

Evaluation of a mobile phone image-based dietary assessment method in adults with type 2 diabetes.

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Abstract:

Photographic and image-based dietary records have limited evidence evaluating their performance and use among adults with a chronic disease. This study evaluated the performance of a mobile phone image-based dietary record, the Nutricam Dietary Assessment Method (NuDAM), in adults with type 2 diabetes mellitus (T2DM). Criterion validity was determined by comparing energy intake (EI) with total energy expenditure (TEE) measured by the doubly-labelled water technique. Relative validity was established by comparison to a weighed food record (WFR). Inter-rater reliability was assessed by comparing estimates of intake from three dietitians. Ten adults (6 males, age=61.2±6.9 years, BMI=31.0±4.5 kg/m²) participated. Compared to TEE, mean EI was under-reported using both methods, with a mean ratio of EI:TEE 0.76±0.20 for the NuDAM and 0.76±0.17 for the WFR. There was moderate to high correlations between the NuDAM and WFR for energy ($r=0.57$), carbohydrate ($r=0.63$, $p<0.05$), protein ($r=0.78$, $p<0.01$) and alcohol ($r_s=0.85$, $p<0.01$), with a weaker relationship for fat ($r=0.24$). Agreement between dietitians for nutrient intake for the 3-day NuDAM (ICC = 0.77-

0.99) was marginally lower when compared with the 3-day WFR (ICC=0.82-0.99). All subjects preferred using the NuDAM and were willing to use it again for longer recording periods.

Keywords: diabetes; doubly labelled water; image-based dietary records; nutrition assessment; photographic dietary records.

1. Introduction

Nutrition therapy provided by a dietitian and self-management education and support are important strategies for the effective long-term management of type 2 diabetes mellitus (T2DM)[1]. The measurement of dietary intake is necessary to inform, support and evaluate these interventions. Traditional prospective methods of recording intake, such as weighed or estimated food records, are ideal as they allow for the natural day-to-day variation in intake to be captured [2], however are associated with high burden and changes to usual intake [3-5].

Photographic or image-based dietary records have shown promise in alleviating the issues associated with subject burden among adults[6,7], including those with T2DM [8]. Evaluation of the performance of photographic and image-based dietary records has been limited. The inter-rater reliability of these records has been reported as moderate to high when used alone to measure nutrient intake [9-13]. Relative validity, through comparison with other dietary assessment methods, has been undertaken [9,10,12-16], however, validation with an objective reference method is essential to determine the true accuracy of image-based and photographic records. The doubly labelled water (DLW) technique is a method used to assess total energy expenditure (TEE) and is considered the “gold standard” method to validate self-reported dietary energy intake (EI) [17,18].

Evaluation of the performance of these methods has been limited. Both inter-rater reliability[10,12,13] and relative validity have been assessed [12-16], however only one study[7] has determined criterion validity of self-reported energy intake (EI). This current study aimed to establish the validity (both relative and criterion) and inter-rater reliability of the Nutricam Dietary Assessment Method (NuDAM) in adults with T2DM. The usability and acceptability of the NuDAM in this group was also assessed.

2. Experimental Section

2.1. Subjects and study design

A convenience sample of adults with T2DM was recruited through the use of a research study database and university staff via internal email list serves. To be eligible to participate in the study, subjects needed to meet the following criteria: be aged 18–70 years; have a diagnosis of T2DM of >3 months; not currently receiving treatment for cancer; no previous diagnosis of liver, kidney or thyroid diseases; and not currently trying to lose weight, with a stable body weight of ± 4 kg over the past 6 months. The study was approved by the Queensland University of Technology Human Research Ethics Committee, with each subject providing written informed consent.

For the evaluation of new dietary assessment methods it is recommended that test and reference methods are used separately, with the test method used first [19]. Therefore, dietary intake was assessed using the NuDAM (test method) in week 1 and the weighed food record (WFR) (reference method) in week 2. Intake was assessed over a three day period (two week days and one weekend day; non-consecutive) for both methods. Dietary restraint was measured [20] and demographic information was collected on Day 0, in addition to height to the nearest 0.1 cm using a stadiometer (Model PE087, Mentone Educational, Australia) and body weight to the nearest 0.1 kg using calibrated electronic scales (Model HD319, Tanita Corporation, Japan). Weight was also measured on Days 8 and 15. At the end of each dietary recording period, subjects were asked to complete a brief questionnaire on the experience of using the NuDAM and the WFR. Response options to questions included Likert and categorical scales in addition to open-ended text.

2.2. Total Energy Expenditure (TEE)

TEE was measured over a two week period using the DLW technique. Administration of the DLW occurred on Day 0, with subjects in a fasted state. Subjects were orally dosed with 1.25 g 10% ^{18}O + 0.1g 99% $^2\text{H}/\text{kg}$ and a post-dose urine sample was collected 6 hours after drinking the DLW. During Days 1–14 subjects were required to collect one urine sample each day. The level of enrichment of ^{18}O and ^2H isotopes contained in the urine samples were measured in triplicate by isotope ratio mass spectrometry (Hydra 20/20 CF-IRMS, Sercon Cheshire, UK). Isotope dilution spaces were derived [21] and used to calculate carbon dioxide production [22]. Indirect calorimetry principles were applied and TEE derived via using the modified Weir [23] equation, with a standard respiratory quotient of 0.85 used for all subjects.

2.3. Nutricam Dietary Assessment Method (NuDAM)

The NuDAM consisted of a prospective mobile phone Nutricam dietary record and brief follow-up phone call to the subject the following day (**Figure 1**).

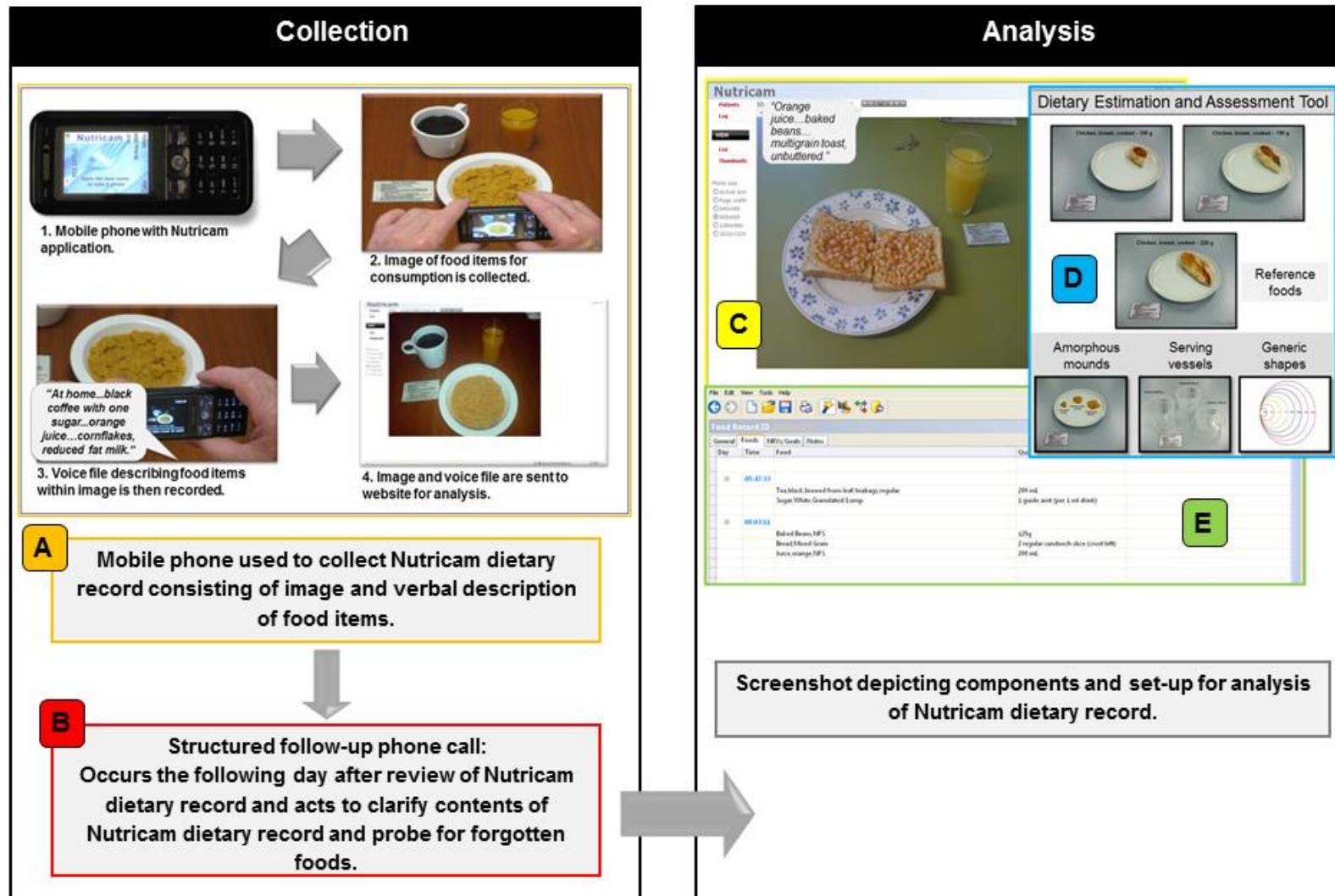


Figure 1: Overview of the Nutricam Dietary Assessment Method (NuDAM). For the collection of dietary intake data, a mobile phone is used to capture the Nutricam dietary record (A) and is combined with information collected via a phone call (using a standardized interview protocol) (B). Analysis consisted of the dietitian identifying and quantifying food items contained in each Nutricam dietary record entry (C). A standardized protocol and the Dietary Estimation and Assessment Tool (DEAT) (a two-dimensional portion size estimation aid (D) was used to assist in the task of quantifying the food items. Dietary data was entered directly into the nutrient analysis software program, FoodWorks® (E) to obtain an estimate of nutrient intake. Data from the follow-up phone call (B) is used to supplement the Nutricam dietary record, with adjustments made by the dietitian to the analysis (E) as required.

The Nutricam dietary record was recorded using a Sony Ericsson K800i mobile phone (Sony Ericsson Mobile Communications AB, Sweden) installed with the software application Nutricam (Alive Technologies, Pty. Ltd., Australia). Details of the development and early testing of Nutricam have been described previously [8]. When recording the image, subjects were instructed to place the reference object (a 9 cm x 5 cm card which also acted as a prompt for recording an entry) next to the food items, hold the phone at an angle of approximately 45° and ensure all items were clearly visible. After capturing the image, subjects were automatically prompted to make a voice recording describing the location, meal occasion, and the foods (name, type, brand/product name, and preparation/cooking method) contained in the photograph. Information of any food leftover at the end of the eating occasion was also collected in a similar manner. Each entry from the Nutricam record was automatically sent to a secure website accessed only by the researchers. Additional intake information, including clarification of the Nutricam record and/or probing for forgotten foods, was collected during a brief structured phone call to the subject on the morning following each recording day by a Dietitian (D1).

2.4. Weighed Food Record (WFR)

In the second week, each subject used the WFR method to document intake in a paper-based record. Subjects were provided with a set of digital food scales (Model HR 2385, Koninklijke Philips Electronics N.V., The Netherlands) (accurate to 1 g) and were required to weigh all food items prior to consumption and record all information (including recipes) into the paper-based record supplied. Any food served but not eaten was also weighed and documented. At the completion of the recording period, the WFR was reviewed by D1 in the presence of the subject to ensure that the information was complete.

2.5. Nutrient analysis from the NuDAM and WFR

The two sets of dietary records were analysed independently by three dietitians (D1 and two additional dietitians, D2 and D3) using the *AUSNUT 1999* food composition database in the nutrient analysis software program FoodWorks® Professional 2009 (Xyris Software, Australia). The Nutricam dietary records were analysed first. Each dietitian identified and quantified food items contained in the Nutricam records and entered this information directly into the nutrient analysis program. To assist with the quantification of foods in the images, each dietitian used a two-dimensional portion size estimation aid, called the Dietary Estimation and Assessment Tool, previously developed by the research team (**Figure 1**). The tool consisted of various reference images of foods, serving vessels,

amorphous mounds and generic shapes and was based on aids developed for other dietary assessment methods [24,25]. The reference object (9 cm x 5cm card) also appeared in the DEAT and provided perspective to the dietitian during the analysis. Dietitians were provided with a recording of the phone calls to each subject and used this information to make any adjustments to the NuDAM analysis. The information contained in the WFRs was entered directly into the FoodWorks® program.

2.6. Statistical Analysis

Data analyses were performed using the SPSS for Windows (version 17.0, 2008, SPSS Inc., Chicago, Illinois). The three dietitians' estimates of nutrient intake for each subject were averaged to obtain an overall mean estimate of energy and macronutrient intake for both methods. Intra-class correlation coefficients (ICC) evaluated agreement between dietitians' estimates of energy and macronutrient intake. Repeat-measures ANOVA or Friedman's ANOVA were used to assess differences between dietitians' estimates (Bonferroni correction post hoc analysis applied). Paired t-tests or Wilcoxon signed-rank test assessed differences in estimated nutrient intake between methods and for EI and TEE. Correlation coefficients were used to determine the relationship between the NuDAM and WFR. Validation of self-reported EI was based on the principle of $EI = TEE \pm \text{body stores}$, where in the absence of non-significant weight change at the group level, the expected ratio of EI:TEE is 1.00 [18], with the 95% confidence limits (CL) calculated to determine mis-reporting at the individual level [26].

3. Results

Six men and four women ranging in age between 48-69 years with T2DM participated in the study. Five were classified as obese ($BMI \geq 30.0 \text{ kg/m}^2$), four as overweight ($BMI 25.0\text{-}29.9 \text{ kg/m}^2$), and one was within the normal BMI range ($18.5\text{-}24.9 \text{ kg/m}^2$). There were no significant group changes in mean body weight during Week 1 (baseline to Day 8), $-0.7 \pm 1.2 \text{ kg}$, Week 2 (Day 8 to Day 15), $0.4 \pm 0.9 \text{ kg}$ and overall (baseline to Day 15) $-0.3 \pm 1.2 \text{ kg}$. The group showed a low level of dietary restraint, with mean individual scores ranging between 1.3 to 3.2 (out of 5).

3.1. Criterion and relative validity

Mean EI was $8.8 \pm 2.0 \text{ MJ/day}$ from the NuDAM and $8.8 \pm 1.8 \text{ MJ/day}$ from the WFR; both significantly lower than mean TEE of $11.8 \pm 2.3 \text{ MJ/day}$ ($p < 0.01$). The mean EI:TEE ratio was 0.76 ± 0.20 and 0.76 ± 0.17 for the NuDAM and WFR, respectively, with 95% CL of <0.72 and >1.28 for the NuDAM (three male under-reporters), and <0.76 and >1.24 for the WFR (four male under-reporters). NuDAM under-reporters were also found to be under-reporting EI with the WFR. Mean nutrient intakes were

not significantly different between the two dietary assessment methods (**Table 1**). Associations between intakes were stronger for protein and alcohol, moderate for energy and carbohydrate, and weaker for fat.

3.2. Inter-rater reliability

The inter-rater reliability and comparison of mean energy and nutrient intakes from the NuDAM and WFR are shown in **Table 1**. Bonferroni post-hoc analysis between dietitians showed estimates by D1 to be significantly different for energy compared to both D2 and D3, protein compared to D3, and fat and carbohydrate compared to D2. No significant difference existed in the estimated weights between dietitians for each day or the average weight for each method.

Table 1: Comparison of energy and nutrient intake obtained from NuDAM and WFR between dietitians and between methods (n=10 subjects)

		Mean(±SD) Intake as assessed by each dietitian [†]			ICC (95% CI) between dietitians	Overall [‡]	
		D1	D2	D3		Mean(±SD) Intake [§]	Correlation [^] between methods
Energy (MJ/day)	NuDAM	8.2±1.7	9.0±2.3*	9.1±2.0*	0.88 (0.58-0.98)***	8.8±2.0	0.57
	WFR	8.5±1.6	8.9±2.0	8.9±1.8	0.92 (0.80-0.98)***	8.8±1.8	
Protein (g/day)	NuDAM	89.3±20.2	99.0±31.4	98.1±23.1*	0.79 (0.53-0.94)***	95.5±23.7	0.78**
	WFR	89.1±26.8	91.9±28.2	91.5±24.9	0.97 (0.92-0.99)***	90.8±26.4	
Fat (g/day)	NuDAM	75.6±18.3	87.0±25.4*	86.6±20.1	0.77 (0.45-0.93)***	83.1±20.3	0.24
	WFR	79.5±16.8	85.4±27.4	80.9±24.2	0.82 (0.59-0.95)***	81.9±21.8	
CHO (g/day)	NuDAM	194.9±52.8	212.0±52.7*	215.3±60.8	0.91 (0.71-0.98)***	207.4±54.4	0.63*
	WFR	206.3±53.8	207.2±54.9	211.9±57.8	0.92 (0.79-0.98)***	208.5±53.9	
Alcohol (g/day)^{#,¶}	NuDAM	15.0±29.4	13.6±28.0	14.4±29.5	0.99 (0.98-0.99)***	14.3±28.9	0.85**
	WFR	16.1±23.4	17.4±30.2	16.5±28.4	0.99 (0.98-0.99)***	16.7±28.3	

Food	NuDAM	3119.3±588.2	3246.5±869.2	3303.6±587.1	0.78 (0.51-0.93)***	-
Weight (g/day)	WFR	2880.6±829.5	2840.5±868.0	2842.6±883.4	0.98 (0.95-0.99)***	-

Abbreviations: D1=dietitian No.1; D2=dietitian No.2; D3=dietitian No.3; CHO=carbohydrate; NuDAM=Nutricam dietary assessment method; WFR=weighed food record. †Repeated-measures ANOVA (GLM) between dietitians for each dietary method, except for alcohol (#) which was Friedman's ANOVA: *p<0.05, compared to D1, all others not significant; ICC = Intra-class Correlation Coefficient significant: ***p<0.001; Difference within each dietitian's mean estimates of nutrient intake, NuDAM vs. WFR (paired t-test or #Wilcoxon Signed Ranked test): not significant; ‡Overall mean (\pm SD) intake = mean (D1, D2, and D3 intake per day); §difference between overall mean (\pm SD) estimate of nutrient intake, NuDAM vs. WFR: not significant for energy or macronutrient intakes or weight; ^Correlations are Pearson's correlation coefficient (r); except for alcohol (¶) which is Spearman's rank correlation coefficient (r_s): *p<0.05, ** p<0.01.

3.3 Usability, acceptability and changes to eating behaviours

All subjects preferred to use the NuDAM to record intake compared to the WFR, with “convenience”, “ease of use”, and “portability” used to explain preferences. All subjects would be willing to use both recording methods again. For the Nutricam mobile phone, the majority (n=9) would be willing to use again to record their intake for periods of up 7 days or longer, compared to the WFR, where up to 3 days was most common (n=5) maximum recording period. Subject responses to additional questions relating to the experience of the NuDAM and WFR are summarized in **Table 2**.

Changes in eating behaviours were reported for both methods (**Table 2**). More than half of the subjects reported a difference in how the methods were used when in the presence of others as opposed to when they were alone. The most common reason for this response was feeling more self-conscious and/or requiring to explain why they were recording their intake when in public compared to at home.

Regardless of the method used, forgetting to record prior to eating was the main reason for not recording all food items consumed. Making changes to the types of foods typically consumed were found for both methods, with most reporting simplify their intake in order to facilitate recording for the WFR.

Table 2: Evaluation of Nutricam dietary assessment method and weighed food record (n=10 subjects).

Questions (as presented):	Count			
Usability and acceptability[^]	<i>Strongly agree</i>	<i>Agree</i>	<i>Neutral</i>	<i>Disagree</i>
1. Overall, I found the <u>Nutricam</u> mobile phone easy to use:	7	2	1	0
2. Overall, I found <u>weighing</u> my foods and drinks easy:	0	3	4	3
NuDAM only:				
3. I found taking photographs of food and drink items easy:	5	5	0	0
4. I found recording the voice file easy:	5	5	0	0
5. I found that the Prompt Card was useful for remembering how	5	1	4	0

to use Nutricam:				
6. When prompted during the call:	8	1	1	0
a) I found it easy to clarify the details of the food and/or drink items that I had eaten during the previous day:				
b) I found it easy to remember if there were any food and/or drink items I had not recorded using the Nutricam mobile phone the previous day:	7	3	0	0
c) I found it easy to remember the description of the food and/or drink items I had not recorded using the Nutricam mobile phone the previous day:	6	4	0	0
d) I found it easy to remember the quantities of the food and/or drink items I had not recorded using the Nutricam mobile phone the previous day:	6	3	1	0
e) Overall, I found that the length of the calls I received were appropriate:	5	4	1	0
Change to eating behaviours	No	Yes		
7. Was there any difference in how you used the Nutricam mobile phone to record your diet when you were alone compared to when you were with other people or in public?	4	6		
8. Was there any difference in how you recorded your diet using the weighed record method when you were alone, compared to when you were with other people or in public?	2	8		
9. Did you record all food and drink items that you consumed during the test period using the Nutricam mobile phone?	5	5		
10. Did you record all food and drink items that you consumed during the test period using the weighed record method?	4	6		
11. Where there any foods and/or drinks that you usually eat, but did not eat during the Nutricam test period?	9	1		
12. Where there any foods and/or drinks that you usually eat, but did not eat during the weighed record method test period?	6	4		

Abbreviations: ^These questions were answered on a 5-point Likert Scale (Strongly agree/Agree/Neutral/Disagree/Strongly disagree); however no responses for the 'strongly disagree' category were recorded.

4. Discussion

This study assessed the criterion and relative validity and the inter-rater reliability of the NuDAM for the estimation nutrient intake in adults with T2DM. Compared to TEE, similar levels of under-reporting of EI were found for the NuDAM (-23.7%) and WFR (-23.9%). The level of reporting accuracy for the NuDAM is comparable with other studies using 3-day estimated or weighed food records, in which mean difference between EI and TEE have ranged from -31.8% to -9.2% [27,28]; and more favourable to using a 3-day food recall in obese adults with T2DM in which an error of -60.6% was reported [29]. Martin et al. used DLW to validate EI collected over 6 days using a mobile phone image-based dietary record among free-living overweight and obese adults. When used with

generic meal time reminders sent to the phone, mean participant error between EI and TEE was -34.3% compared to -8.8% and -3.7% when the reminder were tailored to the specific meal times of the individual[7]. The combination of a longer recording period and customised meal-time prompts may have contributed to the greater accuracy and will be considered for use in the future.

The associations between the NuDAM and WFR for estimated intakes of energy, protein, and carbohydrate were similar to studies in college students [14,15], although others have found stronger correlations [13,16]. Compared to these studies, estimates of fat intake between the NuDAM and WFR showed a weaker relationship ($r=0.24$), however intake was recorded concurrently and therefore differs from our study where records were collected one week apart and higher within-subject variation is expected. Alcohol intake was strongly correlated between methods ($r_s=0.85$) and displayed the strongest agreement between dietitians. The use of standardized serving vessels and detailed descriptions (e.g. “pint” glass) may have contributed to the high level of inter-rater reliability observed.

Inter-rater reliability for the NuDAM was moderate to high. Although discrepancies between dietitians’ nutrient estimates for the NuDAM existed, these did not translate to significant differences between methods in the overall mean intakes of the group. Similar studies have also found acceptable agreement between dietitians for estimates of nutrient intake derived from image-based and photographic records [10,12]. Although these previous studies were conducted in controlled settings of single meal occasions or using pre-prepared food items, while the NuDAM was used in a free-living situation over multiple days with opportunity for greater food variety.

Similar to other studies which have found a preference for image-based methods over traditional dietary assessment methods [8,13-15,30], the NuDAM was also well received among this group of older adults with T2DM. The willingness to use the NuDAM again for periods of time longer than 3 days is encouraging and highlights the potential utility of this method for other applications such as dietary self-monitoring. However, some refinement of the NuDAM is required to minimize the effect on analysis time that occurred with shifting some of the subject burden to the dietitian. New techniques which automate all or some of the quantification of foods within the image-based method hold promise for improving efficiency [31,32].

Change in behaviours were reported for both methods, although there appeared to be a slightly greater change in eating behaviours during the period recording with the WFR compared to the NuDAM. An increased awareness and changes to intake behaviours are common when diet is recorded [3-5],

including when automated image-based wearable devices are used [33]. Further exploration of the effect that using these newer dietary assessment methods has on dietary behaviours and intake are needed.

Strengths of this study include the use of a “gold standard” technique in DLW to validate EI and the use of standardized analysis protocol, including aids to estimate portion size of foods in the Nutricam records. Limitations include the small sample which limits generalisability of these results to the greater population of adults with T2DM. However, when using DLW, small samples have been used initially to validate measures of EI[18] and justify evaluation in larger numbers. The use of the same dietitian (D1) (MER) to review and clarify the dietary data and then to code the records is another potential limitation. Although, a standardized protocol was followed for all dietitians, increased familiarity with the subject intakes in the NuDAM and WRF could have contributed to the difference in nutrient intake estimates.

5. Conclusions

This study has shown that an image-based dietary assessment method with lower subject burden is both valid and reliable when compared to more traditional method of food intake assessment. In comparison to an objective measure of TEE, findings from this study demonstrate the NuDAM to perform equally well to a WFR in adults with T2DM. Relative validity was comparable to other photographic and image-based prospective methods for all nutrients, except for fat. Agreement between dietitians for estimates of nutrient intake was slightly lower for the NuDAM compared to WFR. Strong user preference and a willingness to use the NuDAM to record intake for longer periods suggest the NuDAM has potential to assess and monitor intake in adults with T2DM. Further investigation of mobile phone image-based dietary records in larger and more diverse groups are needed.

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Author Contributions

M. E. R. was involved in the study conception and design; data collection; statistical analysis and interpretation; drafting and critical revision of the manuscript. S. A. was involved in the study conception and design; critical revision of the manuscript; statistical analysis and interpretation; and supervision. P. L.-W. was involved in the study conception and design; critical revision of the manuscript; statistical analysis and interpretation; and supervision. A. R. was involved in the study conception and design; critical revision of the manuscript; and supervision. All authors have reviewed and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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