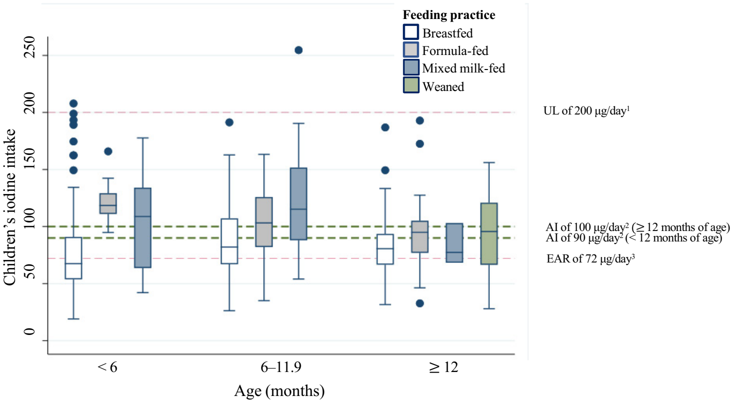

FIGURE 3. Box plot of children's dietary iodine intake by 24-HRs, stratified by the 3 age groups. The horizontal line in the box indicates the median iodine intake, the box indicates the interquartile range (IQR) (25th–75th percentile), the whiskers represent observations within 1.5 times the IQR, and the filled circles are outliers (defined as a value >1.5 length of the box). Sample sizes in the age groups were as follows: <6 mo (n = 132): breastfed (n = 102), formula fed (n = 16), mixed milk-fed (n = 14); 6–11.9 mo (n = 117): breastfed (n = 72), formula fed (n = 32), mixed milk-fed (n = 13); ≥12 mo (n = 84): breastfed (n = 22), formula fed (n = 17), mixed milk-fed (n = 3), and weaned (n = 42). 24-HR, 24-h dietary recall. [1]Upper intake level of 200 µg/d from the European Food Safety Authority [31]. [2]Adequate intake from the Nordic Nutrition Recommendations 2023 (90 µg/d for infants <12 mo of age and 100 µg/d for children ≥12 mo of age [30]. [3]Estimated average requirement of 72 µg/d for children <2 y of age [32].

nutrition (BMIC, UIC, and estimated iodine intake). This supports the importance of maternal iodine nutrition in providing sufficient iodine intake in young children and is also consistent with the findings of other studies [6,39–41].

The finding that 35% of the children in this study had suboptimal usual iodine intakes (below the EAR) is highly concerning and suggests that young children in Norway are at risk of ID. Although assessment of iodine intakes in populations should be based on the EAR [32], few studies in this age group have reported such data. The Little in Norway Study from 2018 reported that none of the 18-mo-old children (N = 416) had suboptimal iodine intakes [37]. However, the authors used a lower EAR than in the current study (65 µg/d from the Institute of Medicine), included a higher age group, and breastfed children were excluded from the iodine intake estimations because of limited knowledge of consumption volumes. Thus, our study is the first of its kind to reveal such concerning levels of iodine intakes across different child age groups and feeding practices.

The lack of a national salt iodization strategy in Norway has been largely attributed to concerns over the potential risks of excessive iodine intakes in young children, specifically 1- and 2-y-olds [42]. Children of this age have been considered vulnerable groups to iodine excess as they have immature thyroid glands and are less capable of adapting to high iodine intakes compared with adults and older children [43]. Children with a high consumption of cow's milk are at higher risk of excess iodine. Thus, with an increase in the iodine concentration in salt (from 5 to 20 µg/g; in line with the recent law change [20]), the National Council of Nutrition has stressed the importance of limiting milk and yogurt intake to 500–600 mL/d for young children [44]. In our study, the mean (SD) intake of cow's milk (including yogurt) among consumers (n = 96) was 260 mL/d (190). Moreover, our data showed that only 2 children (<1%) had usual iodine intakes above the UL (200 µg/d), suggesting that low iodine intakes were a greater concern than excessive intakes in this population.

A considerable strength of the current study was the use of both UIC and extensive dietary data collected from a large sample of children from randomly selected municipalities. Furthermore, it was a strength that we had 2 24-HRs from almost all children, and that we used the MSM to adjust for within-subject variability and estimate usual iodine intakes. A limitation is that there was an oversampling of children below 1 y of age compared with children above 1 y of age, likely because of the higher frequency of consultations at the public health care center during the first year of life compared with the subsequent years. Also, many of the children spent part of the day away from home or with another caregiver, leading to varying levels of knowledge and awareness among the mothers regarding their child's diet. Dietary assessment in young children is already a complex task that faces several respondent and observer considerations related to portion sizes, food spillage, and consumption of breast milk and/or formula. Another limitation is that we used spot urine samples to assess UIC, which does not reflect the usual iodine status. However, our results rely predominantly on the estimated intakes of iodine derived from repeated 24-HRs. Finally, we did not measure any biomarkers of thyroid function, which is warranted to provide a better picture of iodine nutrition and potential health consequences in this age group.

In conclusion, this study suggests that the iodine status of children ≤2 y of age in Norway is adequate on a population level, as indicated by a median UIC >100 µg/L in the overall group. However, the UIC cutoff is debated, and the extensive dietary data indicate that more than a third of the children have suboptimal usual iodine intakes as shown by intakes below the EAR. Our results suggest that many children will benefit from iodine fortification, both directly through increased iodine from solid foods and indirectly through increased iodine in breast milk. Moreover, our results suggest that risk of iodine excess in young children is low.

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Author contributions

The authors' responsibilities were as follows—TAS, KSB, BSS, SK: designed the research; TAS, KSB: coordinated large parts of the data collection; KSB, BSS, SK, TEA: took part in recruitment; KRN, ITF, TEA: prepared the urine and breast milk samples before analyses; THØ, SL, ELFG: iodine analyses of urine and breast milk samples; TEA, SNS, BSS, KSB, SK, TAS: analyzed the data and performed the statistics; TEA: wrote the first draft of the paper; TAS, KSB, SNS: supervised; and all authors: read, contributed to and approved the final manuscript.

Conflict of interest

The authors report no conflicts of interest.

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Data availability

Requests for data presented in this study can be made to the authors. To meet ethical requirements for the use of confidential data, requests must be approved by the Regional Committee for Medical and Health Research Ethics in Norway.

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List of appendices

Appendix I: 24-hour intake of iodine-rich foods, infants 0–12 months, phase I

ID-nummer barn: ☐☐☐☐

1. Fikk barnet ditt morsmelk eller morsmelk erstatning i går?
☐ Ja, Morsmelk ☐ Nei ingen av delene
☐ Ja, Morsmelkerstatning ☐ Begge deler
2. Hvor mange ganger fikk barnet morsmelk/morsmelk erstatning i går ?
Antall ganger ammet: ________________ Antall ganger fått morsmelk:________________
3. Fikk barnet morsmelk eller ammet rett før urinprøven ble tatt ?
☐ Ja ☐ Nei
4. Spiste barnet ditt industrifremstilt grøt i går ?
☐ Ja ☐ Nei Hvis ja, angi type og mengde : ________________
Tidspunkt:____

5. Spiste barnet ditt hjemmelaget grøt i går , hva slags væske ble benyttet?
Hvis ja, angi type og mengde : ________________
Tidspunkt:____

6. Inntok barnet ditt Yoghurt, alle typer i går?
☐ Ja ☐ Nei Hvis ja, angi type og mengde : ________________
Tidspunkt:____
7. Inntok barnet ditt egg som pålegg eller i matlagning i går?
☐ Ja ☐ Nei Hvis ja, oppgi Antall ______
Tidspunkt:____

8. Inntok barnet ditt hvit fisk både til middag og som pålegg (torsk, sei, hyse, etc) ?
☐ Ja ☐ Nei Hvis ja, angi type og mengde : ________________
Tidspunkt:____

9. Inntok barnet ditt hvit fisk i barnemat på glass?
☐ Ja ☐ Nei Hvis ja, angi type og mengde : ________________
Tidspunkt:____

10. Inntok barnet ditt fiskekaker, fiske- boller, pudding og pinner ?
☐ Ja ☐ Nei Hvis ja, angi type og mengde : ________________
Tidspunkt:____

11. Inntok barnet ditt jod beriket smoothie i går ?
☐ Ja ☐ Nei Hvis ja, angi type og mengde : ________________
Tidspunkt:____

12. Inntok barnet mitt rød fisk både til middag og som pålegg (laks, makrell, ørret, tunfisk)
☐ Ja ☐ Nei Hvis ja, angi type og mengde : ________________
Tidspunkt:____
13. Inntok barnet ditt rød fisk i barnemat på glass?
☐ Ja ☐ Nei Hvis ja, angi type og mengde : ________________
Tidspunkt:____

14. Inntok barnet ditt kaviar som pålegg i går

☐ Ja ☐ Nei Hvis ja, angi type og mengde : ________________
Tidspunkt:____
Sett kryss for type:
Kaviar Orginal ☐
Kaviar mix ☐

15. Inntok barnet ditt ost i går ? ☐ Ja ☐ Nei
Tidspunkt:____
Ost, brunost ☐ Antall skiver : ________________
Ost, Hvit ☐ Antall skiver : ________________

16. Inntok barnet ditt prim som pålegg i går?

☐ Ja ☐ Nei Hvis ja, angi type og mengde : ________________
Tidspunkt:____

17. Inntok barnet ditt andre jodberikede barnemat produkter?

☐ Ja ☐ Nei Hvis ja, angi type og mengde : ________________
Tidspunkt:____

18. Hvor ofte får barnet ditt kosttilskudd?

☐Hver dag
☐ 3-6 ganger pr. Uke
☐ 1-2 ganger pr. Uke
☐ Sjeldnere enn 1 gang pr uke
☐ Aldri
Hvilke(n) type(r) benyttes (angi produktnavn og mengde)?
Navn ____________________ Mengde ____________________
Navn ____________________ Mengde ____________________
Navn ____________________ Mengde ____________________
Eksempler: Møllers tran, Sanasol, Nycoplus multi flytende, Nycoplus multi vitamin og mineraltbl for barn, kalsium 250 mg, kalsium 500 mg, NeoFer (jerntilskudd), omega-3 tilskudd, vitamin C, vitaminbjørn

Kan du lese ut fra innholdsdeklarasjonen om noen av disse tilskuddene inneholder jod?

☐ Ja ☐ Nei

Hvis ja, skriv hvilket tilskudd det gjelder og hvor mye jod det er per dose:……………………………………

Hvis ja, skriv hvilket tilskudd det gjelder og hvor mye jod det er per dose: ____________

19. Fikk barnet ditt vitamin og mineraltilskudd med jod i går eller i dag tidlig?

☐ Ja ☐ Nei Hvilket: _______________________ Tidspunkt:____________________

Appendix II: FFQ, infants 0–12 months, phase I

Spørreskjema Spedbarn

Dato for utfylling av skjemaet: ☐☐ ☐☐ ☐☐☐☐

Barnets ID-nummer i prosjektet ☐☐☐☐

Barnets alder : ☐☐ mnd ☐☐ Uker

Skjemaet er utfylt av: ☐Barnets mor ☐Barnets far ☐ Både mor og far ☐ Annen person

Barnets kjønn: Jente ☐ gutt ☐

Spørsmål 1: Får barnet morsmelk?

☐ Ja, bare morsmelk (og eventuelt tran eller annet kosttilskudd)
☐ Ja, morsmelk og vann/juice/saft o.l.
☐ Ja, morsmelk og fast føde samt eventuelt vann/juice/saft
☐ Ja, morsmelk og morsmelkerstatning/annen melk
☐ Ja, morsmelk og morsmelkerstatning/annen melk og fast føde samt eventuelt vann/juice/saft
☐ Nei, men barnet har tidligere fått morsmelk
☐ Nei, barnet har aldri fått morsmelk

Spørsmål 2: Ble barnet fullammet fra fødsel? Ja ☐ Nei ☐

Spørsmål 3: Hvor mange ganger per døgn drikker barnet morsmelk?

☐ 12 ganger eller mer pr døgn

☐ 9-11 ganger pr døgn

☐ 6-8 ganger pr døgn

☐ 3-5 ganger pr døgn

☐ 1-2 ganger pr døgn

☐ sjeldnere enn 1 gang pr døgn

Spørsmål 4: Dersom barnet ikke får morsmelk lenger, hvor gammelt var barnet da det sluttet å få morsmelk?

☐☐ Måneder

Spørsmål 5: Dersom barnet får annet å drikke enn morsmelk (vann, juice, saft, morsmelkerstatning, melk), hvor gammelt var barnet da annen drikke ble gitt for første gang?

☐☐ Måneder Spesifiser: ______________________________

Spørsmål 6: Drikker barnet en annen melketype enn morsmelk?
Ja Nei   Morsmelkerstatning
Hvis ja, hvilke(n) type(r) melk drikker barnet?
Hvilke(n) type(r) benyttes (angi produktnavn)?

____

Hvor mange ganger *per døgn* drikker barnet morsmelkerstatning? ☐☐

Eller

Hvor mange ganger *pr uke* drikker barnet morsmelkerstatning? ☐☐

Spørsmål 7: Dersom barnet startet med fast føde/mat, hvor gammelt var barnet når fast føde (annen mat enn morsmelk/ kosttilskudd) ble gitt for første gang?

☐☐ Måneder

Spørsmål 8: Hvor ofte spiser barnet industrifremstilt grøt/velling?
 3 ganger eller mer pr dag
 1-2 ganger pr dag
 3-6 ganger pr. uke
 1-2 ganger pr. uke
 Sjeldnere enn ukentlig
 Aldri
Hvilke(n) type(r) industrifremstilt grøt/velling benyttes (angi produktnavn, f.eks Hipp, Nestle, Semper, Holle)?

____

Spørsmål 9: Dersom barnet spiser industrifremstilt grøt/velling nå, hva slags væske tilsettes vanligvis ved tilberedning, (sett flere kryss hvis flere produkter benyttes)?
 Vann
 Morsmelk
 Morsmelkerstatning
Hvilke(n) type(r) benyttes (angi produktnavn)?

____

Plantemelk (f.eks havre, soya, ris) Hvilke(n) type(r) benyttes (angi produktnavn)?

____

Spørsmål 10: Hvor ofte spiser barnet hjemmelaget grøt/velling?
 3 ganger eller mer pr dag
 1-2 ganger pr dag
 3-6 ganger pr. Uke
 1-2 ganger pr. uke
 Sjeldnere enn ukentlig
 Aldri

Hvilke(n) type(r) hjemmelaget grøt spiser barnet vanligvis (angi type grøt, f.eks havregrøt, hirsegrøt)?

____

Spørsmål 11: Dersom barnet spiser hjemmelaget grøt/velling nå, hva slags væske tilsettes vanligvis ved tilberedning. (sett flere kryss hvis flere produkter benyttes)?

 Vann

 Morsmelk

 Morsmelkerstatning
Hvilke(n) type(r) benyttes (angi produktnavn)?

____

 Plantemelk (f.eks havre, soya, ris)
Hvilke(n) type(r) benyttes (angi produktnavn)?

____

 Hestemelk, geitemelk, annen melk fra dyr Hvilke(n) type(r) benyttes (angi produktnavn)?

____

Spørsmål 12: Hvor ofte får barnet kosttilskudd?

Hver dag

 3-6 ganger pr. Uke

 1-2 ganger pr. Uke

 Sjeldnere enn 1 gang pr uke

 Aldri
Hvilke(n) type(r) benyttes (angi produktnavn og mengde)?

Navn ______________________ Mengde ______________________

Navn ______________________ Mengde ______________________

Navn ______________________ Mengde ______________________

Eksempler: Møllers tran, Sanasol, Nycoplus multi flytende, Nycoplus multi vitamin og mineraltbl for barn, kalsium 250 mg, kalsium 500 mg, NeoFer (jerntilskudd), omega-3 tilskudd, vitamin C, vitaminbjørn

Hvor ofte har ditt barn i gjennomsnitt drukket eller spist disse de siste 2 ukene?

	Sjelden/ aldri	Sjeldnere enn ukentlig	1-3 ganger per uke	4-6 ganger per uke	1-2 ganger per dag	3-4 ganger per dag	5 + ganger per dag
Brød, alle typer	☐	☐	☐	☐	☐	☐	☐
Yoghurt/surmelk, all typer gitt i antall beger (ca 1 dl)	☐	☐	☐	☐	☐	☐	☐
Rød fisk både til middag og som pålegg (laks, makrell, ørret, tunfisk) (Porsjon á ca 50 g)	☐	☐	☐	☐	☐	☐	☐
Rød fisk i barnemat på glass Oppgi porsjon ca____dl	☐	☐	☐	☐	☐	☐	☐
Hvit fisk både til middag og som pålegg (torsk, sei, hyse, etc) (Porsjon á ca 50 g)	☐	☐	☐	☐	☐	☐	☐
Hvit fisk i barnemat på glass	☐	☐	☐	☐	☐	☐	☐
Fiskekaker, fiske- boller, pudding og pinner (ca 50 gr porsjon)	☐	☐	☐	☐	☐	☐	☐
Jod beriket smoothie, (1 stk) (sjekk pakning for jod og hvor mange mnd den er beregnet for)	☐	☐	☐	☐	☐	☐	☐
Oppgi type ___________							
Produsent_____________	☐	☐	☐	☐	☐	☐	☐
Barnemat på glass, middag							
Oppgi porsjon ca_______dl							
Oppgi type ____________							
Produsent________________							
egg som pålegg eller i matlagning Oppgi Antall _______	☐	☐	☐	☐	☐	☐	☐
Ost, brunost (1 skive)	☐	☐	☐	☐	☐	☐	☐
Ost, Hvit (1 skive)	☐	☐	☐	☐	☐	☐	☐
Vann som drikke Ca dl:_____	☐	☐	☐	☐	☐	☐	☐
Andre jodberikede barnemat produkter (se pakning) Oppgi type: ______________________ Oppgi produsent: ___________	☐	☐	☐	☐	☐	☐	☐

Appendix III: Maternal FFQ and demographics, phase I

Spørreskjema til Mødre

ID-nummer i prosjektet: ☐☐☐☐

Dagens dato: ☐☐ ☐☐ ☐☐☐☐

Bakgrunnsinformasjon

1. Din alder? ☐☐ år

2. Barnets alder uker ? ☐☐ uker

3. Hvor mange barn har du fra før? ☐☐

Hvis du har barn fra før, hvilken dato fødte du ditt forrige barn?
dd mm åååå
☐☐ ☐☐ ☐☐☐☐ ☐☐

4. Ammer du barnet nå?

☐ Ja helt ☐ Ja delvis ☐ Nei

5. Høyde og vekt: Hvor mye veide du før svangerskap og hvor mye veier du nå?

Før svangerskap ☐☐☐ kg

Vekt nå ☐☐☐ kg

Hvor høy er du? ☐☐☐ cm

6. Planlegger du å bli gravid de neste to årene?

☐ Ja ☐Nei ☐ Er gravid igjen nå

7. Hva er din sivilstand
☐ Samboer
☐ Gift
☐ Enslig
☐ Annet, forklar ……………………………………

8. Hvilket land er du født i?
☐ Norge
☐ Annet……………………………………..

☐☐ 9. Hvor mange år har du bodd i Norge?
År

10. Hvilket språk snakker du mest hjemme?
☐ Norsk
☐ Annet land, hvilket:………………………

11. Hva er din høyeste fullførte utdannelse:
☐ <12 år (ikke fullført videregående)
☐ 12 år videregående/fagbrev
☐ 1-4 års høgskole/universitet etter videregående
☐ Mer enn 4 år høgskole/universitet

12. Er du yrkesaktiv:
☐ Oppgi prosent stilling: ………………………
☐ Arbeidsledig
☐ Student
☐ 100% Permisjon

13. Røykevaner: Røyker du nå?
☐ Nei
☐ Nei, men jeg røkte før
☐ Ja, av og til
☐ Ja, daglig

Hvor mye i gjennomsnitt røyker du per dag? Gi antall:

sigaretter …….. stk

Snuser du?
☐Nei ☐Ja,
☐Av og til ☐Ja, daglig, gi antall: ………stk

14. Har du hatt noen av følgende sykdommer knyttet til skjoldbruskkjertelen?

☐ For høyt stoffskifte
☐ For lavt stoffskifte
Bruker du medisiner for dette nå?
☐ Ja ☐Nei

Navn på medisiner:…………………

Kunnskap om jod

1.Vet du hva jod er?

☐ Ja ☐ Nei ☐ Har hørt om det, men husker ikke

Hvis ja, hvor har du hørt om jod?

☐ Helsepersonell

☐ Media (avis, TV)

☐ Skole

☐ Familie, venner

☐ Annet:……………………………………

☐ Jeg har ikke hørt om jod

2. Hva er de viktigste kilder til jod i kosten? (Du kan sette flere kryss).

☐ Kjøtt

☐ Melk- og meieriprodukter

☐ Frukt og grønnsaker

☐ Fisk og sjømat

☐ Brød- og kornprodukter

☐ Vegetabilske oljer

☐ Salt tilsatt jod

☐ Kosttilskudd

☐ Annet:……………………………………

☐ Vet ikke

3. Jod er viktig for? (Du kan sette flere kryss).

☐ Normal vekst og utvikling hos barn

☐ Forebygge blindhet

☐ Normal fosterutvikling

☐ Normal styrke i skjelett og tenner

☐ Opprettholde normalt stoffskifte

☐ Unngå ryggmargsbrokk

☐ Vet ikke

4. Jeg tror jeg får nok jod gjennom kosten?

☐ Enig ☐ Uenig ☐ Vet ikke

5. Jeg har fått informasjon om jod fra helsepersonell

☐ Ja ☐ Nei ☐ Husker ikke

6. Hva vet du om lavt og høyt inntak av jod blant gravide/ammende i Norge? (Du kan sette flere kryss):

☐ For lavt inntak av jod er et problem i Norge i dag

☐ For høyt inntak av jod er et problem i Norge i dag

☐ For høyt inntak av jod er et problem i Norge i dag

☐ For lavt inntak er ikke et problem i dag, men var vanlig før

☐ Vet ikke

☐ Annet …………………………………

Kosthold og kosttilskudd

1. Tar du et eller flere vitamin og mineraltilskudd (for eksempel vitaminer, mineraler, olje, tare-tilskudd)?

☐ Ja ☐ Nei

Hvis Ja, skriv navn på tilskudd(ene) og hvor mange ganger i uken tar du hvert tilskudd:

1.________________________: ☐ ganger/uke
2.________________________: ☐ ganger/uke
3.________________________: ganger uke
4.________________________: ☐ ganger/uke
☐

Kan du lese ut fra innholdsdeklarasjonen om noen av disse tilskuddene inneholder jod?

☐ Ja ☐ Nei

Hvis ja, skriv hvilket tilskudd det gjelder og hvor mye jod det er per dose:……………………………………

Hvis ja, skriv hvilket tilskudd det gjelder og hvor mye jod det er per dose: ___________

2. Tok du vitamin og mineraltilskudd med jod i går eller i dag tidlig?

☐ Ja ☐ Nei

Hvor ofte har du i gjennomsnitt drukket eller spist disse de siste 4 ukene?

	Sjelden/ aldri	Sjeldnere enn ukentlig	1-3 ganger per uke	4-6 ganger per uke	1-2 ganger per dag	3-4 ganger per dag	5 + ganger per dag
1. Brød/knekkebrød, alle typer (2 skiver)	☐	☐	☐	☐	☐	☐	☐
2. Andre frokostblandinger (corn flakes, honni korn, sjokopuff etc) (1 porsjon)	☐	☐	☐	☐	☐	☐	☐
3. Ris/pasta kokt (porsjon á 150g)	☐	☐	☐	☐	☐	☐	☐
4. Kumelk, alle typer gitt i antall glass (ca 2 dl) (og inkludert kaffe latte/cappuccino)	☐	☐	☐	☐	☐	☐	☐
5. Alternativ melk (havre, ris, mandel, soya) ca 2 dl	☐	☐	☐	☐	☐	☐	☐
6. Yoghurt/surmelk, all typer gitt i antall beger (ca2dl)	☐	☐	☐	☐	☐	☐	☐
7. Rød fisk både til middag og som pålegg (laks, makrell, ørret, tunfisk) (Porsjon á ca 100 g)	☐	☐	☐	☐	☐	☐	☐
8. Hvit fisk både til middag og som pålegg (torsk, sei, hyse, etc) (Porsjon á ca 100 g)	☐	☐	☐	☐	☐	☐	☐
9. Fiskekaker, fiske- boller, pudding og pinner (1 porsjon)	☐	☐	☐	☐	☐	☐	☐
10. Sushi med fisk/skalldyr (porsjon á ca 10 biter)	☐	☐	☐	☐	☐	☐	☐
11. Rent kjøtt av okse, gris og lam (steik, koteletter, filet, biff), (Porsjon á ca 100 g)	☐	☐	☐	☐	☐	☐	☐
12. Bearbeidede kjøttprodukter (pølser, hamburger, kjøttkaker o.l.) (Porsjon á ca 100 g)	☐	☐	☐	☐	☐	☐	☐
13. Vilt (elg, hjort, rådyr, villfugl, hære o.l.) (Porsjon á ca 100 g)	☐	☐	☐	☐	☐	☐	☐
14. Kylling og kalkun, (Porsjon á ca 100 g)	☐	☐	☐	☐	☐	☐	☐
15. Pizza/taco/kebab (Porsjon á ca 100 g)	☐	☐	☐	☐	☐	☐	☐
16. Linser, bønner, kikerter	☐	☐	☐	☐	☐	☐	☐
17. Olivenolje/rapsolje (til salat og matlaging)	☐	☐	☐	☐	☐	☐	☐
18. Hvit ost, alle typer, (2 skiver)	☐	☐	☐	☐	☐	☐	☐
19. Ost, brunost (2 skiver)	☐	☐	☐	☐	☐	☐	☐
20. Egg hele (kokt, stekt) og i matlaging (pannekaker/vafler)	☐	☐	☐	☐	☐	☐	☐
21. Kaker, sjokolade, iskrem, smågodt	☐	☐	☐	☐	☐	☐	☐
22. Saltet snacks (f.eks. potetchips, peanøtter)	☐	☐	☐	☐	☐	☐	☐
23. Søte drikker (som saft, Cola, Fanta, nektar, juice, smoothie)	☐	☐	☐	☐	☐	☐	☐
24. Kunstig søte drikker (Cola Zero, Pepsi Zero osv)	☐	☐	☐	☐	☐	☐	☐
25. Vann som drikke	☐	☐	☐	☐	☐	☐	☐
26. Kaffe	☐	☐	☐	☐	☐	☐	☐
27. Te	☐	☐	☐	☐	☐	☐	☐
28. Grønnsaker alle typer (f.eks. gulrot, kål, brokkoli, løk, erter, tomat, salat, agurk)	☐	☐	☐	☐	☐	☐	☐
29. Frukt og bær alle typer (f.eks. epler, pærer, banan, jordbær, druer, appelsin)							
30. Poteter (porsjon á 1 middels stor eller 2 små)							
31. Nøtter (valnøtter, hasselnøtter, mandler o.l.)							

Takk for at du deltok i dette forskningsprosjektet om jod!

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SPEDKOST

Undersøkelse av kostholdet blant spedbarn

Kryss av for "Ja" i ruten under dersom du samtykker i å delta i undersøkelsen. Dersom du ikke ønsker å delta og vil reservere deg mot å bli oppringt samt å bli purret på, kryss av for "Nei" og returner skjemaet.

☐ Ja

☐ Nei

Ved utfylling er det viktig at du går frem slik:

* Sett kryss i boksene. Slik: ☒ Ikke slik: X☐
* Ved rettelser kan du markere tydelig at det er feil, slik: ■
* I de åpne feltene skriver du inn tydelig tekst
* Der det spørres etter tall, skriver du disse slik: 1 2 3 4 5 6 7 8 9
* Skjemaet må ikke brettes
* Det utfylte skjemaet vil bli lest av en maskin. **Bruk blå eller sort kulepenn**.

Fyll inn opplysninger om barnets vekt og lengde - ved fødsel og ved 6 måneders alder (fra helsekortet).

Fylles ut fra helsekortet

Dato for måling av vekt/lengde (6 mnd): ☐☐ dag ☐☐ mnd ☐☐☐☐ år

Barnets vekt (6 mnd): ☐☐☐☐☐ gram **Barnets lengde (6 mnd):** ☐☐ cm

Fødselsvekt: ☐☐☐☐ gram **Lengde ved fødsel:** ☐☐ cm

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BAKGRUNNSSPØRSMÅL OM BARNET

1. Dato for utfylling av skjemaet
Skriv inn datoen for dag, måned og år i rutene.

☐☐ ☐☐ ☐☐☐☐
dag mnd år

2. Hva er barnets kjønn?
*Sett **kun** ett kryss.*

- ☐ Jente
- ☐ Gutt

3. Når ble barnet født i forhold til ultralydstermin?
*Sett **kun** ett kryss.*

- ☐ I 38. svangerskapsuke eller senere
- ☐ Før 38. svangerskapsuke

4. Hvor mange barn har mor født?
*Sett **kun** ett kryss.*

- ☐ 1 barn
- ☐ 2 barn
- ☐ 3 barn
- ☐ 4 barn eller flere

5. Hvem fyller ut skjemaet?
Her kan du sette flere kryss.

- ☐ Barnets mor
- ☐ Barnets far
- ☐ Barnets medmor

SPØRSMÅL OM MORSMELK

6. Hva slags melk og/eller annen drikke fikk barnet på føde-/barselavdelingen?
Her kan du sette flere kryss.

- ☐ Morsmelk
- ☐ Morsmelkerstatning
- ☐ Vann
- ☐ Sukkervann
- ☐ Vet ikke
- ☐ Annet, vennligst spesifiser: ______

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7. **Får barnet morsmelk nå?**
*Sett **kun** ett kryss.*

- ☐ Ja, bare morsmelk (og eventuelt tran eller annet kosttilskudd) ⇨ *Gå til spm 8 og deretter til spm 11*
- ☐ Ja, morsmelk og annen mat og/eller drikke ⇨ *Gå til spm 8 og deretter til spm 11*
- ☐ Nei, men barnet har fått morsmelk tidligere ⇨ *Gå til spm 9*
- ☐ Nei, barnet har aldri fått morsmelk ⇨ *Gå til spm 10*

8. **Hvor mange ganger i døgnet får barnet vanligvis morsmelk nå?**
Regn også med de gangene barnet bare får morsmelk til trøst eller kos, dag- og nattetid.
*Sett **kun** ett kryss.*

- ☐ 1 gang
- ☐ 2-3 ganger
- ☐ 4-5 ganger
- ☐ 6-7 ganger
- ☐ 8-9 ganger
- ☐ 10 ganger eller flere

9. **Hvor gammelt var barnet da det sluttet å få morsmelk?**
*Sett **kun** ett kryss.*

Uker							Måneder									
1	2	3	4	5	6	7	2	2,5	3	3,5	4	4,5	5	5,5	6
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

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10. Hva var viktigste og nest viktigste grunn til at mor ikke ammet barnet eller har sluttet å amme det?
*Sett **kun** ett kryss for viktigste grunn og **kun** ett kryss for nest viktigste grunn.*

	Viktigste grunn	Nest viktigste grunn
Sugeproblemer	☐	☐
Barnet ville ikke	☐	☐
Barnet sykt/for tidlig født	☐	☐
Kolikk/urolig barn	☐	☐
Barnet biter/har fått tenner	☐	☐
For lite melk	☐	☐
Mor syk/medisinbruk	☐	☐
Bekymring/stress/sliten	☐	☐
Brystbetennelse	☐	☐
Tilstoppede melkeganger	☐	☐
Såre brystknopper	☐	☐
Brystoperert	☐	☐
Mor begynte å arbeide/å studere	☐	☐
Andre grunner	☐	☐
Ingen spesielle problemer, men ønsket ikke å amme (lenger)	☐	☐
Ble rådet til å slutte	☐	☐

Dersom mor ble rådet til å slutte å amme, hvem var det som rådet henne til det?
(f.eks. helsepersonell, familie, venner)

SPØRSMÅL OM MORSMELKERSTATNING/ANNEN MELK

11. Har barnet begynt å få morsmelkserstatning eller andre typer melk (kumelk, vegetabilsk melk o.l)?
Her regnes både det som drikkes og det som du selv tilsetter i grøt eller annen mat.
*Sett **kun** ett kryss.*

☐ Ja

☐ Nei ⇨ *Gå til spørsmål 15*

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12. Hvor gammelt var barnet da det begynte med morsmelkerstatning/annen melk i tillegg til eller istedenfor morsmelk?
Her regnes både det som drikkes og det som du selv tilsetter i grøt eller annen mat.
*Sett **kun** ett kryss.*

Uker							Måneder								
1	2	3	4	5	6	7	2	2,5	3	3,5	4	4,5	5	5,5	6
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

13. Hvor ofte drikker barnet vanligvis morsmelkerstatning og hvor mye drikker barnet vanligvis pr. gang?
Se mengdeangivelse på bilde 1 bakerst i spørreskjemaet. Velg mengde A, B, C eller D. Sett kryss i ruten som er nærmest den mengden barnet vanligvis drikker pr. gang. Hvis mengden varierer mye fra gang til gang, prøv å anslå en gjennomsnittsmengde. 100 ml = 1 dl.

*For hver melketype settes **kun** ett kryss for **hvor ofte,** enten ganger pr. uke eller ganger pr. døgn. I tillegg settes **kun** ett kryss for **hvor mye** barnet vanligvis drikker pr. gang.*

	Hvor ofte?									Hvor mye?			
		Ganger pr. uke		*eller* Ganger pr. døgn						Mengde (ml) pr. gang			
	Aldri/sjeldnere enn hver uke	1-3	4-6	1	2	3	4	5 el. flere		60 A	120 B	180 C	240 D
NAN Pro1, NAN Organic 1	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
NAN Pro2, NAN Organic 2	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
NAN H.A. 1	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
HiPP Combiotic 1	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
HiPP Combiotic 2	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
Semper Allomin 1	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
Semper Allomin 2	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
Holle morsmelkerstatning 1	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
Holle tilskuddsblanding 2	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
Annen morsmelkerstatning	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐

Dersom barnet får annen morsmelkerstatning, oppgi type:

14. Hvor ofte drikker barnet vanligvis melk og hvor mye drikker barnet vanligvis pr. gang?

Se mengdeangivelse på bilde 2 bakerst i spørreskjemaet. Velg mengde A, B, C eller D. Sett kryss i ruten som er nærmest den mengden barnet vanligvis drikker pr. gang. Hvis mengden varierer mye fra gang til gang, prøv å anslå en gjennomsnittsmengde. 100 ml = 1 dl.

*For hver melketype settes **kun** ett kryss for **hvor ofte,** enten ganger pr. uke eller ganger pr. døgn. I tillegg settes **kun** ett kryss for **hvor mye** barnet vanligvis drikker pr. gang.*

	Hvor ofte?								**Hvor mye?**			
		Ganger pr. uke		*eller* Ganger pr. døgn					Mengde (ml) pr. gang			
	Aldri/sjeldnere enn hver uke	1-3	4-6	1	2	3	4	5 el. flere	30 A	60 B	120 C	180 D
Helmelk (søt og sur)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lettmelk (1.0 % og 1.2 % fett)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lettmelk (0.5 % fett, tidligere ekstra lett melk)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Skummetmelk (søt og sur)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Kumelksblanding (kumelk-vann-sukker)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Annen melk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Dersom barnet får annen melk, oppgi type:

SPØRSMÅL OM FAST FØDE

15. Har barnet begynt å få fast føde?

Med fast føde menes alle andre matvarer enn vann/melk/saft/juice/annen drikke og kosttilskudd. Fast føde inkluderer velling selv om denne er tyntflytende.
*Sett **kun** ett kryss.*

☐ Ja

☐ Nei ⇨ *Gå til spørsmål 25*

16. Hvor gammelt var barnet da det første gang fikk fast føde?

*Sett **kun** ett kryss.*

Uker							Måneder								
1	2	3	4	5	6	7	2	2,5	3	3,5	4	4,5	5	5,5	6
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

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17. Hvor ofte pleier barnet å spise følgende mat nå?
Med melk menes her morsmelk, morsmelkerstatning eller annen melk.
*Sett **kun** ett kryss for hver matvare, enten ganger pr. uke eller ganger pr. døgn.*

		Ganger pr. uke		*eller* Ganger pr. døgn			
INDUSTRIFREMSTILT GRØT/VELLING FRA PULVER:	Aldri/sjeldnere enn hver uke	1-3	4-6	1	2	3	4 el. flere
Nestlé grøt	☐	☐	☐	☐	☐	☐	☐
Semper grøt	☐	☐	☐	☐	☐	☐	☐
HiPP grøt	☐	☐	☐	☐	☐	☐	☐
Holle grøt (tilberedt med vann/melk)	☐	☐	☐	☐	☐	☐	☐
Velling (fra pulver eller drikkeklar)	☐	☐	☐	☐	☐	☐	☐
INDUSTRIFREMSTILT GRØT PÅ KLEMMEPOSE:							
Nestlé, HiPP, Lillego, Lev Vel, Organix	☐	☐	☐	☐	☐	☐	☐
Ella's Kitchen	☐	☐	☐	☐	☐	☐	☐
Semper	☐	☐	☐	☐	☐	☐	☐
HJEMMELAGET GRØT:							
Grovt/sammalt mel/havregryn	☐	☐	☐	☐	☐	☐	☐
Hirse	☐	☐	☐	☐	☐	☐	☐
Fint/hvitt mel/kavring/semule/ris/mais	☐	☐	☐	☐	☐	☐	☐

18. Dersom barnet får grøt, hva slags væske tilsettes vanligvis grøten ved tilberedning/koking?
Hvis det vanligvis brukes mer enn én type væske, settes flere kryss.

- ☐ Vann
- ☐ Morsmelk
- ☐ Morsmelkerstatning
- ☐ Kumelk
- ☐ Annet

19. Dersom barnet får grøt, hvor store porsjoner spiser barnet vanligvis til hvert måltid?
*Se mengdeangivelse på bilde 3 bakerst i spørreskjemaet. Velg mengde A, B, C, D, E eller F. Sett kryss i ruten som er nærmest den mengden barnet vanligvis spiser pr. gang. Hvis mengden varierer mye fra gang til gang, prøv å anslå en gjennomsnittsmengde. Sett **kun** ett kryss for hver grøttype.*

	Bruker ikke	Noen ts (Bilde A)	0,5 dl (Bilde B)	1 dl (Bilde C)	1,5 dl (Bilde D)	2 dl (Bilde E)	2,5 dl (Bilde F)
Industrifremstilt grøt (inkludert grøt på klemmepose)	☐	☐	☐	☐	☐	☐	☐
Hjemmelaget grøt	☐	☐	☐	☐	☐	☐	☐

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20. Hvor ofte pleier barnet å spise følgende mat nå?
*Sett **kun** ett kryss for hver matvare, enten ganger pr. uke eller ganger pr. døgn.*

		Ganger pr. uke		*eller* Ganger pr. døgn			
INDUSTRIFREMSTILT MIDDAG PÅ GLASS/KLEMMEPOSE:	Aldri/sjeldnere enn hver uke	1-3	4-6	1	2	3	4 el. flere
Potet/grønnsaker	☐	☐	☐	☐	☐	☐	☐
Kjøtt og grønnsaker	☐	☐	☐	☐	☐	☐	☐
Fisk og grønnsaker	☐	☐	☐	☐	☐	☐	☐
HJEMMELAGET MIDDAG:							
Potet/grønnsaker	☐	☐	☐	☐	☐	☐	☐
Kjøtt og grønnsaker	☐	☐	☐	☐	☐	☐	☐
Fisk og grønnsaker	☐	☐	☐	☐	☐	☐	☐
Annen hjemmelaget middag	☐	☐	☐	☐	☐	☐	☐
INDUSTRIFREMSTILT FRUKT-/BÆR-/GRØNNSAKSMOS PÅ GLASS/KLEMMEPOSE:							
Smoothie/frukt-/bærmos, kun frukt/bær	☐	☐	☐	☐	☐	☐	☐
Smoothie/frukt-/bærmos med korn	☐	☐	☐	☐	☐	☐	☐
Smoothie/frukt-/bærmos med yoghurt, med/uten korn	☐	☐	☐	☐	☐	☐	☐
Frukt- og grønnsaksmos	☐	☐	☐	☐	☐	☐	☐
HJEMMELAGET FRUKT-/BÆR-/GRØNNSAKSMOS:							
Hjemmelaget smoothie/frukt-/bærmos	☐	☐	☐	☐	☐	☐	☐
Hjemmelaget frukt- og grønnsaksmos	☐	☐	☐	☐	☐	☐	☐
ANNEN MAT:							
Brød	☐	☐	☐	☐	☐	☐	☐
Yoghurt	☐	☐	☐	☐	☐	☐	☐
Is	☐	☐	☐	☐	☐	☐	☐
Kjeks/kaker	☐	☐	☐	☐	☐	☐	☐
Riskaker	☐	☐	☐	☐	☐	☐	☐
Spinat	☐	☐	☐	☐	☐	☐	☐

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24. Hva var viktigste og nest viktigste grunn til at barnet begynte med fast føde?
Med fast føde menes alle andre matvarer enn vann/melk/saft/juice/annen drikke og kosttilskudd.
Fast føde inkluderer velling selv om det er tyntflytende.
*Sett **kun** ett kryss for viktigste grunn og **kun** ett kryss for nest viktigste grunn.*

	Viktigste grunn	Nest viktigste grunn
Barnet var gammelt nok til å begynne med fast føde	☐	☐
Barnet virket sultent	☐	☐
Barnet viste tydelig interesse for fast føde	☐	☐
Ingen spesiell grunn, men ønsket å gi barnet fast føde	☐	☐
Ønsket å venne barnet til nye konsistenser og smaker	☐	☐
Ønsket å forebygge utvikling av allergiske sykdommer	☐	☐
Fikk råd av lege, helsesøster eller annet helsepersonell om å starte med fast føde	☐	☐
Fikk råd av venner/familie om å starte med fast føde	☐	☐
Håpet at barnet ville sove bedre om natten	☐	☐
Mor begynte å arbeide/studere	☐	☐
Hadde for lite morsmelk	☐	☐
Barnet hadde ikke tilstrekkelig vektøkning	☐	☐
Mor var syk/medisinbruk	☐	☐
Barnet har en medisinsk tilstand som gjorde at det var gunstig å starte med fast føde	☐	☐
Andre grunner, vennligst spesifiser:	☐	☐

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SPØRSMÅL OM VANN, SAFT, JUICE O.L.

25. Har barnet begynt å få vann, saft, juice o.l?
*Sett **kun** ett kryss.*

☐ Ja

☐ Nei ⇨ *Gå til spørsmål 29*

26. Hvor ofte pleier barnet å drikke vann, saft, juice o.l., og hvor mye drikker barnet vanligvis pr. gang?
Se mengdeangivelse på bilde 2 bakerst i spørreskjemaet. Velg mengde A, B, C eller D. Sett kryss i ruten som er nærmest den mengden barnet vanligvis drikker pr. gang. Hvis mengden varierer mye fra gang til gang, prøv å anslå en gjennomsnittsmengde. 100 ml = 1 dl.

*For hver drikk settes **kun** ett kryss for **hvor ofte,** enten ganger pr. uke eller ganger pr. døgn. I tillegg settes **kun** ett kryss for **hvor mye** barnet vanligvis drikker pr. gang.*

	Hvor ofte?								Hvor mye?			
		Ganger pr. uke		*eller* Ganger pr. døgn					Mengde (ml) pr. gang			
	Aldri/sjeldnere enn hver uke	1-3	4-6	1	2	3	4	5 el. flere	30 A	60 B	120 C	180 D
Vann	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Barnedrikk (Nestlé, HiPP o.l.)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Saft, sukret	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Saft, kunstig søtet	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Brus, sukret	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Brus, kunstig søtet	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Juice	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Nektar (eplenektar o.l.)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

27. Dersom barnet får vann nå, hvor gammelt var barnet da det begynte å få dette?
*Sett **kun** ett kryss.*

Ikke fått	Uker							Måneder								
	1	2	3	4	5	6	7	2	2,5	3	3,5	4	4,5	5	5,5	6
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

28. Dersom barnet får saft, juice o.l. nå, hvor gammelt var barnet da det begynte å få dette? *Sett **kun** ett kryss.*

Ikke fått	Uker							Måneder								
	1	2	3	4	5	6	7	2	2,5	3	3,5	4	4,5	5	5,5	6
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

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ANDRE SPØRSMÅL OM BARNETS KOSTHOLD

29. Er det noen matvarer det kunne være aktuelt å gi barnet, men som du unngår å gi fordi du er redd barnet kan reagere med allergi/intoleranse?
*Sett **kun** ett kryss.*

- ☐ Ja
- ☐ Nei ⇨ *Gå til spørsmål 31*

30. Hvilke matvarer/ingredienser i matvarer unngår du å gi barnet?
Her kan du sette flere kryss.

- ☐ Glutenholdig mel/korn (hvete, rug og bygg)
- ☐ Vanlig kumelk
- ☐ Morsmelkerstatning
- ☐ Appelsin/appelsinjuice/annen sitrusfrukt
- ☐ Fisk/skalldyr
- ☐ Nøtter/nøtteprodukter (peanøttsmør o.l.)
- ☐ Belgfrukter (erter, bønner o.l.)
- ☐ Egg
- ☐ Soya
- ☐ Matvarer med tilsetningsstoffer
- ☐ Annet

31. Har barnet hatt problemer i forbindelse med spising/mat?
Her kan du sette flere kryss.

- ☐ Nei, har ikke hatt noen problemer
- ☐ Ja, dårlig matlyst
- ☐ Ja, problemer med svelging/suging
- ☐ Ja, allergi/intoleranse mot enkelte matvarer
- ☐ Ja, andre problemer

Oppgi hvilke:

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SPØRSMÅL OM KOSTTILSKUDD

32. Får barnet vitamin D-tilskudd (som vitamin D-dråper/tran) eller annet kosttilskudd nå?
*Sett **kun** ett kryss.*

- ☐ Ja
- ☐ Nei, men barnet har fått vitamin D-tilskudd/kosttilskudd tidligere ⇨ *Gå til spørsmål 34*
- ☐ Nei, barnet har aldri fått vitamin D-tilskudd/kosttilskudd ⇨ *Gå til spørsmål 35*

33. Hvor ofte får barnet vanligvis vitamin D-tilskudd eller annet kosttilskudd, og hvor mye får barnet pr. gang?
*For hvert kosttilskudd settes **kun** ett kryss for **hvor ofte,** enten ganger pr. uke eller ganger pr. døgn. I tillegg settes **kun** ett kryss for **hvor mye** barnet vanligvis får pr. gang.*

Det er satt opp to mengder for en teskje; 3 ml (liten teskje) og 5 ml (stor teskje).

	Hvor ofte?					Hvor mye?					
		Ganger pr. uke		*eller* Ganger pr. døgn		Mengde pr. gang					
	Aldri/sjeldnere enn hver uke	1-3	4-6	1	2 el. flere						
Tran	☐	☐	☐	☐	☐	1 ts (3 ml) ☐	1 ts (5 ml) ☐	1 bs (7 ml) ☐	1 ss (10 ml) ☐		
Vitamin D-dråper	☐	☐	☐	☐	☐	3 dråper ☐	5 dråper ☐				
Flytende multivitaminer (Sana-sol, Biovit, Nycoplus multi vitaminmikstur o.l.)	☐	☐	☐	☐	☐	1 ts (3 ml) ☐	1 ts (5 ml) ☐	1 bs (7 ml) ☐	1 ss (10 ml) ☐		
Joddråper	☐	☐	☐	☐	☐	1/2 dråpe ☐	1 dråpe ☐	2 dråper ☐			
Tang-/taremel	☐	☐	☐	☐	☐	1/4 knivsodd ☐	1/2 knivsodd ☐	3/4 knivsodd ☐	1 knivsodd ☐		
Annet kosttilskudd	☐	☐	☐	☐	☐	1 ts (3 ml) ☐	1 ts (5 ml) ☐	1 bs (7 ml) ☐	1 ss (10 ml) ☐	3 dråper ☐	5 dråper ☐

Oppgi hvilke:

☐

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34. Hvor gammelt var barnet da det første gang fikk vitamin D-tilskudd?
*Sett **kun** ett kryss.*

	Uker							Måneder									
Ikke fått	1	2	3	4	5	6	7	2	2,5	3	3,5	4	4,5	5	5,5	6
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

BAKGRUNNSSPØRSMÅL OM BARNETS MOR OG FAR

35. Hva er mors alder?
Skriv inn mors alder.

☐☐ År

36. Hvilken utdannelse har barnets mor og far?
*Sett **kun** ett kryss for høyeste fullførte utdannelse hos mor og **kun** ett kryss for høyeste fullførte utdannelse hos far.*

	Barnets mor	Barnets far
9/10-årig grunnskole eller kortere	☐	☐
9/10-årig grunnskole *og* folkehøgskole eller annen ett-årig utdanning	☐	☐
Videregående opplæring (videregående skole/gymnas/fagbrev/svennebrev)	☐	☐
Fagskole	☐	☐
Høgskole- eller universitetsutdanning på 4 år eller mindre	☐	☐
Høgskole- eller universitetsutdanning på mer enn 4 år	☐	☐
Annet	☐	☐
Vet ikke	☐	☐

37. Hvordan var mors arbeidssituasjon før barnet ble født?
Sykemeldinger i forbindelse med svangerskapet skal ikke regnes med. Dersom flere alternativer passer, kryss av for det alternativet som passer best.
*Sett **kun** ett kryss.*

- ☐ Inntektsgivende arbeid heltid
- ☐ Inntektsgivende arbeid deltid
- ☐ Sykemeldt før hun ble gravid
- ☐ Permisjon
- ☐ Ufør
- ☐ Under arbeidsavklaring
- ☐ Hjemmearbeidende
- ☐ Student/skoleelev
- ☐ Arbeidsledig
- ☐ Annet

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38. **Har mor et vegetarisk kosthold?**
*Sett **kun** ett kryss.*

- ☐ Nei
- ☐ Ja, mor er vegetarianer og inkluderer melkeprodukter og egg i kosten (ovolakto-vegetarianer)
- ☐ Ja, mor er vegetarianer og inkluderer melkeprodukter, men ikke egg i kosten (lakto-vegetarianer)
- ☐ Ja, mor er vegetarianer og utelater alle melkeprodukter og egg fra kosten (veganer)

39. **Hvordan er mors familiesituasjon?**
*Sett **kun** ett kryss.*

- ☐ Samboer
- ☐ Gift
- ☐ Bor alene med barnet/barna
- ☐ Annet

40. **Bruker mor, eller har mor brukt snus?**
*Sett **kun** ett kryss.*

- ☐ Nei
- ☐ Ja, men har sluttet
- ☐ Ja, av og til
- ☐ Ja, daglig

41. **Røykte mor i svangerskapet?**
*Sett **kun** ett kryss.*

- ☐ Nei
- ☐ Ja, men sluttet i 1. trimester (uke 1-12)
- ☐ Ja, men sluttet i 2. trimester (uke 13-24)
- ☐ Ja, men sluttet i 3. trimester (uke 25 frem til fødsel)
- ☐ Ja, av og til (ikke hver dag)
- ☐ Ja, 1-9 sigaretter pr. dag
- ☐ Ja, 10 sigaretter eller flere pr. dag

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42. **Røyker mor nå?**
*Sett **kun** ett kryss.*

- ☐ Nei
- ☐ Ja, av og til (ikke hver dag)
- ☐ Ja, 1-9 sigaretter pr. dag
- ☐ Ja, 10 sigaretter eller flere pr. dag

43. **Har barnets foreldre eller søsken astma/allergi, eller har de hatt slike plager tidligere?**
Her kan du sette flere kryss.

- ☐ Nei
- ☐ Mor har/har hatt astma/allergi
- ☐ Far har/har hatt astma/allergi
- ☐ Barnets søsken har/har hatt astma/allergi

44. **På et senere tidspunkt kan det bli aktuelt å knytte andre undersøkelser til Spedkoststudien. Kan vi kontakte deg igjen med forespørsel om å være med i denne typen undersøkelser?**

- ☐ Ja
- ☐ Nei

Tusen takk for at du tok deg tid til å besvare spørsmålene!

Spørreskjemaet postlegges i vedlagte svarkonvolutt.

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SPEDKOST

Undersøkelse av kostholdet blant spedbarn

Kryss av for "Ja" i ruten under dersom du samtykker i å delta i undersøkelsen. Dersom du ikke ønsker å delta og vil reservere deg mot å bli oppringt samt å bli purret på, krysser du av for "Nei" og returnerer skjemaet.

- ☐ Ja
- ☐ Nei

Ved utfylling er det viktig at du går frem slik:

* Sett kryss i boksene. Slik: ☒ Ikke slik: X☐
* Ved rettelser kan du markere tydelig at det er feil, slik: ■
* I de åpne feltene skriver du inn tydelig tekst
* Der det spørres etter tall, skriver du disse slik: 1 2 3 4 5 6 7 8 9
* Skjemaet må ikke brettes
* Det utfylte skjemaet vil bli lest av en maskin. **Bruk blå eller sort kulepenn**.

Fyll inn opplysninger om barnets vekt og lengde - ved fødsel og ved 12 måneders alder (fra helsekortet).

Dersom barnet ikke har vært på 12-månederskontrollen ennå, kan du la feltene for vekt og lengde ved 12 måneders alder stå åpne.

Fylles ut fra helsekortet

Dato for måling av vekt/lengde (12 mnd): ☐☐ dag ☐☐ mnd ☐☐☐☐ år

Barnets vekt (12 mnd): ☐☐☐☐☐ gram **Barnets lengde (12 mnd):** ☐☐☐ cm

Fødselsvekt: ☐☐☐☐ gram **Lengde ved fødsel:** ☐☐ cm

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BAKGRUNNSSPØRSMÅL

1. Dato for utfylling av skjemaet
Skriv inn datoen for dag, måned og år i rutene.

☐☐ ☐☐ ☐☐☐☐

dag mnd år

2. Hva er barnets kjønn?
*Sett **kun** ett kryss.*

- ☐ Jente
- ☐ Gutt

3. Hvem fyller ut skjemaet?
Her kan du sette flere kryss.

- ☐ Barnets mor
- ☐ Barnets far
- ☐ Barnets medmor

SPØRSMÅL OM MORSMELK

4. Får barnet morsmelk nå?
*Sett **kun** ett kryss.*

- ☐ Ja ⇨ *Gå til spørsmål 5 og deretter til spørsmål 8*
- ☐ Nei, men barnet har fått morsmelk tidligere ⇨ *Gå til spørsmål 6*
- ☐ Nei, barnet har aldri fått morsmelk ⇨ *Gå til spørsmål 7*

5. Hvor mange ganger i døgnet får barnet vanligvis morsmelk nå?
Regn også med de gangene barnet bare får morsmelk til trøst eller kos, dag- og nattetid.
*Sett **kun** ett kryss.*

- ☐ 1 gang
- ☐ 2-3 ganger
- ☐ 4-5 ganger
- ☐ 6-7 ganger
- ☐ 8-9 ganger
- ☐ 10 ganger eller flere

6. Hvor gammelt var barnet da det sluttet å få morsmelk?
*Sett **kun** ett kryss.*

Uker							Måneder										
1	2	3	4	5	6	7	2	3	4	5	6	7	8	9	10	11	12
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

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7. Hva var viktigste og nest viktigste grunn til at mor ikke ammet barnet eller har sluttet å amme det?

*Sett **kun** ett kryss for viktigste grunn og **kun** ett kryss for nest viktigste grunn.*

	Viktigste grunn	Nest viktigste grunn
Barnet ville ikke	☐	☐
Barnet biter/har fått tenner	☐	☐
Sugeproblemer	☐	☐
Barnet sykt/for tidlig født	☐	☐
Kolikk/urolig barn	☐	☐
For lite melk	☐	☐
Mor begynte å arbeide/å studere	☐	☐
Mor syk/medisinbruk	☐	☐
Bekymring/stress/sliten	☐	☐
Brystbetennelse	☐	☐
Tilstoppede melkeganger	☐	☐
Såre brystknopper	☐	☐
Brystoperert	☐	☐
Ble rådet til å slutte	☐	☐
Ingen spesielle problemer, men ønsket ikke å amme (lenger)	☐	☐
Andre grunner	☐	☐

Dersom mor ble rådet til å slutte å amme, hvem var det som rådet henne til det?
(f.eks. helsepersonell, familie, venner)

SPØRSMÅL OM MORSMELKERSTATNING/MELK

8. Hvor gammelt var barnet da det begynte med morsmelkerstatning/kumelk i tillegg til eller istedenfor morsmelk?

*Sett **kun** ett kryss for hver matvare.*

	Ikke fått	Barnets alder (måneder) 0-3	4	5	6	7	8	9	10	11	12
Morsmelkerstatning som drikke	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Morsmelkerstatning til grøt o.l.	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Kumelk som drikke	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Kumelk til grøt o.l.	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Kumelk i annen matlaging	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

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9. Hvor ofte og hvor mye morsmelkerstatning pleier barnet å drikke nå?

*For hver melketype settes **kun** ett kryss for **hvor ofte**, enten ganger pr. uke eller ganger pr. døgn. I tillegg settes **kun** ett kryss for **hvor mye** pr. gang. For mengdeangivelse se på bilde 1 i bildeboken. 100 ml = 1 dl.*

	Hvor ofte?								Hvor mye?			
		Ganger pr. uke	*eller*	Ganger pr. døgn					Mengde (ml) pr. gang			
	Aldri/sjeldnere enn hver uke	1-3	4-6	1	2	3	4	5 el. flere	60 A	120 B	180 C	240 D
NAN Pro 1 eller NAN Organic 1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
NAN Pro 2, NAN Organic 2, NAN Pro 3 eller NAN Pro 4	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
NAN H.A. 1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
HiPP Combiotic 1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
HiPP Combiotic 2 eller 3	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Semper Allomin 1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Semper Allomin 2	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Holle morsmelkerstatning 1	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Holle tilskuddsblanding 2 eller 3	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Annen morsmelkerstatning/ tilskuddsblanding	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

oppgi type: ____________________

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10. Hvor ofte og hvor mye melk pleier barnet å drikke nå?

*For hver melketype settes **kun** ett kryss for **hvor ofte**, enten ganger pr. uke eller ganger pr. døgn. I tillegg settes **kun** ett kryss for **hvor mye** pr. gang. For mengdeangivelse se på bilde 2 i bildeboken. 100 ml = 1 dl. Morsmelk regnes ikke med her.*

	Hvor ofte?								Hvor mye?			
		Ganger pr. uke	*eller*	Ganger pr. døgn					Mengde (ml) pr. gang			
	Aldri/sjeldnere enn hver uke	1-3	4-6	1	2	3	4	5 el. flere	30 A	60 B	120 C	180 D
Helmelk (søt og sur)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lettmelk (1.0 % og 1.2 % fett)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lettmelk (0.5 % fett, tidligere ekstra lett melk)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Skummetmelk (søt og sur)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Biola, Cultura o.l.	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sjokolademelk, O'boy, jordbærmelk o.l.	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Drikkeyoghurt (Danonino, Actimel o.l.)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Annen melk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

oppgi type: ☐

SPØRSMÅL OM FAST FØDE

11. Hvor gammelt var barnet da det første gang fikk fast føde?

Med fast føde menes alle andre matvarer enn melk/vann/saft/juice/annen drikke og kosttilskudd.
Fast føde inkluderer velling selv om denne er tyntflytende.
*Sett **kun** ett kryss.*

Uker							Måneder										
1	2	3	4	5	6	7	2	3	4	5	6	7	8	9	10	11	12
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

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12. Hvor gammelt var barnet da det fikk følgende matvarer for første gang?
*Sett **kun** ett kryss for hver matvare.*

	Ikke fått	Barnets alder (måneder) 0-3	4	5	6	7	8	9	10	11	12
Mais-/ris-/hirsegrøt	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Havre-/hvete-/bygg-/ kavringgrøt	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Frukt-/bærmos	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Poteter	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Grønnsaker	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Kjøtt	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fisk	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Brød	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Yoghurt	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Nøtter/nøtteprodukter (peanøttsmør o.l.)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

SPØRSMÅL OM YOGHURT

13. Hvor ofte og hvor mye yoghurt pleier barnet å spise nå?
*For hver yoghurttype settes **kun** ett kryss for **hvor ofte** og **kun** ett kryss for **hvor mye** barnet vanligvis spiser pr. gang.*

	Hvor ofte?						Hvor mye?				
		Ganger pr. uke		*eller* Ganger pr. dag			Mengde pr. gang				
	Aldri/sjeldnere enn hver uke	1-3	4-6	1	2	3 el. flere		¼	½	¾	1
Barnefruktyoghurt (Sprett, Safari, Danonino o.l.)	☐	☐	☐	☐	☐	☐	beger/ pose	☐	☐	☐	☐
Barnefruktyoghurt med topping (Q-meieriene o.l.)	☐	☐	☐	☐	☐	☐	beger	☐	☐	☐	☐
Fruktyoghurt (Tine, Q-meieriene o.l.)	☐	☐	☐	☐	☐	☐	beger/ pose	☐	☐	☐	☐
Go'morgen yoghurt	☐	☐	☐	☐	☐	☐	beger	☐	☐	☐	☐
Fruktyoghurt uten fett og sukker (Yoplait Double 0% o.l.)	☐	☐	☐	☐	☐	☐	beger	☐	☐	☐	☐
Yoghurt naturell, Biola yoghurt, gresk yoghurt naturell	☐	☐	☐	☐	☐	☐	ss	2 ☐	4 ☐	6 ☐	8 ☐
Skyr Mini (klemmepose)	☐	☐	☐	☐	☐	☐	pose	¼ ☐	½ ☐	¾ ☐	1 ☐

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21. Hvor mye smører du vanligvis på brød, knekkebrød o.l. til barnet?
Se mengdeangivelse på bilde 5 i bildeboken.
*Sett **kun** ett kryss.*

- ☐ Skrapet lag (Bilde A)
- ☐ Middels lag (Bilde B)
- ☐ Godt dekket lag (Bilde C)
- ☐ Tykt lag (Bilde D)

22. Hvilke påleggstyper pleier barnet å spise nå? (fortsetter også på neste side)
*For hver påleggstype settes **kun** ett kryss for antall brødskiver, knekkebrød o.l. pålegget brukes til i løpet av en uke. Ta utgangspunkt i sum brødskiver pr. uke fra spørsmål 18.*

		På antall skiver pr. uke							
	Aldri/sjeldnere enn hver uke	½ -1	2-3	4-5	6-7	8-14	15-21	22-28	29 el. flere
Brunost/prim	☐	☐	☐	☐	☐	☐	☐	☐	☐
Barnebrunost/barneprim	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lett/mager brunost/prim	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hvitost	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lett/mager hvitost	☐	☐	☐	☐	☐	☐	☐	☐	☐
Smøreost	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lett/mager smøreost	☐	☐	☐	☐	☐	☐	☐	☐	☐
Leverpostei	☐	☐	☐	☐	☐	☐	☐	☐	☐
Mager leverpostei	☐	☐	☐	☐	☐	☐	☐	☐	☐
Kyllingpostei	☐	☐	☐	☐	☐	☐	☐	☐	☐
Servelat	☐	☐	☐	☐	☐	☐	☐	☐	☐
Kokt skinke, lettservelat o.l.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Kylling/kalkunpålegg	☐	☐	☐	☐	☐	☐	☐	☐	☐
Salami, fårepølse o.l.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Svolværpostei, Lofotpostei	☐	☐	☐	☐	☐	☐	☐	☐	☐
Makrell i tomat o.l.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Kaviar	☐	☐	☐	☐	☐	☐	☐	☐	☐
Egg (kokt, stekt, eggerøre)	☐	☐	☐	☐	☐	☐	☐	☐	☐

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22. Hvilke påleggstyper pleier barnet å spise nå?
*For hver påleggstype settes **kun** ett kryss for antall brødskiver i løpet av en uke.*
Ta utgangspunkt i sum brødskiver pr. uke fra spørsmål 18.

	Aldri/sjeldnere enn hver uke	På antall skiver pr. uke: ½ -1	2-3	4-5	6-7	8-14	15-21	22-28	29 el. flere
Syltetøy, marmelade	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lett syltetøy/syltetøy med mindre sukker	☐	☐	☐	☐	☐	☐	☐	☐	☐
Honning	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hapå	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sjokolade-, nøttepålegg o.l.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sjokoladepålegg med mindre sukker	☐	☐	☐	☐	☐	☐	☐	☐	☐
Annet søtt pålegg (Banos, Sunda o.l.)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Peanøttsmør o.l.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Salat med majones (rekesalat o.l.)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Frukt som pålegg (banan o.l.)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Grønnsaker som pålegg	☐	☐	☐	☐	☐	☐	☐	☐	☐
Annet pålegg	☐	☐	☐	☐	☐	☐	☐	☐	☐

oppgi type: ____________________

SPØRSMÅL OM MIDDAGSMAT (UTENOM INDUSTRIFREMSTILT BARNEMAT)

23. Hvor ofte og hvor mye middagsmat pleier barnet å spise nå? (fortsetter også på neste side) *For hver type middagsmat settes **kun** ett kryss for **hvor ofte** og **kun** ett kryss for **hvor mye** pr. gang. Industrifremstilt barnemat på glass/pose regnes ikke med her. Spørsmål om grønnsaker og tilbehør som poteter, ris og pasta kommer senere i skjemaet.*

Kjøtt og kjøttretter:	Aldri/sjeldnere enn hver måned	Hvor ofte? Ganger pr. mnd: 1	2	3	*eller* Ganger pr. uke: 1	2	3 el. flere	Hvor mye? Mengde pr. gang	A	B	C	D
Grill-, wiener-, kjøttpølser o.l. av storfe- og svinekjøtt	☐	☐	☐	☐	☐	☐	☐	bilde 7	☐	☐	☐	☐
Grill-, wiener-, kjøttpølser o.l. av kylling/kalkun	☐	☐	☐	☐	☐	☐	☐	bilde 7	☐	☐	☐	☐
Magre grill-, wiener-, kjøttpølser o.l.	☐	☐	☐	☐	☐	☐	☐	bilde 7	☐	☐	☐	☐
Kjøttkaker, medisterkaker, kjøttpudding, kjøttboller av storfe/svin o.l.	☐	☐	☐	☐	☐	☐	☐	bilde 8	☐	☐	☐	☐
Kjøttkaker, karbonader, kjøttboller av kylling/kalkun	☐	☐	☐	☐	☐	☐	☐	bilde 8	☐	☐	☐	☐
Hamburgere, karbonader av storfe/svin o.l.	☐	☐	☐	☐	☐	☐	☐	stk.	½ ☐	1 ☐	1½ ☐	2 ☐

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23. Hvor ofte og hvor mye middagsmat pleier barnet å spise nå?

*For hver type middagsmat settes **kun** ett kryss for **hvor ofte** og **kun** ett kryss for **hvor mye** pr. gang. Industrifremstilt barnemat på glass/pose regnes ikke med her. Spørsmål om grønnsaker og tilbehør som poteter, ris og pasta kommer senere i skjemaet.*

	Hvor ofte?							Hvor mye?				
		Ganger pr. mnd			*eller* Ganger pr. uke			Mengde pr. gang				
Kjøtt og kjøttretter:	Aldri/sjeldnere enn hver måned	1	2	3	1	2	3 el. flere					
Kjøttsaus/kjøttretter av kjøttdeig	☐	☐	☐	☐	☐	☐	☐	bilde 6	A ☐	B ☐	C ☐	D ☐
Kjøttsaus/kjøttretter av karbonadedeig/svinekjøttdeig	☐	☐	☐	☐	☐	☐	☐	bilde 6	A ☐	B ☐	C ☐	D ☐
Kjøttsaus/kjøttretter av kylling/kalkunkjøttdeig	☐	☐	☐	☐	☐	☐	☐	bilde 6	A ☐	B ☐	C ☐	D ☐
Kjøtt av okse, lam, svin o.l.	☐	☐	☐	☐	☐	☐	☐	bilde 6	A ☐	B ☐	C ☐	D ☐
Kylling, høne, kalkun	☐	☐	☐	☐	☐	☐	☐	bilde 6	A ☐	B ☐	C ☐	D ☐
Gryte med helt kjøtt fra okse, lam, svin o.l.	☐	☐	☐	☐	☐	☐	☐	bilde 6	A ☐	B ☐	C ☐	D ☐
Gryte med kylling/kalkun	☐	☐	☐	☐	☐	☐	☐	bilde 6	A ☐	B ☐	C ☐	D ☐
Taco (fylte lefser)	☐	☐	☐	☐	☐	☐	☐	liten lefse	¼ ☐	½ ☐	¾ ☐	1 ☐
Fisk og fiskemat:												
Fiskeboller, fiskepudding o.l.	☐	☐	☐	☐	☐	☐	☐	stk./ skive	½ ☐	1 ☐	2 ☐	3 ☐
Fiskegrateng	☐	☐	☐	☐	☐	☐	☐	bilde 11	A ☐	B ☐	C ☐	D ☐
Fiskekaker	☐	☐	☐	☐	☐	☐	☐	stk.	½ ☐	1 ☐	2 ☐	3 ☐
Fiskepinner, panert fisk o.l.	☐	☐	☐	☐	☐	☐	☐	stk.	1 ☐	2 ☐	3 ☐	4 ☐
Fiskegryte/suppe	☐	☐	☐	☐	☐	☐	☐	bilde 10	A ☐	B ☐	C ☐	D ☐
Torsk, sei, annen hvit fisk	☐	☐	☐	☐	☐	☐	☐	bilde 9	A ☐	B ☐	C ☐	D ☐
Ørret, laks, makrell, sild	☐	☐	☐	☐	☐	☐	☐	bilde 9	A ☐	B ☐	C ☐	D ☐
Annen middagsmat:												
Tomatsuppe, annen suppe	☐	☐	☐	☐	☐	☐	☐	bilde 10	A ☐	B ☐	C ☐	D ☐
Pannekaker	☐	☐	☐	☐	☐	☐	☐	stk.	½ ☐	1 ☐	2 ☐	3 ☐
Risgrøt	☐	☐	☐	☐	☐	☐	☐	bilde 12	A ☐	B ☐	C ☐	D ☐
Pizza (1 bit = 1/8 Pizza Grandiosa)	☐	☐	☐	☐	☐	☐	☐	bit	½ ☐	1 ☐	1½ ☐	2 ☐
Omelett	☐	☐	☐	☐	☐	☐	☐	av antall egg	½ ☐	1 ☐	1½ ☐	2 ☐
Vegetarrett (linsegryte, bønnegryte o.l.)	☐	☐	☐	☐	☐	☐	☐	bilde 6	A ☐	B ☐	C ☐	D ☐

Annen middagsmat, oppgi type:

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24. Hvor ofte og hvor mye poteter, ris, pasta, grønnsaker og saus pleier barnet å spise nå?
*For hver matvaretype settes **kun** ett kryss for **hvor ofte** og **kun** ett kryss for **hvor mye** pr. gang. Her regnes både det som spises til middag og eventuelt til andre måltider i løpet av dagen. Industrifremstilt barnemat på glass/pose regnes ikke med her.*

	Hvor ofte?					Hvor mye?				
		Ganger pr. uke	*eller*	Ganger pr. dag		Mengde pr. gang				
Poteter, ris, pasta:	Aldri/sjeldnere enn hver uke	1-3	4-6	1	2 el. flere					
Poteter, kokt/most	☐	☐	☐	☐	☐	bilde 11	☐ A	☐ B	☐ C	☐ D
Pommes frites, stekte poteter	☐	☐	☐	☐	☐	stav/båt	☐ 1	☐ 2	☐ 4	☐ 6
Ris	☐	☐	☐	☐	☐	bilde 12	☐ A	☐ B	☐ C	☐ D
Pasta/nudler	☐	☐	☐	☐	☐	bilde 12	☐ A	☐ B	☐ C	☐ D
Fullkornspasta	☐	☐	☐	☐	☐	bilde 12	☐ A	☐ B	☐ C	☐ D
Hamburger-, pølsebrød, lomper	☐	☐	☐	☐	☐	stk.	☐ ½	☐ 1	☐ 1½	☐ 2
Saus og annet:										
Brun saus, hvit saus	☐	☐	☐	☐	☐	ss	☐ 1	☐ 2	☐ 3	☐ 4
Smeltet margarin, smør	☐	☐	☐	☐	☐	ss	☐ 1	☐ 2	☐ 3	☐ 4
Ketchup	☐	☐	☐	☐	☐	ss	☐ ½	☐ 1	☐ 1½	☐ 2
Grønnsaker (rå, kokte, moset):										
Gulrot	☐	☐	☐	☐	☐	bilde 13	☐ A	☐ B	☐ C	☐ D
Kålrot	☐	☐	☐	☐	☐	bilde 13	☐ A	☐ B	☐ C	☐ D
Blomkål, brokkoli	☐	☐	☐	☐	☐	bilde 13	☐ A	☐ B	☐ C	☐ D
Frossen grønnsaksblanding	☐	☐	☐	☐	☐	bilde 14	☐ A	☐ B	☐ C	☐ D
Råkost	☐	☐	☐	☐	☐	bilde 15	☐ A	☐ B	☐ C	☐ D
Spinat	☐	☐	☐	☐	☐	ss	☐ 1	☐ 2	☐ 3	☐ 4
Agurk	☐	☐	☐	☐	☐	skiver	☐ 2	☐ 4	☐ 6	☐ 8
Tomat (¼ tomat = 1 cherrytomat)	☐	☐	☐	☐	☐	stk.	☐ ¼	☐ ½	☐ ¾	☐ 1
Erter	☐	☐	☐	☐	☐	ss	☐ 1	☐ 2	☐ 3	☐ 4
Bønner, linser o.l.	☐	☐	☐	☐	☐	ss	☐ 1	☐ 2	☐ 3	☐ 4
Mais	☐	☐	☐	☐	☐	ss	☐ 1	☐ 2	☐ 3	☐ 4
Paprika	☐	☐	☐	☐	☐	ringer	☐ ½	☐ 1	☐ 2	☐ 3
Avokado (1 bit = 1/8 avokado)	☐	☐	☐	☐	☐	bit	☐ 1	☐ 2	☐ 3	☐ 4
Andre grønnsaker	☐	☐	☐	☐	☐					

oppgi type: ____________________

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25. Hvilken type fett bruker du vanligvis til matlaging (sauser, steking o.l.)?
Her kan du sette flere kryss.

- ☐ Bruker ikke
- ☐ Smør (meierismør o.l.)
- ☐ Bremykt
- ☐ Melange
- ☐ Soft Flora, Vita
- ☐ Olivero
- ☐ Flytende margarin på flaske (Vita, Melange, Bremykt o.l.)
- ☐ Margarin fra Rema 1000, First Price, Coop o.l.
- ☐ Annen margarin
- ☐ Rapsolje
- ☐ Olivenolje
- ☐ Andre oljer (solsikke, soya, mais o.l.)

SPØRSMÅL OM INDUSTRIFREMSTILT BARNEMAT PÅ GLASS/POSE

26. Dersom barnet får industrifremstilt barnemat på glass/pose, hvor ofte og hvor mye pleier det å spise?
*For hver type industrifremstilt barnemat på glass/pose settes **kun** ett kryss for **hvor ofte** og **kun** ett kryss for **hvor mye** pr. gang. For mengdeangivelser se på bilde 16 og 17 i bildeboken. 1 klemmepose = mengde B.*

	Hvor ofte?							Hvor mye?			
		Ganger pr. uke		*eller*	Ganger pr. dag			Mengde (glass) pr. gang			
	Aldri/sjeldnere enn hver uke	1-3	4-6	1	2	3 el. flere		¼ A	½ B	¾ C	1 D
Potet/grønnsaker (uten kjøtt og fisk)	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
Pasta/ris og grønnsaker (uten kjøtt)	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
Pasta/ris, grønnsaker og kylling/kalkun	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
Pasta/ris, grønnsaker og kjøtt av okse, lam, svin o.l.	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
Grønnsaker og kjøtt av okse, lam, svin o.l.	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
Grønnsaker og fisk	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
Industrifremstilt frukt-/bær-/grønnsaksmos:								¼ A	½ B	¾ C	1 D
Smoothie/frukt-/bærmos, <u>kun</u> frukt/bær	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
Smoothie/frukt-/bærmos med korn	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
Smoothie/frukt-/bærmos med yoghurt, med/uten korn	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐
Frukt- og grønnsaksmos	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐

Dersom barnet får andre typer barnemat på glass/pose, oppgi type:

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SPØRSMÅL OM IS, KAKER, KJEKS, GODTERIER O.L.

27. Hvor ofte og hvor mye is, kaker, kjeks, godterier o.l. pleier barnet å spise nå?
*For hver matvaretype settes **kun** ett kryss for **hvor ofte** og **kun** ett kryss for **hvor mye** pr. gang.*

	Hvor ofte?							Hvor mye?				
		Ganger pr. mnd	***eller*** **Ganger pr. uke**					**Mengde pr. gang**				
	Aldri/sjeldnere enn hver måned	1-3	1	2	3	4	5 el. flere					
Is - fløteis (1 pinne = mengde C)	☐	☐	☐	☐	☐	☐	☐	bilde 18	A ☐	B ☐	C ☐	D ☐
Is - saftis	☐	☐	☐	☐	☐	☐	☐	pinne	½ ☐	1 ☐		
Puddinger, gelé, fromasj	☐	☐	☐	☐	☐	☐	☐	bilde 18	A ☐	B ☐	C ☐	D ☐
Boller, skolebrød o.l.	☐	☐	☐	☐	☐	☐	☐	stk.	¼ ☐	½ ☐	1 ☐	2 ☐
Kaker (sjokoladekake, formkake, muffins o.l.)	☐	☐	☐	☐	☐	☐	☐	stk.	¼ ☐	½ ☐	1 ☐	2 ☐
Vafler	☐	☐	☐	☐	☐	☐	☐	plate	¼ ☐	½ ☐	1 ☐	1½ ☐
Barnekjeks (HiPP, Holle o.l)	☐	☐	☐	☐	☐	☐	☐	stk.	1 ☐	2 ☐	3 ☐	4 ☐
Andre barnekjeks (Tom & Jerry, Eventyrkjeks, Bokstavkjeks o.l.)	☐	☐	☐	☐	☐	☐	☐	stk.	1 ☐	2 ☐	3 ☐	4 ☐
Søte kjeks (Mariekjeks, fylte kjeks o.l.)	☐	☐	☐	☐	☐	☐	☐	stk.	½ ☐	1 ☐	2 ☐	3 ☐
Smørbrødkjeks (Kornmo, Kaptein, Ritz o.l.)	☐	☐	☐	☐	☐	☐	☐	stk.	½ ☐	1 ☐	2 ☐	3 ☐
Riskaker	☐	☐	☐	☐	☐	☐	☐	stk.	¼ ☐	½ ☐	1 ☐	2 ☐
Müslibar (Bixit, Mellombar, Go'morgen o.l.)	☐	☐	☐	☐	☐	☐	☐	stk.	¼ ☐	½ ☐	¾ ☐	1 ☐
Sjokolade	☐	☐	☐	☐	☐	☐	☐	bit	2 ☐	4 ☐	6 ☐	8 ☐
Smågodt, seigmenn, drops o.l.	☐	☐	☐	☐	☐	☐	☐	stk.	2 ☐	4 ☐	6 ☐	8 ☐
Snacks (potetgull, popcorn, ostepop o.l.)	☐	☐	☐	☐	☐	☐	☐	dl	½ ☐	1 ☐	1½ ☐	2 ☐
Barnemaissnacks (Skumpinner, Maismums o.l.)	☐	☐	☐	☐	☐	☐	☐	stk.	2 ☐	4 ☐	6 ☐	8 ☐

Dersom barnet får andre typer is, kaker, kjeks, godterier o.l., oppgi type:

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SPØRSMÅL OM KOSTTILSKUDD

36. Får barnet vitamin D-tilskudd (som vitamin D-dråper/tran) eller annet kosttilskudd nå?
*Sett **kun** ett kryss.*

- ☐ Ja
- ☐ Nei, men barnet har fått vitamin D-tilskudd/kosttilskudd tidligere ⇨ *Gå til spørsmål 38*
- ☐ Nei, barnet har aldri fått vitamin D-tilskudd/kosttilskudd ⇨ *Gå til spørsmål 38*

37. Hvor ofte og hvor mye vitamin D-tilskudd eller annet kosttilskudd pleier barnet å få nå?
*For hver type kosttilskudd settes **kun** ett kryss for **hvor ofte** og **kun** ett kryss for **hvor mye** pr. gang.*
Det er satt opp to mengder for en teskje: 3 ml (liten teskje) og 5 ml (stor teskje).

	Hvor ofte?					Hvor mye?
		Ganger pr. uke		***eller*** **Ganger pr. dag**		**Mengde pr. gang**
	Aldri/sjeldnere enn hver uke	1-3	4-6	1	2 el. flere	
Multivitamin-tabletter for barn (Nycoplus Multi Barn o.l.)	☐	☐	☐	☐	☐	1 stk ☐ 2 stk ☐
Kalsium/kalktabletter	☐	☐	☐	☐	☐	1 stk ☐ 2 stk ☐ 3 stk ☐
Vitamin C	☐	☐	☐	☐	☐	1 stk ☐ 2 stk ☐
Tyggetablett med omega 3 (Nycoplus geleputer o.l.)	☐	☐	☐	☐	☐	1 stk ☐ 2 stk ☐
Vitamin D-dråper	☐	☐	☐	☐	☐	3 dråper ☐ 5 dråper ☐
Tran	☐	☐	☐	☐	☐	1 ts 3 ml ☐ 1 ts 5 ml ☐ 1 bs 7 ml ☐ 1 ss 10 ml ☐
Flytende multivitaminer (Sana-sol, Biovit og Nycoplus Multi Vitaminmikstur o.l.)	☐	☐	☐	☐	☐	1 ts 3 ml ☐ 1 ts 5 ml ☐ 1 bs 7 ml ☐ 1 ss 10 ml ☐
Jern	☐	☐	☐	☐	☐	1 ts 3 ml ☐ 1 ts 5 ml ☐ 1 bs 7 ml ☐ 1 ss 10 ml ☐ 1 tablett ☐ 2 tabletter ☐
Joddråper	☐	☐	☐	☐	☐	1/2 dråpe ☐ 1 dråpe ☐ 2 dråper ☐
Tang-/taremel (pulver, tabletter o.l.)	☐	☐	☐	☐	☐	knivsodd: 1/4 ☐ 1/2 ☐ 3/4 ☐ 1 ☐ 1 tablett ☐ 2 tabletter ☐
Annet kosttilskudd	☐	☐	☐	☐	☐	1 ts 3 ml ☐ 1 ts 5 ml ☐ 1 bs 7 ml ☐ 1 ss 10 ml ☐ 1 tablett ☐ 2 tabletter ☐

oppgi type: ____________________

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BAKGRUNNSSPØRSMÅL OM BARNET

38. Når ble barnet født i forhold til ultralydstermin?
*Sett **kun** ett kryss.*

- ☐ I 38. svangerskapsuke eller senere
- ☐ Før 38. svangerskapsuke

39. Hvem har tilsyn med/passer barnet vanligvis på dagtid (hverdager)?
Her kan du sette flere kryss.

- ☐ Mor
- ☐ Far
- ☐ Medmor
- ☐ Dagmamma
- ☐ Barnehage
- ☐ Besteforeldre eller annen omsorgsperson

BAKGRUNNSSPØRSMÅL OM BARNETS MOR OG FAR

40. Hva er mors alder?
Skriv inn mors alder.

☐☐ År

41. Hvor mange barn har mor født?
*Sett **kun** ett kryss.*

- ☐ 1 barn
- ☐ 2 barn
- ☐ 3 barn
- ☐ 4 barn eller flere

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42. Hvilken utdannelse har barnets mor og far/medmor?
*Sett **kun** ett kryss for høyeste fullførte utdannelse hos mor og **kun** ett kryss for høyeste fullførte utdannelse hos far/medmor.*

	Barnets mor	Barnets far/ medmor
9/10-årig grunnskole eller kortere	☐	☐
9/10-årig grunnskole *og* folkehøgskole eller annen ett-årig utdanning	☐	☐
Videregående opplæring (videregående skole/gymnas/fagbrev/svennebrev)	☐	☐
Fagskole	☐	☐
Høgskole- eller universitetsutdanning på 4 år eller mindre	☐	☐
Høgskole- eller universitetsutdanning på mer enn 4 år	☐	☐
Annet	☐	☐
Vet ikke	☐	☐

43. Hvordan var mors arbeidssituasjon før barnet ble født og hvordan er arbeidssituasjonen hennes nå?
Sykemeldinger i forbindelse med svangerskapet skal ikke regnes med. Dersom flere alternativer passer, kryss av for det alternativet som passer best.
*Sett **kun** ett kryss for arbeidssituasjon før fødsel og **kun** ett kryss for arbeidssituasjon nå.*

	Før	Nå
Inntektsgivende arbeid heltid	☐	☐
Inntektsgivende arbeid deltid	☐	☐
Sykemeldt	☐	☐
Permisjon	☐	☐
Ufør	☐	☐
Under arbeidsavklaring	☐	☐
Hjemmearbeidende	☐	☐
Student/skoleelev	☐	☐
Arbeidsledig	☐	☐
Annet	☐	☐

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44. Har mor et vegetarisk kosthold?
*Sett **kun** ett kryss.*

- ☐ Nei
- ☐ Ja, mor er vegetarianer og inkluderer melkeprodukter og egg i kosten (ovolakto-vegetarianer)
- ☐ Ja, mor er vegetarianer og inkluderer melkeprodukter, men ikke egg i kosten (lakto-vegetarianer)
- ☐ Ja, mor er vegetarianer og utelater alle melkeprodukter og egg fra kosten (veganer)

45. Har barnet et vegetarisk kosthold?
*Sett **kun** ett kryss.*

- ☐ Nei
- ☐ Ja, barnet er vegetarianer og inkluderer melkeprodukter og egg i kosten (ovolakto-vegetarianer)
- ☐ Ja, barnet er vegetarianer og inkluderer melkeprodukter, men ikke egg i kosten (lakto-vegetarianer)
- ☐ Ja, barnet er vegetarianer og utelater alle melkeprodukter og egg fra kosten (veganer)

46. Hvordan er mors familiesituasjon?
*Sett **kun** ett kryss.*

- ☐ Samboer
- ☐ Gift
- ☐ Bor alene med barnet/barna
- ☐ Annet

47. Røyker mor nå?
*Sett **kun** ett kryss.*

- ☐ Nei
- ☐ Ja, av og til (ikke hver dag)
- ☐ Ja, 1-9 sigaretter pr. dag
- ☐ Ja, 10 sigaretter eller flere pr. dag

48. Bruker mor snus nå?
*Sett **kun** ett kryss.*

- ☐ Nei
- ☐ Ja, av og til
- ☐ Ja, daglig

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49. Har barnets foreldre eller søsken astma/allergi, eller har de hatt slike plager tidligere?
Her kan du sette flere kryss.

- ☐ Nei
- ☐ Mor har/har hatt astma/allergi
- ☐ Far har/har hatt astma/allergi
- ☐ Barnets søsken har/har hatt astma/allergi

50. På et senere tidspunkt kan det bli aktuelt å knytte andre undersøkelser til Spedkost-studien. Kan vi kontakte deg igjen med forespørsel om å være med i denne typen undersøkelser?

- ☐ Ja
- ☐ Nei

Tusen takk for at du tok deg tid til å besvare spørsmålene!

Spørreskjemaet postlegges i vedlagte svarkonvolutt - bildeboken skal du ikke returnere.

Errata for
"Iodine in Early Life"

"A cross-sectional study of children 0–2 years of age and their mothers in Norway"

"Tonje Eiane Aarsland"

Thesis for the degree philosophiae doctor (PhD)

at the University of Bergen

30.04.24 Tonje E. Aarsland

(date and sign. of candidate)

03.05.24

(date and sign. of faculty)

Errata

- Page 5, corrected ":" to "." three places in the acknowledgements for consistency
- Page 9, missing word: «både Norge og I andre land" – corrected to "både i Norge og i andre land"
- Page 9, excessive space between number and % – corrected to "Videre hadde 35% av barna et suboptimalt jodinntak"
- Page 11, misspelling in author name, corrected to "Groufh-Jacobsen"
- Italics in "*μ*g" removed and corrected to "μg" in the following pages: 17, 24, 31, 60, 66 and 75
- Page 18, missing full stop after reference 41 – corrected to "... or early infancy (myxedematous cretinism) (41)."
- Corrected grams to g in the following pages: 21, 31, 40, 41
- Page 40, corrected deciliters to dL
- Page 25, deleted space between > and 100 μg/L - "For lactating women and children <2 years of age, a median UIC >100 μg/L..."
- Page 26, missing unit after 100–200 - corrected to "A median BMIC of 100–200 μg/L has..."
- Page 39: removed capital letters in subheadings two places – corrected to "Infant blood samples" and "Short-term assessment: 24-hour intake of iodine-rich foods and 24-hour dietary recalls"
- Page 42, removed comma after **(Table 7)** – corrected to "In phase II, global age-specific reference volumes by Rios-Leyvraz et al. (131) (**Table** 7) were multiplied with the measured BMIC of the corresponding mother"
- Page 50, missing unit behind 153– corrected to "The median (P25, P75) usual iodine intake from food and supplements in the same groups was 153 μg/day (107, 227)
- Page 52, removed "38/137" behind 28%. It was removed from the other percentages in the same section before submission, but accidentally overlooked this one place.
- Page 55, corrected "phase 1" to "phase I" for consistency (written as phase I in the rest of the thesis
- Page 67, corrected "(with and FFQ)" to "(by FFQ)" for consistency with the rest of the thesis
- Page 68, missing % behind 45 – corrected to «... and older, 45% and 60% respectively were reported to not drink..."

- Page 69, removed space before comma, corrected to ", although the extent may vary with…"
- Page 75, corrected "young and childbearing women" to "young women and women of childbearing age" for more correct language and consistency with the rest of the thesis
- Page 79, added comma behind Norway, corrected to "The work presented in this thesis suggests that children between 0–2 years of age in Innlandet County, Norway, have adequate iodine status…"
- Page 51, corrected large P to small p for consistency with the rest of the page and thesis

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