Review Article

Quantification of human milk intake of the babies

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Introduction
Breast milk is the premier source of nutrition and hydration for babies around the world. Human milk nourishes infants with all the nutrients they require for healthy growth and development. World Health Organization (WHO) recommends that infants should be breastfed exclusively during their first six months of life and thereafter be given nutritionally adequate and safe complementary foods while continuing breastfeeding up to two years or beyond[1]. Even though human milk composition and breastfeeding practices have been extensively subjected to research, only limited information is available on the amount of human milk consumption by infants[2]. This is mainly due to the difficulties involved in the quantification of human milk intake. This article is a broad summary of the scientific literature on the methods used for the quantification of human milk intake, their applicability and their advantages and shortcomings.

Method
A literature search was conducted with the help of databases PubMed, Medline, Google Scholar, and Cochrane library. "Human milk intake", "breast milk intake", "test weighing", "isotope dilution" etc., were the main search terms used. It was unable to access the full articles of some studies. Therefore, their abstracts were evaluated. The literature search was restricted to articles that were published in the English language and was conducted without considering a specific time period. Literature on the human milk intake quantification extends from 1970s up to date.

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Results
Human milk intake has been measured using several methods such as test-weighing, isotope dilution and Doppler ultrasound[3,4]. Devices such as "Hi-tech breastfeeding milk consumption measuring device" and "Milk Sense model BFM1" are also available for the measurement of breast milk output during breast feeding. Test-weighing and isotope dilution technique are the most frequently used among all the documented methods. These two methods are considered to be the most accurate for measurement of the milk intake in babies[5].

Test weighing
Test weighing was the first method used to assess human milk intake[5,6]. It is the conventional method for quantification of human milk intake. In this method, the infant is weighed before and after each breastfeeding session and the increase in the infant's weight in grammes after feeding is assumed to reflect the amount of milk in millilitres consumed by the infant. Test weighing is simple as well as direct and it exerts minimal interference for the lactation process. However, during test weighing, the mother-infant pair needs to be near the scale around 24 hours and this is the major disadvantage. Technological advances in weighing instrumentation have enhanced the accuracy and precision of test weighing and reduced reliance on the operator's skills[4]. WHO considers test weighing to be a useful method for assessing milk intake of breast-fed infants. The above consideration is based on the research findings which reported the reliability of test weighing in bottle-fed infants, comparing the difference in weight with the amount of milk consumed from the bottle[7,8]. However, doubts have been cast on the accuracy and precision of test weighing. Saveniji and Brand[9,10] studied the precision and accuracy of test weighing in newborn infants by assessing the frequency distribution of the difference between weight change and actual milk intake. They concluded that test weighing is not a precise method for determining milk intake in infants and recommended that it should not be used in clinical practice. They postulated that this inaccuracy is probably due to insensitivities of the infant weighing scales to pick up small changes in an infant's weight after feeding[10]. Test weighing also affects the normal feeding pattern of infants and is time consuming.

Radioactive isotope technique to assess milk intake in animals

An isotopic technique based on estimating body water turnover of the nursing offspring with tritiated water and equating body water turnover to milk intake was proposed in 1969[11]. This tritium method has been successfully applied to measure the milk intake in sheep, cattle, reindeer, caribou and baboons[11-14]. The method minimised the disturbances in experimental animals. It required the water in milk to be the only exogenous source of water in the offspring and therefore it has been restricted to the nursing animals before they commence forage for themselves because tritium (^3H) is a radioactive isotope. Even though it is used mostly in animal studies, it is not ethical to use it in breast-fed babies. Instead, use of non-radioactive, stable isotopes of deuterium (^2H) and oxygen-18 (^{18}O] started to gain popularity in human studies. Deuterium is the most extensively employed isotope because it is much less expensive than ^{18}O.

Stable isotope technique for the determination of human milk intake

In 1979, Coward WA, *et al*[15] first introduced an isotope technique to measure human milk intake. The technique used deuterium oxide (^2H_2O) and was based on the measurements of water turnover rates after an oral administration of a small dose of ^2H_2O to the infant. This technique was reported to carry two probable errors: (i) overestimations of water flux due to exchange of water molecules at the integumental and respiratory surfaces and (ii) unreported intake of water from sources other than human milk. Coward WA, *et al*[16] subsequently forwarded the second/revised version of the technique in 1982, successfully overcoming the above-mentioned overestimations in the original technique. In the revised technique ^2H_2O was administered to the mother and then followed the disappearance of deuterium from the mother and its appearance in the baby. This method was commonly known as the 'Deuterium-dose-to-mother-technique'.

Deuterium-dose-to-mother-technique

As described in the International Atomic Energy Agency (IAEA), Human Health Series (No. 7) 2010[2], during the deuterium-dose-to-mother-technique, a dose of ^2H_2O (approximately 10 g) is orally administered to the lactating mother. Following ingestion of the dose, the ^2H_2O is then distributed throughout the mother's body within a few hours and ^2H_2O incorporated into breast milk. The baby obtained the ^2H_2O only during breast-feeding. Mother's saliva and urine of baby (2mL) are collected which is enriched with deuterium. Deuterium enrichment of the samples could be quantified either by Isotope Ratio Mass Spectrometer (IRMS) or Fourier Transform Infrared spectrometer (FTIR). Curves are generated using data obtained from the deuterium enrichments of saliva and urine samples and the time passed after the administration of isotope to the mothers, reflecting the disappearance of the isotope from the mothers' body water and its appearance and disappearance from the infant's body water. These deuterium enrichment data are fitted to a model for water turnover in the mother and in the baby[2]. This method calculates the mean breast milk intake by the infant over a period of 14 days. In addition, the technique enables the measurement of non-milk (oral) intake of the infant as well as an assessment of body composition of the mothers. It is more advantageous as it allows greater mobility of the mother-infant pair. Furthermore, it interferes less with normal feeding patterns and milk production compared to the conventional test-weighing technique[17].

However, measurement of human milk intake using isotopes carries huge practical challenges and constraints. Recruitment of the mother-baby pairs is the topmost difficulty due to myths regarding isotope usage that are believed not only by the parents but also by some of the healthcare professionals. Next, it is very hard to get the parents to agree to the two-week period of sample collection. Further, the stable isotope studies carry huge costs posing restrictions on their implementation, especially in the developing countries. Thus, extensive data generated on the human milk intake by the stable isotope method is not available. Isotope dilution technique was first used to quantify human milk intake in developed countries. During the last 6-7 years, some of the developing countries have also reported human milk intake of exclusive and partially breast-fed babies using the same method. USA, Morocco, Scotland, Brazil, Kenya, Bangladesh, Thailand and Sri Lanka are among the countries that reported on the human milk intake of exclusive breast-fed infants using the stable isotope dilution method and majority of these studies were cross-sectional in design. Butte NF, *et al*[18] recorded that the average human milk intake of infants aged 1-6 months in the USA as 648 ± 63 g/day. Haisma H, *et al*[19] has reported the human milk intake of exclusively breast-fed infants in Brazil was 806 g/day. Bangladesh reported 884 ± 167 mL/day of breast milk intake in 2-3 months old infants[20]. The values reported in Kenya and Scotland were 555 ± 22 mL/day (for 2-4 months old infants) and 923 ± 122 g/day (mean age of infants - 3.7 months), respectively[21,22.] Thailand has reported that the human milk intakes of exclusively and partially breast-fed infants at 6 months of age were 743-776 g/day and 748-862 g/day, respectively using the deuterium dilution technique[23]. Human milk intakes of exclusively breast-fed Sri Lankan babies were found to be 672 ± 123 g/day, 776 ± 212 g/day, and

801 ± 51 g/day, at <2 months, 2 to <4 months, and 4–6 months of age, respectively[24].

The target of the World Health Assembly is to enhance exclusive breast feeding (EBF) rates in the first 6 months up to at least 50% by the year 2025. Data on the EBF rates are drawn by the maternal recall method. Recent studies have confirmed that in comparison to the objective deuterium dilution method, mothers' own recall of EBF is biased, leading to an overestimate of about 40% at age of 3–6 months[25]. This emphasizes the value of the deuterium-dose-to-mother technique not only to determine the human milk intake, but also to determine whether the baby is exclusively breast fed or not.

Other methods for the measurement of human milk intake

In 1979, How TV, *et al*[26] described a Doppler ultrasound flow transducer which could be used together with a zero-crossing demodulator for measuring of human milk flow. They presented their *in vitro* preliminary evaluation results with the intention of miniaturising the design in order to use the transducer for *in vivo* measurement[26]. In 1982, the same research team reported a method for continuous milk intake measurement during a breast-feed. They used a miniature Doppler ultrasound flow transducer (located in the tip of a latex nipple shield) interposed between baby and mother while feeding. Initial individual feed analysis indicated that two factors contributed to the reduction of intake from one breast during a feed. These factors are a gradual decline in intake volume per suck, and an increase in the time fraction spent pausing between bursts of sucking[27]. This invention has obtained a patent. Some electronic devices are commercially available in the market for the estimation of breast-milk intake. "Hi-tech breastfeeding milk consumption measuring device" and "MilkSense model BFM1 are some of them. MilkSense utilize electromagnetic signals to quantify the volume of milk in the breast before and after a feed. Such electronic devices are usually marketed as home care devices. However, scientific data to document their accuracy and reliability are not available. Therefore, their usefulness to measure human milk intake is questionable.

Conclusion and Summary

Test weighing, isotope dilution in babies, deuterium-dose-to mother technique and electronic devices are available to measure human milk intake of babies. Test weighing is the oldest and the conventional technique although it is less accurate. Currently, deuterium-dose-to mother technique remains the gold standard for the measurement of human milk intake. However, its application is still limited as it is expensive and carries multiple practical challenges. Therefore, validating the accuracy and reliability of the commercially available electronic devices to measure breast milk intake against the deuterium-dose-to mother method might be a worthwhile alternative.

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