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Accuracy of formula preparation equipment for liquid measurement

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ABSTRACT

Background: Modular specialist feeds may consist of a number of individual liquid ingredients. Accurate feed preparation is dependent on competent liquid measurement. We investigate the accuracy of two measuring jugs (one retail mix-and-measure; and one produced to laboratory standards); and the influence of volume and technique on accuracy.

Materials and methods: 20 health professionals aged 18–60 y (mean: 46 y) measured 3 different volumes of water with each of two measuring jugs. For each volume with each jug, 2 measurements in randomised order were made: 1) eye-level with the jug, and 2) standing upright (total of 12 measurements). Measured quantities were weighed and the difference between measured and target volumes calculated.

Results: The laboratory jug was more accurate (mean difference 9.3 ml, range −30.5 to 57.5 ml, std error mean 1.59) than the retail jug (mean difference −17.7 ml, range −92.0 to 48.5 ml, std error mean 1.59). Accuracy improved with increased volume (450 ml: mean difference −9.4 ml, range −75.5 to 49.5 ml, std error mean 1.95; and 810 ml: mean difference −0.7 ml; range −92.0 to 43.0 ml, std error mean 1.95).

Abbreviations: IMD, Inherited metabolic disorders; Jug RMM, Retail mix and measure jug; Jug L, Laboratory standard jug.

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Conclusions: Accurate measurement of liquid ingredients is difficult to achieve even for trained professionals. The cumulative effect of many different liquid measurement errors (inappropriate jug type, inaccurate volume measured and poor technique) may lead to clinically important errors in the preparation of modular specialist feeds.

1. Introduction

Many children with inherited metabolic disorders (IMD) are nutritionally dependent on modular feeds with multiple ingredients. It has been demonstrated that in specialist modular feeds for IMD, increasing number of feed ingredients is associated with greater error and inaccurate feed preparation is common [1–4]. Inaccurate feed production may be associated with feed intolerance, diarrhoea, hypernatraemia, and uneven intake of prescribed nutrients such as protein or fat and even metabolic decompensation [5–8].

Pre-measured modular ingredients have been developed to help feed accuracy production in IMD. However, one consistent finding from a series of studies examining feed preparation in IMD is that fluid ingredients (commonly water, fat emulsions, and electrolyte solutions) are measured incorrectly. Some of these appear to be 'user error.' For example in a recent unpublished study, when preparing specialist feeds, 69% of caregivers measured liquids at standing height rather than eye level, thereby over diluting the end feed recipe [9]. Some of the fluid inaccuracies could also be due to equipment inaccuracies. Common practice is to use retail polypropylene plastic jugs for measuring liquids in feed production due to their low cost, availability and resilience. Bowl-shaped jugs are often used to enable feed mixing within the jug. The quality, size and graduation scale of available jugs vary and they are not precisely calibrated. The degree of error associated with different types of measuring jugs together with height positioning of feed maker has not been reported. This study assesses the accuracy and precision of two different measuring jugs and the impact on accuracy of fluid measurement when different volumes are measured at both eye level and at standing height.

2. Methods

2.1. Subjects

Twenty hospital dietetic health professionals all previously trained in weighing and measuring were recruited; median participant age: 46 years (range: 18–60); 18 female. Ethical approval was not required; however local Research and Development approval and written informed consent were obtained and the project was registered with the clinical governance team according to standard hospital procedures.

2.2. Study design

Participants measured 3 different volumes of water (450 ml, 650 ml and 810 ml) with each of two different measuring jugs. Each specified amount of water was measured twice by participants for each jug: 1) at eye level and 2) standing upright; a total of 12 measurements in randomised order. Each measured quantity was then weighed (unblinded) by the same two researchers using calibrated digital weighing scales. All water was at room temperature and maintained at 20–21 °C.

Results were then compared with target volumes (weight of water − assuming 450 ml = 450 g, 650 ml = 650 g and 810 ml = 810 g).

2.3. Study jugs

Jug L (laboratory standard): a tall, straight sided, 2000 ml polypropylene measuring jug; with moulded graduations in 50 ml increments (Manufacturer: Azlon [SciLabware], JPM2000P).

Jug RMM (retail mix and measure): a 2000 ml, bowl shaped polypropylene measuring jug from a retail outlet; with printed graduations in 100 ml increments (Manufacturer: Stewart, 1484008).

All jugs were new and unused. Three of each jug type was available for use during each measurement.

2.4. Statistics

Based on pilot data, a 3% difference in mean accuracy between eye level and upright position would be found as statistically significant ($p < 0.05$) with 97% power probability; and a 2% difference in mean accuracy between jug types would be significant ($p < 0.05$) with 85% power probability with a sample size of 20 participants.

The difference between target volume and actual amount was calculated for each jug and for each measuring technique (eye level vs. upright) and compared using general linear model analysis of variance to assess and adjust for the additional variation in the differences between measurers, between jug types and their possible interactions. Normality of residual variation unaccounted for by these analyses was assessed by the Shapiro–Wilk test.

3. Results

3.1. Jug type

Jug L was more accurate (closer to the accepted or 'true' value) and more precise (with a lower spread of values) than Jug RMM (Table 1; Figs. 1 and 2).

3.2. Volume measured

The 3 volumes of measurement (450 ml, 650 ml, 810 ml) produced significantly different results ($p < 0.0001$; ANOVA; Table 1). When the interaction between target volume and jug type was taken into account, differences were still significant ($p = 0.05$; ANOVA). Accuracy and precision were correlated with increased volume measured (Table 1). Volumes were measured less accurately in jug RMM particularly in an upright position possibly due to the curvature of the jug and the less frequent incremental markings on the jug.

3.3. Technique

Measurements made at eye level (mean difference 1.5 ml; range −75.5 to 57.5 ml, *SD* 1.59) were significantly more accurate and more precise than those made in an upright position (mean difference −9.9 ml; range −92.0 to 49.5 ml, *SD* 1.59) ($p < 0.0001$; ANOVA). However, when the interaction between target volume and technique was taken into account, differences were no longer significant

Table 1
Mean difference in millilitres (range) between measured and target (weighed) volumes for: jug type (L and RMM), technique (eye level vs. upright) and volume (450 ml, 650 ml and 810 ml) including analysis of variance for differences between jug types and between volumes (n = 20).

		Jug L		Jug RMM		Mean of all values	p value*
		Eye level	Upright	Eye level	Upright		
450ml	ml (range) *SD*	13.4 (−3.0–39.0)	0.8 (−30.5–49.5)	−21.4 (−75.5–1.5)	−30.4 (−69.5–20.0)	−9.4 (−75.5–49.5) *1.95*	<0.0001
650ml	ml (range) *SD*	13.2 (−10.0–57.5)	8.3 (−27.0–36.0)	−4.9 (−22.5–48.5)	−26.7 (−59.5–8.0)	−2.5 (−59.5–57.5) *1.95*	
810ml	ml (range) *SD*	12.9 (−7.0–43.0)	7.4 (−22.5–39.5)	−4.1 (−21.0–27.5)	−19.0 (−92.0–23.0)	−0.7 (−92.0–43.0) *1.95*	
Mean of all values	ml (range) *SD*	9.3 (−30.5–57.5) *1.59*		−17.7 (−92.0–48.5) *1.59*			
p value#		<0.0001					

Jug L = Laboratory standard jug; Jug RMM = Retail mix and measure jug.
SD = Standard deviation.
* ANOVA (Analysis of variance): significant difference between each of the 3 volumes of measurement.
# ANOVA: significant difference between jug type L and RMM for all measurements.

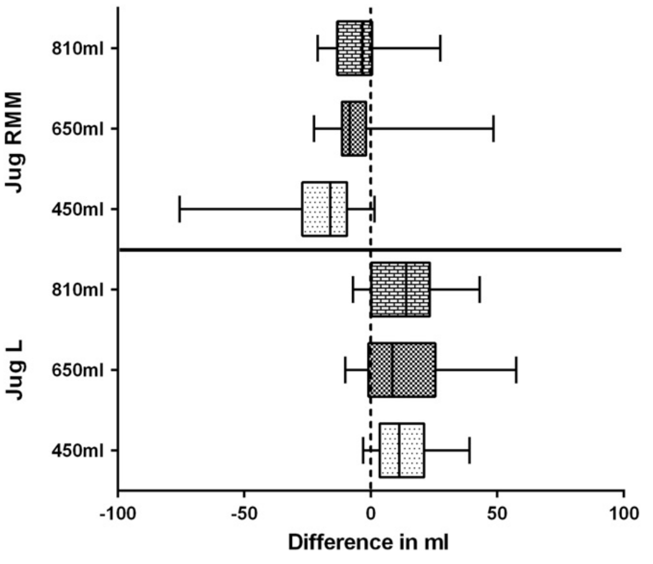

Fig. 1. Difference in ml between observed volume and expected volume for all *eye level* measurements (n = 20). Footnote: boxes = first to third quartile; line = second quartile (median); whiskers = minimum and maximum of all data.

(p = 0.81; ANOVA). This suggests that the volume of water was a confounding factor that had more influence on the accuracy of measurement than did the technique.

3.4. Variability in jugs

Each jug of the same type was used by between 3 and 10 participants for each of the measurements. A comparison of the results for each jug type (Jug L1, L2, L3; Jug RRM1, RMM2, RMM3) showed that there was significant variability between jugs of the same type ($p < 0.0001$; ANOVA) (Table 2; Figs. 3 & 4). No two jugs

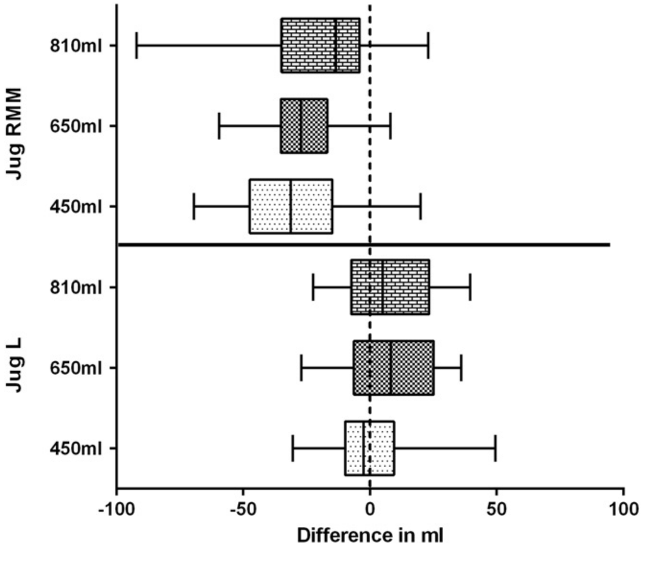

Fig. 2. Difference in ml between observed volume and expected volume for all *upright* measurements (n = 20). Footnote: boxes = first to third quartile; line = second quartile (median); whiskers = minimum and maximum of all data.

of the same type measured exactly the same, although Jug RMM did consistently measure less than expected and Jug L more than expected but the latter was also consistently more accurate and more precise.

3.5. Participants

Measurements between individual participants were also significantly different ($p = 0.001$; ANOVA).

4. Discussion

Measuring liquid volumes accurately is fundamental in specialist modular feed production and accuracy is vital in some conditions where feed composition can influence feed tolerance and metabolic stability. There have been known case reports of hospital admissions attributable to incorrect liquid measurement of feed ingredients [3]. We have observed some children with organic acidaemias on low protein modular feeding plans receive excessively diluted feeds resulting in low energy density feeds and poor weight gain possibly affecting metabolic control and leading to metabolic decompensation. We have also seen children with glycogen storage disease receiving over-diluted feeds leading to a lower than calculated carbohydrate feed profile and consequential hypoglycaemia. Liquid measurement is susceptible to equipment and execution inaccuracies. These study results demonstrate that accuracy and precision are dependent upon the type of jug, measuring technique and the volume of water measured.

A laboratory standard jug, measured at eye level for a large volume is generally more accurate and more precise than a retail jug measured in an upright position for a smaller volume. In addition, no two jugs even of the same design, measure as accurately and precisely as each other. There is a significant degree of inaccuracy inherent in the shape and design of measuring jugs, even when measured by health professionals who understand the importance of correct feed preparation. However it is acknowledged that the laboratory standard jug had smaller and therefore potentially more accurate graduations than the retail jug and this may have been a confounding factor. In addition, neither jug was 100% accurate (i.e. 100 ml = 100 g) to begin with and this will naturally increase overall errors.

There are few published studies examining accuracy of fluid measurements in hospital practice [10]. However, it is unsurprising that measuring jugs purchased from retail shops are likely to have lower accuracy and precision than volumetric measuring equipment used by laboratories which carry a CE mark (an indicator that the jug meets essential safety and environmental requirements as defined in the European Directives). However, these receptacles are impractical and no measuring jugs carrying a CE mark are suitable for clinical feed preparation [11].

The results suggest there may be a number of simple practices that can enhance accuracy of fluid measurement:

- allowing fluid to drain from measuring containers;
- measuring at eye level rather than standing height;
- using the smallest measuring jug that will accommodate the required volume;
- calculating modular feed recipes so that the final volume is rounded up to a major graduation mark;
- advocating jugs with clear and distinct graduation marks;
- minimising the use of liquid ingredients in feed recipes;
- if there is no alternative but to use more than one liquid ingredient in a feed recipe, checking that caregivers do not confuse the volume required of each liquid;

Table 2
Mean difference in millilitres between measured and target (weighed) volumes for jugs of the same type (n = 20).

Jug	Laboratory jugs			Retail mix & measure jugs		
	L1 ml	L2 ml	L3 ml	RMM 1 ml	RMM 2 ml	RMM 3 ml
Mean difference (range)	−2.6 (−30.5–33.5)	24.5 (−3.5–57.5)	8.7 (−15–31.5)	−16.3 (−59–20)	−24.2 (−92–48.5)	−13.6 (−75.5–27.5)
SD	*2.34*	*2.45*	*2.18*	*2.41*	*2.40*	*2.18*

Jug L = Laboratory standard jug; Jug RMM = Retail mix and measure jug.
SD = Standard deviation.

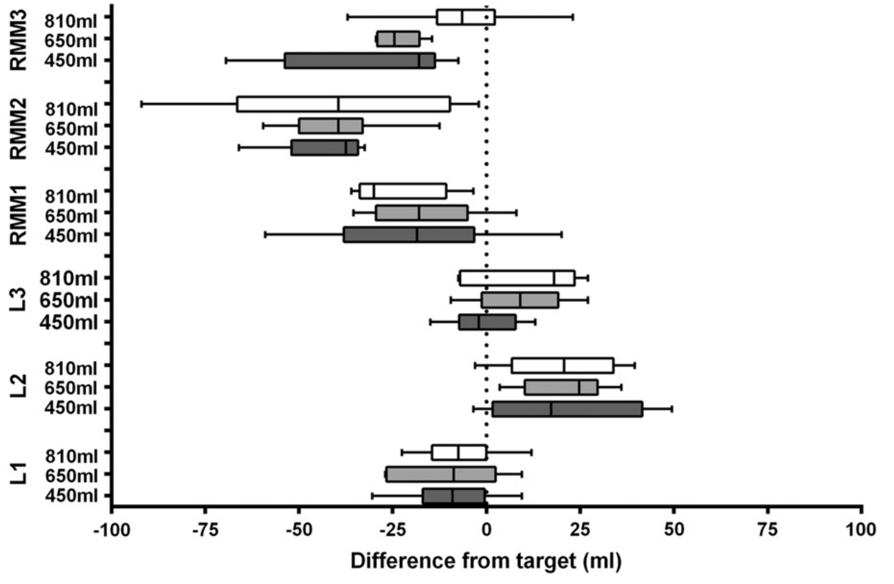

Fig. 3. Variability of results for jug L and jug RMM for all *upright* measurements (n = 20). Footnote: boxes = first to third quartile; line = second quartile (median); whiskers = minimum and maximum of all data.

- using the same jug for individual patients to minimise day-to-day variations;
- checking caregiver feed preparation technique and reviewing this annually.

Routinely weighing fluids rather than using measuring jugs may be a safer alternative.

In conclusion, whilst individual errors in fluid measurement due to inherent errors within the equipment (e.g. jug type), or the volume measured, or poor technique (upright vs. eye level), may not be clinically

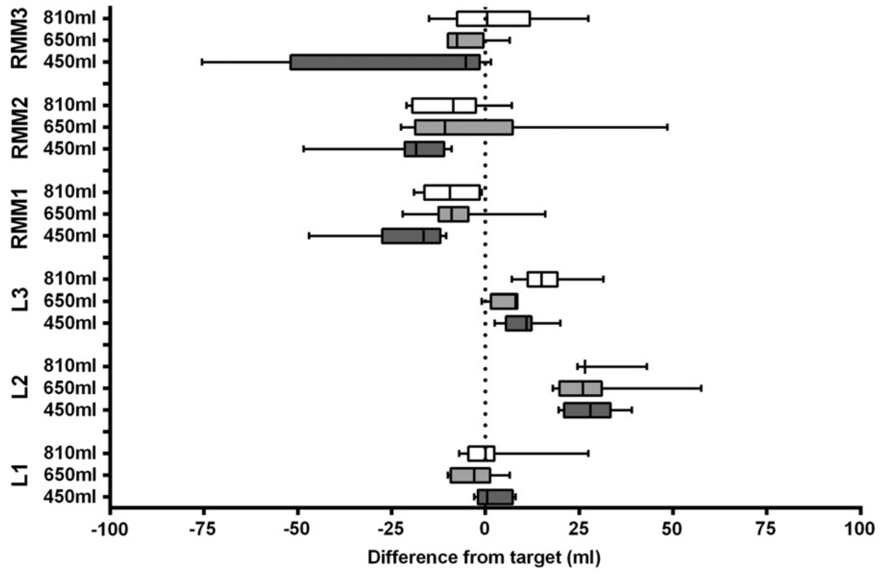

Fig. 4. Variability of results for jug L and jug RMM for all *eye level* measurements (n = 20). Footnote: boxes = first to third quartile; line = second quartile (median); whiskers = minimum and maximum of all data.

significant, the cumulative effect of errors in all these parameters, may lead to considerable inaccuracy in special feed production. This work was conducted by health professionals under research conditions, but under home conditions any liquid measurement errors may be multiplied particularly if parents/caregivers are inexperienced in feed production. Further work is required to assess: the influence of fluid viscosity on accuracy of measurement; the effect of cleaning conditions on jug performance over time; how caregiver competency compares with that of health professionals and the accuracy of weighing fluids.

Authorship

All authors were involved in the initial study conception and design, collection of data and critical review of the manuscript. In addition, SE and AM were involved in the analysis of the data and drafting of the manuscript. All authors have read and approved the final manuscript.

Conflict of interest

Anita MacDonald receives research funding and honoraria from Nutricia, Vitaflo International and Merck Serono International. She is a Member of the European Nutrition Expert Panel (Merck Serono International), the Sapropterin Advisory Board (Merck Serono International) and the Advisory Board Element (Danone-Nutricia). Sharon Evans is a research dietitian funded by Nutricia and along with Catherine Ashmore and Anne Daly, receives financial support from Nutricia and Vitaflo International to attend study days and conferences. However, this study was not done in collaboration with any commercial companies in terms of the study design, conduct, funding, or preparation of the paper and we do not anticipate benefit for any companies in direct connection with the results of the study.

Source of funding

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