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The Remote Food Photography Method accurately estimates dry powdered foods—the source of calories for many infants

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Abstract

Background—Infant formula is a major source of nutrition for infants with over half of all infants in the United States consuming infant formula exclusively or in combination with breast milk. The energy in infant powdered formula is derived from the powder and not the water making it necessary to develop methods that can accurately estimate the amount of powder used prior to reconstitution.

Objective—To assess the use of the Remote Food Photography Method (RFPM) to accurately estimate the weight of infant powdered formula before reconstitution among the standard serving sizes.

Methods—For each serving size (1-scoop, 2-scoop, 3-scoop, and 4-scoop), a set of seven test bottles and photographs were prepared including the recommended gram weight of powdered formula of the respective serving size by the manufacturer, three bottles and photographs containing 15%, 10%, and 5% less powdered formula than recommended, and three bottles and

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Conflict of Interest Disclosure:

Ms. Duhé, Dr. Gilmore, Dr. Burton, and Dr. Redman report no conflicts of interest. The Remote Food Photography Method copyright is held by the Board of Supervisors of Louisiana State University and Agricultural and Mechanical College. SmartIntake™ is a trademark of the Board of Supervisors of Louisiana State University and Agricultural and Mechanical College, with the trademarked approach having been developed by Dr. Martin and Dr. H. Raymond Allen.

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photographs containing 5%, 10%, and 15% more powdered formula than recommended (n=28). Ratio estimates of the test photographs as compared to standard photographs were obtained using standard RFPM analysis procedures. The ratio estimates and the United States Department of Agriculture (USDA) data tables were used to generate food and nutrient information to provide the RFPM estimates.

Statistical Analyses Performed—Equivalence testing using the two one-sided t- test (TOST) approach was used to determine equivalence between the actual gram weights and the RFPM estimated weights for all samples, within each serving size, and within under-prepared and over-prepared bottles.

Results—For all bottles, the gram weights estimated by the RFPM were within 5% equivalence bounds with a slight under-estimation of 0.05 g (90% CI [-0.49, 0.40]; $p<0.001$) and mean percent error ranging between 0.32% and 1.58% among the four serving sizes.

Conclusion—The maximum observed mean error was an overestimation of 1.58% of powdered formula by the RFPM under controlled laboratory conditions indicating that the RFPM accurately estimated infant powdered formula.

Keywords

dietary assessment; digital photography; infant feeding; powdered formula; bottle feeding

INTRODUCTION

Food intake and proper nutrient intake are important for maintaining adequate growth and development, maintaining a healthy weight, and preventing chronic diseases, yet accurate measurement of food intake to help inform consumers, clinicians and researchers is challenging. Objective assessment methods have a high degree of accuracy, but considerably high burden and cost for most settings¹⁻³, particularly when implementation is required on a large scale such as in clinical practice. On the other hand, methods that are subjective are relatively simple to execute but are less accurate since estimation is reliant on the individual for identification of foods and portion estimation⁴⁻⁶. The Remote Food Photography Method (RFPM) is a validated method for assessing food intake that allows individuals or caregivers to utilize the SmartIntake™ smartphone application to capture photographs of food provision and plate waste and to describe the food contained in the photographs within the application. Then, the photographs and descriptions are transmitted automatically to the Food Photography Application® analysis program for energy and nutrient intake estimation. Portion estimation of foods contained in the photographs is completed by trained raters with the estimations expressed as ratios to food standard photographs. The Food Photography Application® uses United States Department of Agriculture (USDA) data tables and manufacturers' instructions to generate food and nutrient intake^{4,7}. In comparison to doubly labeled water, the RFPM was found to underestimate energy intake by only 3.7% (-152 ± 694 kcal/day, $p=0.16$) in free-living adults and by 1.2% in a buffet meal setting⁷.

Traditionally, compared to conventional foods, food intake assessment methods are less successful at estimating energy intake from condiments and beverages leading to the potential for inaccurate estimation^{8,9}. Indeed, Williamson and colleagues found that digital

photography was highly correlated with directly weighed foods for intake of various foods except for condiment intake, which was overestimated by 16.6% ($p < 0.05$, $ICC = 0.60$)^{2,8}. The ability to measure calories in small quantities (e.g. infant powdered formula) is becoming increasingly important since, according to the most recent Centers for Disease Control and Prevention (CDC) Breastfeeding Report Card, over half of all infants in the United States consuming infant formula exclusively or in combination with breast milk¹⁰. Infant powdered formula is not only packaged in single use servings but also in larger containers requiring the caregiver to portion the required amount of powder to mix. An additional nuance of reporting infant formula intake is that the caloric density of the reconstituted product is likely to vary between each preparation as this is dependent on the exact measurement of the powder and liquid (e.g. milk, water) that is placed into the serving container⁹ and the amount of the prepared formula that is consumed. Egemen and colleagues showed that 50% of mothers in their study sample added 10% more or 10% less water to a second formula bottle as compared to a first formula bottle that was prepared¹¹, illustrating that caregivers may not precisely measure powdered infant formula and water prior to infant feeding. Therefore, infant formula has potential for a large degree of misreporting which presents a need for methodology to assess the caloric density in prepared formula and to provide measurement of infant formula intake from free-living infants.

Since the source of energy or kilocalories is derived from the powdered formula and not the water which is typically used as the mixer with powdered formula, it is vital to develop methods that can accurately estimate the amount of powdered formula in bottles being prepared for infants. The aim of this proof-of-concept study was to assess the use of the RFPM in estimating powdered formula using standard infant formula photographs and the variability in accuracy of the RFPM among different serving sizes of powdered formula. If successful, the RFPM could be applied to the measurement of infant formula intake.

METHODS

Study Design

This was a laboratory-based, proof-of-concept study that was designed to evaluate the feasibility of applying the RFPM in the estimation of powdered formula. The Pennington Biomedical Research Center Institutional Research Board considered this study with no human subjects a proof of concept and, therefore, exempt from human subjects research approval. The study was designed to determine if the RFPM could be used to accurately estimate powdered formula before reconstitution using established standard photographs and USDA database food codes among standard formula serving sizes.

Development of Standard Photographs—Standard procedures of the RFPM require that photographs of foods be compared to a standard photograph showing the standard serving size of the food being analyzed. To prepare standard photographs of powdered formula, exact gram weight of powdered formula in each of the four recommended standard serving sizes; 1-scoop (8.7 g), 2-scoops (17.4 g), 3-scoops (26.1 g), and 4-scoops (34.8 g) was measured into a clear, generic infant bottle (Figure 1a). A digital photograph of each bottle containing the specific serving size of the powdered formula was

captured with the RFPM reference card which is used for food sizing according to standard RFPM practices⁷. The gram weight for each serving size was determined from the nutrient label recommendation provided on the commercial packaging. All standard photographs were stored in the RFPM analysis database, the Food Photography Application[®]. The standard photographs were used by trained raters as a reference standard to estimate the ratio of powdered formula present in the test photographs as compared to the standard photographs (Figure 1b) using previously described visual comparison methods^{2,4,7}.

Preparation of Test Photographs—To test the accuracy of the RFPM gram estimates as compared to actual gram weight in unknown bottles and to assess the lower limit of estimation for each serving size, an individual impartial to the study (lab manager) prepared bottles and captured test photographs of powdered formula used in the study. The bottles were prepared with powdered formula that was fresh and stored according to the package instructions. For each serving size (1-scoop, 2-scoop, 3-scoop, and 4-scoop bottles), a set of seven test bottles were prepared and photographs immediately captured. Each set of test bottles and photographs contained the recommended amount of powdered formula specified for the individual serving size by the manufacturer (100%) as well as three bottles and photographs containing 15%, 10%, and 5% less powdered formula than recommended and three bottles and photographs containing 5%, 10%, and 15% more powdered formula than recommended. The seven different conditions allowed for the investigation of the use of the RFPM to estimate differing gram weights for each scoop size, and it provided translation to real world settings as individuals are unlikely to scoop the recommended gram weight every scoop. For each serving size, the test photographs were randomly assigned labels A through G. In order to objectively test inter-rater reliability in estimating the amount of powdered formula in the bottles, the test photographs were then analyzed using the Food Photography Application[®] by a trained rater. Using the Food Photography Application[®], the rater compared each test photograph to the standard photograph prepared for this study using the RFPM analysis procedures described previously^{2,4}. The rater was blinded to the amount of formula contained in the photographs, and the photographs were analyzed in random order^{2,4}. To ensure accurate portion size estimates by the rater, the same photographs were analyzed a second time by another independent, trained rater blind to the first rater's estimations.

Data Analysis

All analyses were completed by the biostatistician using SAS/STAT[®] software, Version 9.4 of the SAS System for Windows (Cary, NC, USA). All tests were performed with significance level $\alpha=0.05$, and findings were considered significant when $p<\alpha$. The unit of analysis was powdered infant formula across 28 simulated feeding bottles.

An intra-class correlation coefficient (ICC) and two one-sided t- tests (TOST) were used to examine inter-rater agreement, and an ICC of 0.95 or higher was considered acceptable based on previous RFPM studies^{2,4}. Considering all bottles, estimates of gram weight using the RFPM differed between raters by 0.09 g (90% CI [-0.94, 0.75], $p=0.03$) with acceptable inter-rater agreement (ICC 0.97, $p<0.001$). Since a high level of agreement between raters

was demonstrated, RFPM data in all analyses reflected that of the raters combined to provide the RFPM estimated values.

TOST was used to determine overall equivalence ($n=28$), equivalence within each serving size ($n=7$), and equivalence within under-prepared ($n=12$) or over-prepared ($n=12$) bottles. The equivalence test using the TOST approach involved testing whether the mean difference between two measures occurred within a pre-determined set of bounds¹². Equivalence test bounds of $\pm 5\%$, $\pm 7\%$, and $\pm 10\%$ of the actual gram weights of bottles were selected based on the acceptable level of precision reported with other infant food intake measures^{2,13–17}. Equivalence was assessed overall and within each serving size (1-scoop, 2-scoop, 3-scoop, and 4-scoop) based on whether the 90% confidence interval of the respective serving size fell within the equivalence test bounds.

In addition to evaluating point estimates of bottle serving sizes, the ability of RFPM estimates to be correctly identified as over-prepared and under-prepared bottles was investigated. A correct identification denoted that the gram weight of an over-prepared (or under-prepared) bottle was accurately estimated as over (or under) the standard bottle weight using the RFPM. The focus of this test was not on the precision of the gram weight estimate but whether the RFPM estimate was correctly classified as either over-prepared or under-prepared. The proportion of correct and incorrect classification of bottles over- and under-prepared were computed along with 95% confidence intervals.

RESULTS

RFPM Estimates of Gram Weight by Serving Size

As compared to actual gram weight, gram weights estimated by the RFPM for all bottle sizes were within 5% equivalence bounds with a slight under-estimation of 0.05 g (90% CI $[-0.49, 0.40]$; $p<0.001$).

To assess whether the estimates of gram weight from the RFPM were consistent for individual serving sizes (data summarized in Table 1 for all serving sizes), analyses were performed for each serving size (1-scoop, 2-scoop, 3-scoop, and 4-scoop bottles) separately. For all 1-scoop bottles, there was a mean percent error of 1.05% between gram weights estimated by the RFPM and actual gram weights, and the RFPM estimated weights were equivalent to actual gram weights within 7% bounds (0.03 g, 90% CI $[-0.48, 0.54]$, $p=0.03$). For all 2-scoop bottles, gram weights estimated by the RFPM were underestimated as compared to actual gram weights with a small mean percent error of 0.32%. RFPM estimated gram weights were considered equivalent to actual gram weights of 2 scoop bottles within 7% equivalence bounds (-0.12 g, 90% CI $[-0.93, 0.68]$, $p=0.02$). The 3-scoop bottles had a mean percent error of 1.58% for the RFPM gram weight estimates as compared to the actual gram weights. For all 3-scoop bottles, the RFPM estimated gram weights were not equivalent to actual gram weights within 7% bounds ($p=0.06$), but estimates were equivalent within 7.5% equivalence bounds (-0.47 g, 90% CI $[-1.89, 0.96]$, $p=0.04$). For all 4-scoop bottles, RFPM overestimated actual gram weights with mean percent error of 0.93%, and RFPM estimated weights were considered equivalent to actual gram weights within 7% equivalence bounds (0.37 g, 90% CI $[-0.49, 1.24]$, $p<0.001$).

RFPM Estimates of Gram Weight by Over-preparation and Under-preparation

RFPM estimates were correctly categorized as under-prepared bottles on 63% of occasions (95% CI [0.41, 0.81]). The RFPM estimated gram weights for under-prepared bottles were equivalent to the actual gram weights within 5% equivalence bounds (0.42 g, 90% CI [-0.16, 0.99], $p=0.03$). The over-prepared bottles were correctly categorized on 67% of occasions (95% CI [0.45, 0.84]), and the RFPM estimated gram weights were equivalent as compared to the actual gram weights of over-prepared bottles within 5% equivalence bounds (-0.27 g, 90% CI [-1.06, 0.51], $p=0.04$).

DISCUSSION

Since the kilocalories of powdered formula are derived mostly from the powder and not from the added liquid, developing and using methods that accurately assess the powdered component is important. The RFPM was evaluated for the ability of the method to estimate laboratory-prepared test meals of powdered formula. The RFPM accurately estimated the amount of powdered formula in bottles among all serving sizes with minimal variability. Considering all bottle sizes, the RFPM slightly underestimated actual weight with a mean difference between methods of 0.05 g. The test sample weights measured by the RFPM were shown to be statistically equivalent to the directly weighed samples with mean percent error between 0.32% and 1.58% among the serving sizes. Furthermore, the mean error between the RFPM and the actual weights was within 2% for all test samples of each serving size. The maximum observed mean error of 0.5 g (1.58%) that was observed equates to only a 2 kcal mis-estimation of the powdered formula by the RFPM under controlled laboratory conditions.

The current study demonstrated that the RFPM could successfully estimate energy intake of infant powdered formula. The findings from this work can be further applied to the estimation of infant formula intake. This was the first attempt to consider the estimation of energy intake from powdered foods before reconstitution with the planned liquid. A potential limitation of using the RFPM to measure infant formula intake prepared from powder is that it requires photographs to be captured in a specified order which may not represent the typical preparation method adopted by caregivers or clinicians and may require caregivers to change their behavior for a period of the measurement. Namely, the RFPM requires a photograph of the feeding bottle containing the dry powder before reconstitution with water as well as a prepared photograph of powder and liquid mixed before feeding. Although instructions on commercially available infant formula products are not uniform, instructions typically recommend water to be added before powder, but it is likely that caregivers are inconsistent in their bottle preparation. Furthermore, as demonstrated in this proof of concept study, measuring the amount of powder to be consumed before reconstitution is critical as it is the source of calories in prepared infant formula.

For the equivalence testing, $\pm 5\%$, $\pm 7\%$, and $\pm 10\%$ were identified as test bounds based on the acceptable level of precision reported with other infant food intake measures with direct weight comparisons. For all test samples, the 90% confidence interval of the difference between the RFPM and direct weight of the bottles was within 5%–7.5% equivalence bounds. When test samples were analyzed within each serving size, the mean difference

between the RFPM weights and the direct weights was within 2% for all serving sizes. The magnitude of this difference was extremely small with mean error consistent or better than other current food intake methods used as investigative tools.

Two-thirds of the RFPM estimates were correctly categorized as either under-prepared or over-prepared. For both over- and under-prepared bottles, the 90% confidence interval of the difference between the RFPM and actual weight of the bottles was within 5% equivalence bounds. Over-prepared bottles however tended to be slightly underestimated, whereas under-prepared bottles tended to be slightly overestimated.

The maximum mis-estimation of about 0.5 g with the RFPM represents minimal error, but depending on the number of bottles an infant consumes could represent larger or smaller error in terms of intake. Not only does the total error depend on the estimation of the powder, but, for reconstituted foods like infant powdered formula, it also includes measurement error for estimating the amount of liquid that was added to the powder as well as the amount of prepared liquid that was not consumed. This highlights the importance of including details about the powder and liquid used in reconstituted foods in the measurement of energy intake.

In this first study that attempted to assess the feasibility of using the RFPM to quantify infant foods, existing RFPM procedures were adapted to accommodate powdered formula. Following the development of a set of standard photographs for each serving size of powdered formula, the RFPM accurately estimated the weight of test photographs in comparison to direct weights within 2% mean error. Since the source of calories is mostly yielded from the powdered component, dietitians need to evaluate methods that accurately obtain this information. It is not sufficient to rely only on the amount of reconstituted food consumed because it is likely that few servings are accurately prepared and contain the exact number of expected calories specified on the nutrient label. Therefore, without a method to discern the caloric density of a powdered formula, methods such as the RFPM that directly estimate powder in relatively small quantities need to be developed and tested. An obvious disadvantage of this study was the strict laboratory control and preparation of the test samples, but this was the necessary first step in RFPM development for infant foods including infant formula.¹⁰⁶

CONCLUSION

In this study, the maximum observed mean error of the RFPM that was observed was an overestimation of powdered formula of 1.58% indicating that the RFPM accurately estimated powdered formula. All aspects of the reconstituted food including the amount of powder, the amount of liquid, the amount of prepared liquid not consumed, and the caloric density of the preparation should be considered for energy intake estimation. Future studies are planned to evaluate the RFPM in laboratory conditions with study subjects who will be purposely recruited to prepare bottles of infant formula. The objective of these future studies will be to establish the RFPM as a clinical tool for monitoring infant formula intake available to clinicians.

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Figure 1a **Figure 1a****Figure 1b** **Figure 1b****Figure 1.**

Figure 1a: Standard photographs for recommended standard serving sizes.

Figure 1b: Test photograph with respective standard photograph for ratio comparison with the Food Photography Application©.

Actual Gram Weights and RFPM Estimated Gram Weights across Different Serving Sizes

Table 1

Serving Size	Weight (g)	% Difference from Standard Scoop Weight							
		-15%	-10%	-5%	0%	+5%	+10%	+15%	
1-scoop	Actual	7.4	7.8	8.3	8.7	9.1	9.6	10.0	
	Estimated	9.4	7.8	8.0	8.0	9.4	8.3	10.2	
2-scoops	Actual	14.8	15.7	16.5	17.4	18.3	19.1	20.0	
	Estimated	15.7	17.0	18.3	14.4	16.5	18.7	20.4	
3-scoops	Actual	22.2	23.5	24.8	26.1	27.4	28.7	30.0	
	Estimated	22.8	21.5	25.4	26.8	26.8	30.7	25.4	
4-scoops	Actual	29.6	31.3	33.1	34.8	36.5	38.3	40.0	
	Estimated	28.7	31.3	33.9	34.8	36.5	40.9	40.0	