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DIETETIC PROFESSION

Communication skills teaching for student dietitians using experiential learning and simulated patients

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Keywords
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Abstract

Background: Dietitians require communication competencies for effective dietetic practice. There is little evidence on how student dietitians experience and value communication skills teaching. The present study aimed to measure attitudes of student dietitians with respect to communication skills teaching and how experiential learning using simulated patients impacts confidence in their communication skills.

Methods: Communication skills teaching adopting an experiential skills-based approach including practice with simulated patients, feedback and reflection were developed. A 67-item questionnaire with three sections: (i) views regarding the importance of communication skills to dietetic practice; (ii) attitudes to learning communication skills using a modified Communication Skills Attitude Scale; and (iii) confidence in their own communication skills, was completed by students before and after the course, with responses recorded on a five-point Likert scale and analysed pairwise using McNemar's test.

Results: Over three academic years, 112 students (91.8% response rate) completed the evaluation. After training, students rated communication skills as important for patient satisfaction (100%) and relationships with patients (99.1%). Student dietitians had positive attitudes to learning communication skills with positive attitudes scale score before teaching of mean (SD) 53.6 (5.3) and after of 54.0 (5.8) ($P = 0.162$). Following experiential teaching, the proportion of students feeling 'very or extremely confident' in understanding a patient's perspective increased from 27.7% to 41.1% ($P = 0.008$) and for reaching agreement with a patient from 4.5% to 17.9% ($P = 0.001$).

Conclusions: Student dietitians consider communication skills important for dietetic practice. They receive teaching positively and an experiential skills-based approach can improve self-rated confidence.

Introduction

Effective communication is a fundamental component of dietetic practice and is critical to the success of nutrition interventions across all settings (1). Interpersonal communication has been identified as one of the defining features of professionalism in dietetic practice (2). This is reflected in the prominence given to communication skills in curricula and professional standards internationally (3–5).

In recent years, there has been a move to a more patient-centred approach in healthcare. The principles of patient-centred care afford people dignity, compassion and respect at the same time as offering co-ordinated, personalised and enabling care (6,7). Research confirms that patient-centred care is also important to patients (8).

The World Health Organization endorse the broader people-centred approach in both clinical encounters and public health settings [9]. Communication skills are fundamental to the provision of patient-centred care and are a key competence for dietitians.

Studies exploring effective communication in dietetic practice measure different aspects of communication using different tools, although they identify a range of positive aspects of communication [1,10–13]. Skills such as active listening, paraphrasing and questioning are important communication skills that help develop collaborative relationships with patients [14]. Dietitians require a range of communication competencies to enhance the dietitian–patient relationship [15]. In practice, teaching methods in this area are evolving, moving from traditional didactic approaches to more experiential methods [16] and acquiring the range of communication competencies required relies on student dietitians valuing and engaging with training in this area.

Registered dietitians have reported some dissatisfaction with their pre-registration training in communication skills. Dietitians in the UK reported that their pre-registration training was deficient in active listening skills and behaviour change techniques [17], which was confirmed in a more recent survey where only 44% of dietitians reported having communication skills training for behaviour change during pre-registration training with lectures, role play and observation being the preferred teaching methods [18]. Dietitians in Australia varied in their perceptions of how pre-registration training prepared them for counselling in practice, with 49% rating it 'good or excellent' among those qualifying between 1964 and 1987, rising to 87% in those graduating in the previous 3 years [19]. In a study examining the nutrition counselling self-efficacy of dietitians in the USA, those with the lowest scores were generally newly qualified and inexperienced with higher scores associated with years of experience and skill usage [20]. These studies conclude that dietitians perceive pre-registration training should have more communication training with greater emphasis on skills rather than knowledge but do not specifically measure the attitudes, experiences and confidence of student dietitians regarding communication skills and communication skills training.

Understanding attitudes to communication skills and communication skills teaching is of paramount importance [21]. Studies in medical students report more positive attitudes to learning communication skills among females and younger students [21,22]. However, there is limited research on attitudes among student dietitians. In a survey of 300 student dietitians, no differences in attitudes to communication skills were identified between females and males (although 95.7% of respondents were female). Students held more positive attitudes to learning communication skills earlier in their university career, with a decline during their training [23]. This study did not address how communication skills were taught across the different universities and it is unclear whether the method of teaching communication skills influences students' attitudes to learning.

Communication skills teaching has evolved to reflect more recent evidence regarding effectiveness [1]. Experiential learning can enhance healthcare students' engagement with teaching and communication skills development [24] and, although there are only limited studies, role playing can be effective [25]. Simulated patients and objective structured clinical exams (OSCE), assessments designed to test clinical skill performance and competence in relation to key aspects of a consultation, are increasingly employed to provide experiential learning opportunities for students to apply theory, practise skills and receive feedback [26]. Despite extensive research on simulated patients and OSCEs among medical and nursing students, almost no research has been undertaken in student dietitians. In one study, repeated exposure of dietetic students to simulated patients during OSCEs improved communication skills, particularly for students who were borderline on initial assessment [27]. Further research is warranted on the effectiveness of this resource-intensive approach in dietetic pre-registration education.

The present study aimed to measure pre-registration student dietitians' attitudes to communication skills and communication skills training and to evaluate the impact of experiential learning using simulated patients and OSCEs on their confidence in their own communication skills.

Materials and methods

The study was an evaluation of pre-registration dietetic students' compulsory communication skills teaching, completed as part of their programme at King's College London, using a before and after questionnaire design.

Communication skills teaching

Students undertaking either a Bachelor of Science in Nutrition and Dietetics (4 years) or a Postgraduate Diploma/Masters in Dietetics (1.5–2 years) completed a communication skills course as part of their programme. This was delivered after a 2-week introductory practice placement and immediately before a 12-week practice placement in the latter part of the programme. The course includes a component specifically for communication skills that adopts an experiential skills-based approach rather than a didactic teaching style [16]. The course content covers the essential communication skills required for dietetic practise including the concepts of patient-centred care and nutrition counselling [4,28].

The essential elements of this experiential learning model include defining and isolating the essential skills that need to be taught to provide a focus for each skills-based session [16], direct observation of students using simulated patients, provision of detailed and constructive verbal feedback and enabling communication skills to be practised until attained (Fig. 1). The course was delivered using a mixture of teaching strategies incorporating formal classroom teaching, communication skills practice with simulated patients (trained patient actors), including active participation as both a participant and observer, peer feedback and assessed using summative OSCEs. This took the form of six 3-hour sessions, each focussed on an aspect of communication skills, facilitated by registered dietitians trained in working with simulated patients and facilitating feedback. The simulated patients were actors trained in undertaking patient-related teaching activities and are used widely in medical, nursing and healthcare education throughout the College.

Questionnaire survey

All students were invited to complete a questionnaire before (immediately before starting) and after (within 16 weeks) the communication skills teaching component of the course during the academic years 2012–13, 2013–14 and 2015–16. The survey was not undertaken in 2014–2015. Ethical approval was not required for this service evaluation of communication skills training [29]. Participation was voluntary. Completed questionnaires were anonymised and assigned a unique identifier for matching purposes and the anonymised data were entered by researchers independent of the teaching team prior to analysis.

The 67-item questionnaire consisted of three sections: (i) attitudes regarding the importance of communication skills to dietetic practice; (ii) attitudes to learning communication skills; and (iii) confidence in their own communication skills. Questions were developed after a review of the literature on communication skills in healthcare.

Views on the importance of communication skills in dietetic practice were measured using 10 questions from an unvalidated questionnaire used previously to measure

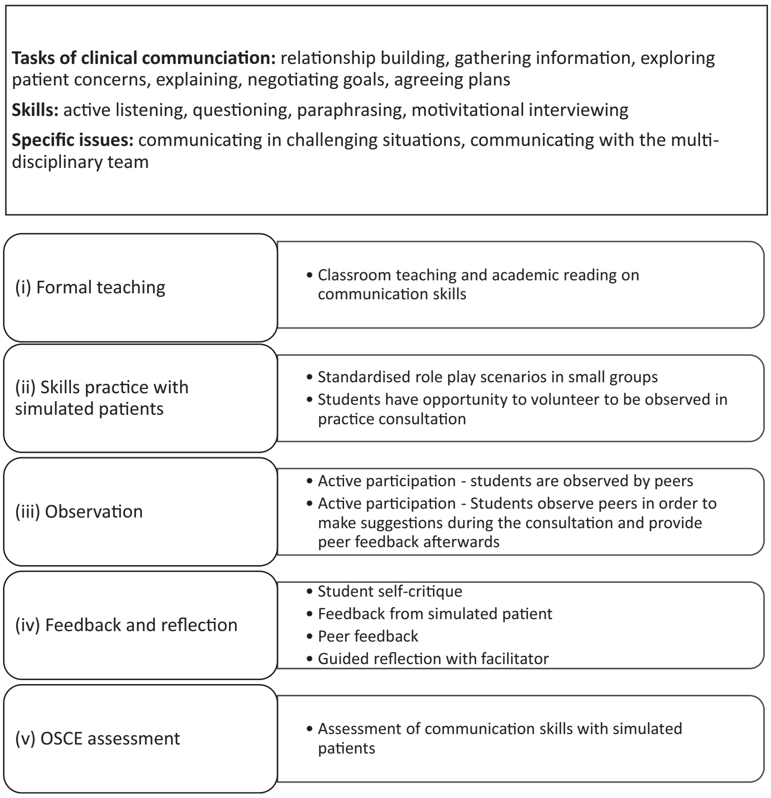

Figure 1 Overview of the model of communication skills teaching. OSCE, objective structured clinical exams.

the views of dietitians regarding communication skills for behaviour change [18]. Each question related the importance of communication skills to an aspect of practice (e.g. patient satisfaction, relationships with patients and colleagues) and responses were reported on a five-point Likert scale from 1 (not at all important) to 5 (extremely important). The sum of responses to the 10 questions was used to investigate correlations with other variables.

Attitudes to learning communication skills were measured using the Communication Skills Attitude Scale (CSAS), which has proven internal consistency in measuring medical students' attitudes to learning communication skills [30] and was later adapted for use in student dietitians [23]. The CSAS consists of 26 statements measuring both positive attitudes (e.g. learning communication skills is interesting, learning communication skills is important because the ability to communicate is a lifelong skill) and negative attitudes (e.g. I can't see the point in learning communication skills, learning communication skills is too easy) and reported on a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). The sum of the scores of different CSAS statements was used to determine positive attitude (PAS) and negative attitude (NAS) subscales with each subscale having a range of 13-65 and larger values representing more positive or negative attitudes.

Students' confidence in their own communication skills was assessed using statements developed from the Kalamazoo Consensus Statement [31]. This framework was developed with the aim of delineating the essential communication tasks required for effective medical encounters and lists seven competencies of communication: (i) building relationships; (ii) opening the discussion; (iii) gathering information; (iv) understanding the patient's perspective; (v) sharing information; (vi) reaching agreement on problems and plans; and (vii) providing closures. Each competency has a range of sub-competencies. Students were asked to rate their confidence in each of the seven competencies and 24 sub-competencies on a five-point Likert scale ranging from 1 (not at all confident) to 5 (extremely confident).

Statistical analysis

Where students did not complete an entire questionnaire before or after the teaching, the entire dataset for that student before and after teaching was excluded (n = 10). Where data were missing for individual responses in the pre- or post-questionnaire, values were imputed using the median response for that question, and this was performed for 107 (0.7%) data points.

All quantitative data were entered into and analysed using SPSS, version 24 [32]. Categorical data are expressed as frequencies and percentages and continuous data as mean and standard deviation. Normality of the data was assessed using Kolmogorov–Smirnov test. Continuous data were compared using Wilcoxon signed-rank tests and paired categorical data were compared using McNemar's test (e.g. confidence before and after teaching). A series of Spearman's rank-order correlations were performed to determine the relationship between sample characteristics, views on the importance of communication skills and attitudes to learning these skills.

Results

Over the three academic years under investigation, 122 student dietitians underwent communication skills training. Of these, 112/122 (91.8%) completed the questionnaire both before and after teaching. The reason for non-completion was predominantly non-attendance when questionnaires were administered. Paired questionnaires were completed by 36 students in 2012–13, 41 in 2013–14 and 35 in 2015–16. Participant details are presented in Table 1. Participants were predominantly female (n = 99, 88.4%) with a mean (SD) age of 24.4 (21.1) years.

Importance of communication skills

Students completed the questionnaire before and after communication skills training. Following teaching, in general scores for the importance of communication skills increased. These were not statistically significant apart from the scores for perceiving communication skills to be important for job satisfaction which increased after communication skills teaching [before 4.0 (0.7) versus after 4.2 (0.7), P = 0.035] (Table 2).

Table 1 Participant characteristics of 112 student dietitians who completed communication skills teaching

	Student characteristics (n = 112)
Gender, n (%)	
Male	13 (11.6)
Female	99 (88.4)
Age, years, *mean (SD)*	24.4 (21.1)
Programme, n (%)	
BSc Nutrition and Dietetics	67 (59.8)
MSc/PGDip Dietetics	45 (40.2)
Highest educational qualification, n (%)	
A level	43 (38.4)
University access course	4 (3.6)
BSc/BA	47 (42.0)
MSc/MA	17 (15.2)
PhD	1 (0.9)
Previous healthcare experience, n (%)	40 (35.7)

Following communication skills teaching, the majority of students rated communication skills as 'very important' or 'extremely important' for all 10 aspects of dietetic practice in the questionnaire (70.5–100%) (Table 2). All students rated communication skills as 'very important' or 'extremely important' for patient satisfaction and almost all rated communication skills as important for relationships with patients (99.1%) and for job satisfaction (86.6%). Although most responses were positive, small numbers of students reported some aspects of communication skills to be less important (i.e. 'not at all, slightly or moderately' important), including 'relationships with colleagues' 17 (15.2%) and 'patient did not attend rates' 26 (23.2%). Fewer students rated communication skills as important for time keeping (70.5%).

Attitudes to learning communication skills

Student dietitians had positive attitudes to learning communication skills. The mean (SD) PAS score before the training programme was 53.6 (5.3) and after training was 54.0 (5.8) ($P = 0.162$), whereas the NAS score was 23.6 (4.3) before training and 23.3 (5.0) after training ($P = 0.26$).

Following communication skills teaching, the vast majority of students either agreed or strongly agreed that 'in order to be a good dietitian I must have good communication skills' (99.2%) and that 'developing my communication skills is just as important as developing my knowledge of dietetics' (86.6%) (Table 3).

Although the majority held positive attitudes and agreed or strongly agreed that 'learning communication skills is interesting' (88.4%), just over half considered that 'learning communication skills is fun' (58%). Some responses indicated negative attitudes; for example, 27 (24.1%) considered that 'communication skills teaching states the obvious and then complicates it' (24.1%) and a quarter indicated they 'found it hard to admit having problems with communication skills' (25.9%).

Before teaching, the sum of responses to questions on the importance of communication skills strongly and positively correlated with PAS score (Spearman's rho, $r_s = 0.609$, $P \leq 0.001$) and negatively correlated with NAS score ($r_s = .438$, $P = 0.001$, $n = 112$). Mann–Whitney *U*-tests revealed no difference between either PAS or NAS scores depending upon either sex or programme of study, with the exception of males reporting higher NAS scores [median 26, interquartile range (IQR) = 5, $n = 13$] than females (median 23, IQR = 6, $n = 99$) before teaching ($Z = -2.664$, $P = 0.018$).

After teaching, there was a significant difference in attitude scores according to highest qualification. Students holding a previous Bachelor's degree (or higher) had greater PAS scores (median = 56, IQR = 7, $n = 65$) than those without a previous degree (median = 52, IQR = 7, $n = 47$, $Z = -2.564$, $P = 0.010$) and lower NAS (median = 22, IQR = 6, $n = 65$) than those without a

Table 2 Attitudes to the importance of communication skills in 112 student dietitians

	After communication skills teaching						Attitudes score*		
How important are communication skills for behaviour change in relation to:	Not at all important *n* (%)	Slightly important *n* (%)	Moderately important *n* (%)	Very important *n* (%)	Extremely important *n* (%)	Either very or extremely important *n* (%)	Before teaching mean (SD)	After teaching mean (SD)	*P* value†
Relationships with patients	0 (0)	1 (0.9)	0 (0)	22 (19.6)	89 (79.5)	111 (99.1)	4.7 (0.5)	4.8 (0.5)	0.225
Relationships with colleagues	0 (0)	5 (4.5)	12 (10.7)	39 (34.8)	56 (50.0)	95 (84.8)	4.2 (0.9)	4.3 (0.8)	0.131
Job satisfaction	1 (0.9)	0 (0)	14 (12.5)	59 (52.7)	38 (33.9)	97 (86.6)	4.0 (0.7)	4.2 (0.7)	0.035
Patient satisfaction	0 (0)	0 (0)	0 (0)	19 (17.0)	93 (83.0)	112 (100.0)	4.8 (0.4)	4.8 (0.4)	0.371
Patient 'did not attend' rates	1 (0.9)	4 (3.6)	21 (18.8)	34 (30.4)	52 (46.4)	86 (76.8)	4.1 (0.8)	4.2 (0.9)	0.112
Patient clinical outcomes	1 (0.9)	0 (0)	7 (6.3)	48 (42.9)	56 (50.0)	104 (92.9)	4.4 (0.6)	4.4 (0.7)	0.716
Your confidence in client interviews	0 (0)	0 (0)	2 (1.8)	33 (29.5)	77 (68.8)	110 (98.2)	4.6 (0.6)	4.7 (0.5)	0.186
Your time keeping in client interviews	5 (4.5)	5 (4.5)	23 (20.5)	36 (32.1)	43 (38.4)	79 (70.5)	3.9 (0.9)	4.0 (1.1)	0.633
Coping with challenging clients	0 (0)	3 (2.7)	1 (0.9)	22 (19.6)	86 (76.8)	108 (96.4)	4.6 (0.6)	4.7 (0.6)	0.255
Obtaining an accurate diet history	0 (0)	6 (5.4)	8 (7.1)	45 (40.2)	53 (47.3)	98 (87.5)	4.2 (0.9)	4.3 (0.8)	0.488

*Attitudes score is the mean (SD) score from each question on the 5-point Likert scale for all participants before or after communication skills teaching.

†Wilcoxon signed-rank test.

Table 3 Attitudes to learning communication skills in 112 student dietitians

	Attitudes after communication skills teaching					Attitude score*		
	Strongly disagree *n* (%)	Disagree *n* (%)	Neutral *n* (%)	Agree *n* (%)	Strongly Agree *n* (%)	Before teaching mean (sd)	After teaching mean (sd)	*P* value†
In order to be a good dietitian I must have good communication skills	1 (0.9)	0 (0)	0 (0)	6 (5.4)	105 (93.8)	5.0 (0.2)	4.9 (0.4)	0.206
I can't see the point in learning communication skills	85 (75.9)	19 (17.0)	3 (2.7)	2 (1.8)	3 (2.7)	1.4 (0.6)	1.4 (0.9)	0.884
Nobody is going to fail their dietetics degree for poor communication skills	28 (25.0)	57 (50.9)	22 (19.6)	3 (2.7)	2 (1.8)	2.1 (0.8)	2.1 (0.9)	0.525
Developing my communication skills is just as important as developing my knowledge of dietetics	1 (0.9)	6 (5.4)	8 (7.1)	42 (37.5)	55 (49.1)	4.3 (0.7)	4.3 (0.9)	0.935
Learning communication skills has helped or will help me respect patients	0 (0)	3 (2.7)	11 (9.8)	46 (41.1)	52 (46.4)	4.2 (0.7)	4.3 (0.8)	0.234
I haven't got time to learn communication skills	47 (42.0)	50 (44.6)	9 (8.0)	6 (5.4)	0 (0)	1.8 (0.7)	1.8 (0.8)	0.72
Learning communication skills is interesting	0 (0)	3 (2.7)	10 (8.9)	61 (54.5)	38 (33.9)	4.1 (0.8)	4.2 (0.7)	0.042
I can't be bothered to turn up to sessions on communication skills	77 (68.8)	27 (24.1)	8 (7.1)	0 (0)	0 (0)	1.6 (0.7)	1.4 (0.6)	0.003
Learning communication skills has helped or will help facilitate my team-working skills	1 (0.9)	2 (1.8)	11 (9.8)	56 (50.0)	42 (37.5)	4.2 (0.7)	4.2 (0.8)	0.989
Learning communication skills has improved or will improve my ability to communicate with patients	0 (0)	1 (0.9)	0 (0)	35 (31.3)	76 (67.9)	4.6 (0.6)	4.7 (0.5)	0.101
Communication skills teaching states the obvious and then complicates it	8 (7.1)	51 (45.5)	26 (23.2)	25 (22.3)	2 (1.8)	2.5 (0.8)	2.7 (1.0)	0.029
Learning communication skills is fun	0 (0)	8 (7.1)	39 (34.8)	55 (49.1)	10 (8.9)	3.4 (0.6)	3.6 (0.8)	0.011
Learning communication skills is too easy	25 (22.3)	67 (59.8)	18 (16.1)	1 (0.9)	1 (0.9)	2.2 (0.7)	2.0 (0.7)	0.003
Learning communication skills has helped or will help me respect my colleagues	1 (0.9)	7 (6.3)	25 (22.3)	59 (52.7)	20 (17.9)	3.8 (0.8)	3.8 (0.8)	0.498
I find it difficult to trust information about communication skills given to me by dietitians who do not work in a clinical environment	30 (26.8)	64 (57.1)	12 (10.7)	6 (5.4)	0 (0)	2.0 (0.8)	2.0 (0.8)	0.36
Learning communication skills has helped or will help me recognise patients' rights regarding confidentiality and informed consent	0 (0)	10 (8.9)	20 (17.9)	64 (57.1)	18 (16.1)	3.9 (0.8)	3.8 (0.8)	0.502
Communication skills teaching would have a better image if it sounded more like a science subject	28 (25.0)	54 (48.2)	19 (17.0)	11 (9.8)	0 (0)	2.2 (0.8)	2.1 (0.9)	0.598
When applying for dietetics, I thought it was a really good idea to learn communication skills	1 (0.9)	7 (6.3)	19 (17.0)	56 (50.0)	29 (25.9)	4.0 (0.8)	3.9 (0.9)	0.064
I don't need good communication skills to be a dietitian	94 (83.9)	17 (15.2)	0 (0)	0 (0)	1 (0.9)	1.2 (0.4)	1.2 (0.5)	0.67
I find it hard to admit to having problems with my communication skills	7 (6.3)	60 (53.6)	16 (14.3)	28 (25.0)	1 (0.9)	2.6 (1.0)	2.6 (1.0)	0.087
I think it's really useful learning communication skills on the dietetics degree	1 (0.9)	1 (0.9)	5 (4.5)	46 (41.1)	59 (52.7)	4.5 (0.6)	4.4 (0.7)	0.262
My ability to pass exams will get me through my dietetics degree rather than my ability to communicate	21 (18.8)	48 (42.9)	20 (17.9)	19 (17.0)	4 (3.6)	2.4 (0.9)	2.4 (1.1)	0.5

Table 3 Continued

	Attitudes after communication skills teaching					Attitude score*		
	Strongly disagree n (%)	Disagree n (%)	Neutral n (%)	Agree n (%)	Strongly Agree n (%)	Before teaching mean (sd)	After teaching mean (sd)	P value†
Learning communication skills is applicable to learning dietetics	1 (0.9)	0 (0)	3 (2.7)	38 (33.9)	70 (62.5)	4.5 (0.6)	4.6 (0.6)	0.044
I find it difficult to take learning communication skills seriously	45 (40.2)	52 (46.4)	10 (8.9)	4 (3.6)	1 (0.9)	1.8 (0.7)	1.8 (0.8)	0.347
Learning communication skills is important because my ability to communicate is a lifelong skill	1 (0.9)	1 (0.9)	1 (0.9)	37 (33.0)	72 (64.3)	4.6 (0.5)	4.6 (0.7)	0.056
Learning communication skills should be left to psychology students, not dietetic students	76 (67.9)	34 (30.4)	1 (0.9)	0 (0)	1 (0.9)	1.3 (0.5)	1.4 (0.6)	0.739

*Attitudes score is the mean (SD) score from each question on the 5-point Likert scale for all participants before or after communication skills teaching.
†Wilcoxon signed-rank test.

previous degree (median = 24, IQR = 8, n = 47, Z = 2.095, P = 0.036).

Confidence in communication skills

Before communication skills teaching, the proportion of student dietitians feeling 'very or extremely confident' in the seven competencies ranged between 4.5% (reaching agreement with a patient) and 27.7% (understanding a patient's perspective), whereas after communication skills training this increased to 17.9% (reaching agreement with a patient) and 44.6% (opening a discussion with a patient) (Table 4) and there was a statistically significant improvement in confidence ('very or extremely confident) for six of the seven competencies. For student's mean confidence scores, there was a significant improvement in all seven communication competencies after completing communication skills training (Table 4).

Meanwhile, for the individual sub-competencies, before communication skills teaching 6.3–57.1% of student dietitians felt 'very or extremely confident' in the 24 sub-competencies, whereas after communication skills teaching this increased to 16.1–63.4% (Table 4). The increase in numbers feeling 'very or extremely confident' was statistically significant for 18 out of the 24 sub-competencies. After completing communication skills teaching, there was a significant improvement in students' confidence score in performing 22 of the 24 tasks with the exception of task 6d ('identifying additional resources as appropriate') and task 7c ('clarifying follow-up or contact arrangements').

Discussion

There is limited breadth of research on student dietitians' attitudes to communication skills and little systematic evaluation of the impact of communication skills teaching, a deficit our study aimed to address. Our findings indicate that student dietitians have positive attitudes to the importance of communication skills in dietetic practice and to communication skills teaching and that their confidence in their communication skills increase following training based on experiential learning and the use of simulated patients.

In the present study, the majority of students rated communication skills as 'very or extremely important' for all aspects of dietetic practice included in the questionnaire and 100% agreed that these skills are important for patient satisfaction. These results are similar to those found in a survey of UK dietitians where 98% agreed that communication skills for behaviour change were either 'very or extremely important' when working with clients [(18)]. That study may have included some students as the survey was sent to all members of the British Dietetic Association but results for students were not presented separately. Student dietitians in our sample rated communication skills as less important for timekeeping (71% very or extremely important') compared to other aspects of practice (e.g. patient satisfaction; 100% very or extremely important'), which may be a result of the early stage of their dietetic education and therefore lack of experience in running a busy clinic. This is supported by the previous survey of UK dietitians where, in those who had undertaken post-

Table 4 Confidence in communication skills in 112 student dietitians before and after completing communication skills teaching

Competency and sub-competency		Confidence in communication skills (*n* = 112) Not at all, *n* (%)	Slightly, *n* (%)	Moderately, *n* (%)	Very, *n* (%)	Extremely, *n* (%)	Very or extremely, *n* (%)	*P* value*	Confidence score, mean (SD)	*P* value**
(C1) Building and sustaining a trusting relationship with a patient	Pre	8 (7.1)	29 (25.9)	58 (51.8)	14 (12.5)	3 (2.7)	17 (15.2)	0.001	2.8 (0.9)	<0.001
	Post	0 (0)	11 (9.8)	65 (58.0)	27 (24.1)	9 (8.0)	36 (32.1)		3.3 (0.8)	
(1a) Greeting and showing interest in a patient as a person	Pre	2 (1.8)	17 (15.2)	29 (25.9)	57 (50.9)	7 (6.3)	64 (57.1)	0.324	3.5 (0.9)	<0.001
	Post	0 (0)	5 (4.5)	36 (32.1)	44 (39.3)	27 (24.1)	71 (63.4)		3.8 (0.9)	
(1b) Using words that show care and concern throughout the patient interview	Pre	7 (6.3)	20 (17.9)	56 (50.0)	23 (20.5)	6 (5.4)	29 (25.9)	<0.001	3 (0.9)	<0.001
	Post	2 (1.8)	6 (5.4)	45 (40.2)	44 (39.3)	15 (13.4)	59 (52.7)		3.6 (0.9)	
(1c) Using tone, pace, eye contact and posture that show care and concern	Pre	5 (4.5)	16 (14.3)	46 (41.1)	37 (33.0)	8 (7.1)	45 (40.2)	<0.001	3.2 (0.9)	<0.001
	Post	0 (0)	5 (4.5)	36 (32.1)	54 (48.2)	17 (15.2)	71 (63.4)		3.7 (0.8)	
(C2) Opening the discussion with a patient	Pre	10 (8.9)	26 (23.2)	62 (55.4)	13 (11.6)	1 (0.9)	14 (12.5)	<0.001	2.7 (0.8)	<0.001
	Post	0 (0)	9 (8.0)	53 (47.3)	39 (34.8)	11 (9.8)	50 (44.6)		3.5 (0.8)	
(2a) Allowing a patient to complete opening statements without interruption	Pre	3 (2.7)	28 (25.0)	50 (44.6)	28 (25.0)	3 (2.7)	31 (27.7)	<0.001	3.0 (0.8)	<0.001
	Post	0 (0)	7 (6.3)	47 (42.0)	45 (40.2)	13 (11.6)	58 (51.8)		3.6 (0.8)	
(2b) Asking a patient "Is there anything else?" to elicit full set of concerns	Pre	4 (3.6)	25 (22.3)	48 (42.9)	32 (28.6)	3 (2.7)	35 (31.3)	<0.001	3 (0.9)	<0.001
	Post	0 (0)	13 (11.6)	41 (36.6)	42 (37.5)	16 (14.3)	58 (51.8)		3.5 (0.9)	
(2c) Explaining and/or negotiating an agenda for the visit	Pre	13 (11.6)	51 (45.5)	34 (30.4)	12 (10.7)	2 (1.8)	14 (12.5)	0.001	2.5 (0.9)	<0.001
	Post	3 (2.7)	25 (22.3)	52 (46.4)	29 (25.9)	3 (2.7)	32 (28.6)		3.0 (0.8)	
(C3) Gathering information from a patient	Pre	8 (7.1)	42 (37.5)	55 (49.1)	5 (4.5)	2 (1.8)	7 (6.3)	<0.001	2.6 (0.8)	<0.001
	Post	1 (0.9)	16 (14.3)	72 (64.3)	22 (19.6)	1 (0.9)	23 (20.5)		3.1 (0.6)	
(3a) Beginning with patient's story, using open questions to gather information	Pre	10 (8.9)	46 (41.1)	45 (40.2)	10 (8.9)	1 (0.9)	11 (9.8)	<0.001	2.5 (0.8)	<0.001
	Post	2 (1.8)	18 (16.1)	54 (48.2)	34 (30.4)	4 (3.6)	38 (33.9)		3.2 (0.8)	
(3b) Clarifying details with more specific or close-ended questions	Pre	13 (11.6)	45 (40.2)	40 (35.7)	13 (11.6)	1 (0.9)	14 (12.5)	0.001	2.5 (0.9)	<0.001
	Post	3 (2.7)	15 (13.4)	61 (54.5)	29 (25.9)	4 (3.6)	33 (29.5)		3.1 (0.8)	
(3c) Summarising and giving a patient the opportunity to correct or add information	Pre	12 (10.7)	40 (35.7)	45 (40.2)	14 (12.5)	1 (0.9)	15 (13.4)	0.009	2.6 (0.9)	<0.001
	Post	4 (3.6)	23 (20.5)	53 (47.3)	25 (22.3)	7 (6.3)	32 (28.6)		3.1 (0.9)	
(3d) Transitioning effectively to additional questions and new topics	Pre	20 (17.9)	47 (42.0)	38 (33.9)	7 (6.3)	0 (0)	7 (6.3)	0.027	2.3 (0.8)	<0.001
	Post	6 (5.4)	33 (29.5)	55 (49.1)	17 (15.2)	1 (0.9)	18 (16.1)		2.8 (0.8)	
(C4) Understanding a patient's perspective	Pre	4 (3.6)	25 (22.3)	52 (46.4)	29 (25.9)	2 (1.8)	31 (27.7)	0.008	3.0 (0.8)	<0.001
	Post	1 (0.9)	8 (7.1)	57 (50.9)	38 (33.9)	8 (7.1)	46 (41.1)		3.4 (0.8)	
(4a) Asking about life events, circumstances, other people that affect a patient's concerns	Pre	13 (11.6)	37 (33.0)	48 (42.9)	13 (11.6)	1 (0.9)	14 (12.5)	<0.001	2.6 (0.9)	<0.001
	Post	2 (1.8)	17 (15.2)	55 (49.1)	34 (30.4)	4 (3.6)	38 (33.9)		3.2 (0.8)	
(4b) Eliciting patient's beliefs and expectations about dietary treatment	Pre	17 (15.2)	34 (30.4)	46 (41.1)	14 (12.5)	1 (0.9)	15 (13.4)	<0.001	2.5 (0.9)	<0.001
	Post	1 (0.9)	19 (17.0)	53 (47.3)	35 (31.3)	4 (3.6)	39 (34.8		3.2 (0.8)	
(4c) Responding explicitly to a patient's statements about ideas and feelings	Pre	18 (16.1)	47 (42.0)	32 (28.6)	14 (12.5)	1 (0.9)	15 (13.4)	0.002	2.4 (0.9)	<0.001
	Post	2 (1.8)	21 (18.8)	57 (50.9)	30 (26.8)	2 (1.8)	32 (28.6)		3.1 (0.8)	

Table 4 Continued

Competency and sub-competency		Confidence in communication skills (n = 112) Not at all, n (%)	Slightly, n (%)	Moderately, n (%)	Very, n (%)	Extremely, n (%)	Very or extremely, n (%)	P value*	Confidence score, mean (SD)	P value**
(C5) Sharing information with patients	Pre	10 (8.9)	38 (33.9)	50 (44.6)	13 (11.6)	1 (0.9)	14 (12.5)	0.143	2.6 (0.8)	<0.001
	Post	3 (2.7)	24 (21.4)	64 (57.1)	19 (17.0)	2 (1.8)	21 (18.8)		2.9 (0.8)	
(5a) Assessing a patient's understanding of problem and desire for more information	Pre	10 (8.9)	46 (41.1)	38 (33.9)	18 (16.1)	0 (0)	18 (16.1)	0.034	2.6 (0.9)	<0.001
	Post	1 (0.9)	20 (17.9)	59 (52.7)	27 (24.1)	5 (4.5)	32 (28.6)		3.1 (0.8)	
(5b) Explaining using words that a patient can understand	Pre	11 (9.8)	34 (30.4)	43 (38.4)	22 (19.6)	2 (1.8)	24 (21.4)	0.122	2.7 (0.9)	0.001
	Post	4 (3.6)	26 (23.2)	49 (43.8)	26 (23.2)	7 (6.3)	33 (29.5)		3.1 (0.9)	
(5c) Asking if a patient has any questions	Pre	3 (2.7)	17 (15.2)	39 (34.8)	45 (40.2)	8 (7.1)	53 (47.3)	0.009	3.3 (0.9)	<0.001
	Post	0 (0)	9 (8.0)	34 (30.4)	50 (44.6)	19 (17.0)	69 (61.6)		3.7 (0.9)	
(C6) Reaching agreement with a patient	Pre	7 (6.3)	43 (38.4)	57 (50.9)	5 (4.5)	0 (0)	5 (4.5)	0.001	2.5 (0.7)	<0.001
	Post	4 (3.6)	24 (21.4)	64 (57.1)	19 (17.0)	1 (0.9)	20 (17.9)		2.9 (0.8)	
(6a) Including a patient in choices and decisions to the extent they desire	Pre	6 (5.4)	38 (33.9)	45 (40.2)	18 (16.1)	5 (4.5)	23 (20.5)	0.290	2.8 (0.9)	0.001
	Post	3 (2.7)	19 (17.0)	53 (47.3)	33 (29.5)	4 (3.6)	37 (33.0)		3.1 (0.8)	
(6b) Checking for mutual understanding of the problem and plan	Pre	6 (5.4)	36 (32.1)	48 (42.9)	17 (15.2)	5 (4.5)	22 (19.6)	0.110	2.8 (0.9)	<0.001
	Post	3 (2.7)	17 (15.2)	54 (48.2)	33 (29.4)	5 (4.5)	38 (33.9)		3.2 (0.8)	
(6c) Asking about a patient's ability to follow the agreed upon plan	Pre	9 (8.0)	34 (30.4)	46 (41.1)	21 (18.8)	2 (1.8)	23 (20.5)	0.711	2.8 (0.9)	0.004
	Post	4 (3.6)	22 (19.6)	60 (53.6)	22 (19.6)	4 (3.6)	26 (23.2)		3.0 (0.8)	
(6d) Identifying additional resources as appropriate	Pre	13 (11.6)	27 (24.1)	59 (52.7)	11 (9.8)	2 (1.8)	13 (11.6)	0.009	2.7 (0.9)	0.69
	Post	8 (7.1)	29 (25.9)	48 (42.9)	26 (23.2)	1 (0.9)	27 (24.1)		2.9 (0.9)	
(C7) Closing the discussion	Pre	12 (10.7)	50 (44.6)	36 (32.1)	13 (11.6)	1 (0.9)	14 (12.5)	<0.001	2.5 (0.9)	<0.001
	Post	5 (4.5)	13 (11.6)	54 (48.2)	35 (31.3)	5 (4.5)	40 (35.7)		3.2 (0.9)	
(7a) Asking if a patient has questions, concerns or other issues	Pre	4 (3.6)	36 (32.1)	45 (40.2)	24 (21.4)	3 (2.7)	27 (24.1)	<0.001	2.9 (0.9)	<0.001
	Post	1 (0.9)	14 (12.5)	39 (34.8)	47 (42.0)	11 (9.8)	58 (51.8)		3.5 (0.9)	
(7b) Summarising problems/concerns and plan	Pre	12 (10.7)	33 (29.5)	48 (42.9)	16 (14.3)	3 (2.7)	19 (17.0)	0.090	2.7 (0.9)	0.001
	Post	3 (2.7)	23 (20.5)	56 (50.0)	25 (22.3)	5 (4.5)	30 (26.8)		3.1 (0.9)	
(7c) Clarifying follow-up or contact arrangements	Pre	4 (3.6)	29 (25.9)	48 (42.9)	27 (24.1)	4 (3.6)	31 (27.7)	1.000	3.0 (0.9)	0.517
	Post	4 (3.6)	24 (21.4)	53 (47.3)	24 (21.4)	7 (6.3)	31 (27.7)		3.1 (0.9)	
(7d) Acknowledging a patient and closing the interview	Pre	6 (5.4)	37 (33.0)	37 (33.0)	29 (25.9)	3 (2.7)	32 (28.6)	0.280	3 (1.0)	<0.001
	Post	4 (3.6)	15 (13.4)	46 (41.1)	36 (32.1)	11 (9.8)	47 (42.0)		3.3 (1.0)	

Pre refers to student responses before communication skills teaching, Post refers to responses after completing communication skills teaching.
*McNemars test of paired categorical variables comparing 'very or extremely confident' between pre- and post- communication skills teaching.
**Wilcoxon signed rank test of paired continuous variables comparing mean score between pre- and post- communication skills teaching.

registration training in communication skills, some felt timekeeping improved as a result (32%) but a similar number felt timekeeping worsened (29%), with 19% reporting lack of time as a barrier to implementing communication skills [18].

Student dietitians reported positive attitudes to learning communication skills, indeed the PAS score was higher in the present study (mean PAS 54.0, SD 5.8) than that reported by UK student dietitians previously (47.4–50.0) albeit that study was undertaken over 3 years previously, was collected using an anonymous survey and included all stages of dietetic training [23]. Studies have shown a decrease in positive attitudes as students' progress through their programmes [23,33], potentially linked to a decline in idealism or more socially desirable responses in earlier years. It is possible that attitudes of students in the present study will change as they progress through practice placements and further study, although this was not measured here. Our findings confirm that students' attitudes to training in communication skills are positive when the teaching is based on experiential learning and the use of simulated patients. More positive attitudes to learning communication skills have previously been reported in female students [21,22], who were highly represented in the present study, thus our findings may be artificially higher. More positive attitudes were seen in students who held a degree or higher qualification. This may indicate that students have developed their interpersonal skills in other educational or employment contexts. There is no conclusive evidence that attitudes are more positive with increasing age [22], although educators should consider the demographics of the student population when developing teaching and learning strategies. There is evidence that social anxiety can contribute to negative attitudes to learning communication skills, particularly among students [34]. Although this was not assessed in the present study, it is important that educators consider this in the delivery of teaching and feedback. In general, before teaching student dietitians held highly positive attitudes to both communication skills and communication skills training. The limited improvements in attitudes following the teaching may be explained by ceiling effects, in that there was limited capacity for improvement in already positive attitudes. It is also important to note that small numbers of students held less positive views about learning communication skills and the importance of these skills. Because these skills are an important component of professional practice and lapses in this area of dietetic practice may impact on student learning, placement outcomes and patient experiences, dietetic education should be strengthened to explore this [2]. Further research is needed to investigate the relationship between attitudes to learning these skills, the impact on students' communication skills and the effectiveness of these skills in impacting patient outcomes.

Students reported increased confidence in their communication skills following communication skills teaching, and this was seen across all competencies and subcompetencies, except for 'clarifying follow-up or contact arrangements' and 'identifying additional resources as appropriate'. These skills were not explicitly addressed in teaching, so this finding is not unexpected. Self-rated confidence was assessed using a tool based on the Kalamazoo Consensus Statement on communication in medical encounters [31]. Assessment tools adapted from this have been used effectively in medical and multidisciplinary education [35,36] and multi-rater assessment including self-rating of skills [37]. Some caution is needed in interpreting results based on self-rated confidence. Confidence is frequently measured to assess outcomes but a review of confidence measurement scales for dietitians highlighted the need for evidence-based measures [38]. Confidence can have several overlapping meanings and is sometimes used interchangeably with self-perceived competence; however, the latter focuses on an individual's judgement of how they perform against set competency standards whereas confidence can refer to capability to achieve across a spectrum including beyond a competency standard. Furthermore. there are concerns about the use of confidence scales in healthcare students with self-rated confidence not confirmed by objective assessment [39]. In the present study, we did not compare self-rated confidence with outcomes of the OSCE.

In teaching communication skills, simulated patients have been used across a range of healthcare disciplines including dietetics to bridge the gap between learning in the academic and practice settings. Practical sessions with actors were included as part of a counselling course in a dietetics programme in the USA [25]. In that study, all students who completed the course and attended a focus group evaluation 3 months later felt confident about counselling patients compared to none of the students who completed an earlier course based on didactic teaching only [25]. The present study also supports the use of simulated patients in dietetic education, although further research is needed to investigate the effect on students' communication skills and patient outcomes of this resource-intensive approach.

Although the emphasis on communication skills in dietetic curricula has increased, how student dietitians develop competence in communication and therefore how teaching should be delivered and assessed is subject to discussion. Attempts have been made to describe the communication skills dietitians need for effective communication. Four main communication competencies were described in an Australian study [15]; (i) interpersonal communication skill; (ii) non-verbal communication; (iii) professional values; and (iv) counselling skills, that were accompanied by 26 performance skills (e.g. listening, empathy, integrity and respect). No single skill set operated alone, although all need to be applied together for effective counselling.

A qualitative exploration regarding how student dietitians construct competence found they associated the development of competence more with practice placements than university training but that activities such as simulation did prepare students for placement competence [(40)]. There is some evidence that communication skills are improved through repeat exposure to simulated patients when these skills are then assessed as a series of OSCEs, in particular for students whose skills were less proficient on initial assessment suggesting there may be a ceiling effect to the development of these skills [(27)].

Dietitians have reported that further training in communication skills is essential post-qualification [(19,41,42)]. Current evidence suggests that there is variation in the standard of communication skills in practice [(41)] and as an important part of developing competence is exposure to competent performance, this may hinder effective teaching and assessment in the practice setting [(40)]. Further longitudinal research could explore how skills taught in pre-registration education are further developed in the workplace.

Internationally, dietetic associations are exploring how the profession needs to change considering drivers such as our ageing population, increasing population diversity, technological innovation and advances in nutrition science [(43)]. In the UK, the Future Dietitian 2025 project identified the need for wider career opportunities and greater influence for dietitians with prospects for wider scope of practice in public health, foodservice, policy and extended specialist roles [(44)]. Although the present study focusses on communication skills for individual consultations, educators will need to consider the broader interpersonal skills needed for the future workforce. Interpersonal communication has been identified as a key theme in a model defining professionalism [(2)] but, because professionalism is a multi-dimensional construct, dietetic educators will need to consider which teaching, learning and assessment strategies will enable students to develop these skills alongside other personal qualities and behaviours.

The strengths of the present study include the number of respondents, especially for a relatively small discipline such as dietetics, with a high response rate from eligible participants and representation from both undergraduate and postgraduate students across three academic years of communication skills teaching. Validated tools were used where available to assess student's experience and skills development and where not available, tools were developed from the literature on communication skills education. A limitation of the study is the potential for bias with evidence that student evaluations can be influenced by a range of psychodynamic factors and the potential for social desirability bias [(45)]. The study used self-reported assessment of confidence and did not measure if these were consistent with objective assessment of skills, such as course marks in the OSCEs or subsequent performance on practice placements. Further research could investigate this, comparing self-reported confidence with observed performance, using a valid and reliable tool (e.g. DIET-COMMS) [(41)] and also consider how programmatic assessment approaches might be used to assess competence in these skills as they are developed throughout pre-registration training rather than as single point assessment of competence [(46)]. To best explore how students experience learning about communication skills and how they develop competence in these skills, qualitative methodologies should be considered for future research [(40)].

Conclusions

The present study has demonstrated that communication skills teaching based on experiential learning and incorporating practice with simulated patients and OSCEs is associated with positive attitudes to learning and self-rated improvement in confidence in communication skills among student dietitians. Further research is needed to determine the most effective ways to teach and assess these skills and to explore patient-centred and clinical outcomes.

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Conflict of interests, source of funding and authorship

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CB, DR and KW designed the study. AMK, CB and KW analysed the data. AMK wrote the first draft with contributions from CB and KW. All authors reviewed and commented on subsequent drafts of the manuscript and approved the final version submitted for publication.

Transparency declaration

The lead author affirms that this manuscript is an honest, accurate and transparent account of the study being reported. The reporting of this work is compliant with STROBE guidelines. The lead author affirms that no important aspects of this study have been omitted and that any discrepancies from the study as planned have been explained.

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DIETETIC PROFESSION

A model of the multidimensional nature of experienced dietitian clinical decision-making in the acute care setting

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Keywords
acute care, clinical decision-making, clinical dietetics, clinical reasoning, judgement, nutrition assessment.

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Abstract

Background: Clinical decision-making (CDM) is an essential component of dietetic practice that can significantly affect the quality of patient care. Research around CDM in clinical dietetics is scarce, with research in other healthcare professions offering limited insight into dietitian CDM in the specific setting of the acute care hospitals. The aim of this qualitative research was to deepen our understanding of the nature of the CDM of experienced dietitians in the acute care setting.
Methods: The present study employed philosophical hermeneutics to guide methods situated within the interpretative paradigm. This study invited dietitians currently practising in adult acute care hospitals with at least 3 years of experience to be involved two in-depth semi-structured interviews using the principles of hermeneutics. A reference focus group session was then used to provide rigour and further interpretation of the findings.
Results: Ten dietitians participated in the interviews and five of these same participants in the reference focus group. The findings have informed the development of *A Model of the Multidimensional Nature of Dietitian CDM in the Acute Care Setting*, which reflects the nature of making decisions for patient care through the synergistic relationship between five key dimensions: (i) tasks; (ii) interactions; (iii) reasoning; (iv) practitioner factors; and (v) context, all of which are managed and monitored by the higher-order reasoning process of the dietitian's clinical judgement.
Conclusions: Because there is scarcity of research on the CDM of dietitians in acute care settings, the present study can provide training and professional development insights to managers, educators and supervisors.

Introduction

Clinical decision-making (CDM) is an essential component of dietetic practice that can significantly affect the quality of patient care. Descriptions of CDM are constantly evolving with multiple related and overlapping terms and concepts used by different scholars, often used interchangeably, including clinical reasoning, clinical problem-solving, critical thinking and clinical judgement [(1–6)]. In the literature, these terms are described and used in different ways by different professions; however, for the present study, CDM was considered an umbrella concept having been described as a multidimensional problem-solving activity that focuses on defining patient problems and selecting appropriate therapeutic interventions [(7)]. Empirical research on the nature of dietitian CDM in any context or setting is very limited. Dietetics research about critical thinking, reasoning and decision-making has been focused on gaining consensus on a standardised and assessable process that dietitians should use to help validate intervention decisions and subsequent patient outcomes [(8–10)].

The context in which clinical decisions are made can impact on the process of CDM and also on what decisions can be made by the dietitian for patient care [(11–14)]. Little research has been undertaken that explores the influence of practice setting and its various characterising elements on dietitians' CDM. In particular, the acute care setting is distinguished by the criticality of patient health issues and focus on short-term treatments as patients recover from illness or surgery.

Of concern, recent professional competencies used by universities to guide student assessment, workforce preparation and practice-based education for entry into the dietetics profession have removed any context-specific components and focus [15,16]. This contrasts with an increasing acknowledgment in other health professional literature of the significant influence of a broad range of contextual factors on the nature of CDM, required expertise and how this expertise develops [17].

Exploration of how experienced dietitians manage this complexity would better inform dietitians in developing the necessary expertise to make clinical decisions and provide quality care for patients in the acute care setting. Dietitian CDM needs to be better understood by those who formally and informally support the preparation and ongoing professional development of dietitians engaging in this complex practice.

The present study aimed to investigate the nature of experienced dietitian CDM in the acute care setting. The study explored how clinical dietitians working in the acute care setting make decisions, and the place of professional judgement in making such decisions.

Materials and methods

Study design and researcher position

The present study was undertaken within the interpretive research paradigm [18–21] guided by Gadamer's philosophic hermeneutic principles [22–24]. Ethical approval was provided by the Charles Sturt University Research Ethics Committee. The present study was part of the author's doctoral research and this author was experienced in clinical dietetic practice in the acute care setting.

Participants and recruitment

Eligibility criteria required participants to (i) be actively engaged in practice for greater than or equal to 24 h per week; (ii) have an equivalent of 3 years or greater experience in the acute setting; (iii) be currently practising in an adult acute care setting; and (iv) willing and able to discuss their CDM. Participant selection used purposeful sampling once eligibility criteria had been met to ensure a diverse and relevant sample of participants from a variety of clinical specialty areas, years of experience and geographical location across the country who could provide in-depth accounts of their CDM experiences [25]. Recruitment was initiated via communication through the e-mail distribution list of the Dietitians Association of Australia [26], which, at the time, had a reach of over 4000 practising dietitian members of whom potentially 40% worked in hospitals [27]. Twelve participants initially responded; however, two of the potential participants withdrew prior to data collection. All remaining 10 participants (Table 1) were from major or principal referral public hospitals in major cities except for one who was from an Australian regional area. The aim of participant recruitment was the construction of a rich text set that facilitated in-depth understanding of the research phenomenon and it was decided that 10 participants was an adequate number of participants to begin data collection. Participants were assigned a pseudonym (Table 1). Guiding principles of thematic saturation, adequacy [28,29] and redundancy [30,31] were used to determine the final numbers of participants as text interpretation proceeded. In addition, based on a proposed model of informational power [32], 10 participants were considered to offer adequate informational power. Therefore, when engaging in concurrent interpretation of the interview transcripts, researchers attained confidence that adequate informational power had been achieved to reveal new and meaningful findings with respect to the research question.

Recruitment for the reference focus group began 24 months after the initial first interviews had taken place and preliminary data analysis had occurred. All interview participants were invited to participate in a face-to-face reference focus group. Five participants responded and five declined for practical reasons and then purposeful sampling was used to ensure participants represented all levels of experience and had variations to clinical areas and inclusion of specialist and nonspecialist dietitians. It was decided that it was was adequate to proceed using five participants who were willing to participate.

Table 1 Profile summary of participants

Pseudonym	Years of experience	Area of work in hospital	Reference focus group
Melissa	35	General (past renal specialist)	No
Penny	22	Critical care (specialist)	Yes
Theresa	17	Renal (specialist)	No
Belinda	12	Oncology/management	Yes
Kate	11	Critical care & Head & neck surgery	No
Sally	8	Critical care (specialist)	Yes
Alice	8	Gastroenterology	Yes
Lila	7	Gastrointestinal Surgery/management	No
Sarah	5	General medicine/ surgery	Yes
Mary	5	General medicine/ surgery	No

Data collection

Consistent with research conducted in a qualitative paradigm two data construction strategies were employed, semi-structured interviews and a reference focus group, with each strategy chosen for its ability to reveal the phenomenon in a different way. Given the complex, embodied and implicit nature of CDM, it was decided, prior to data collection, that two face-to-face interviews would be undertaken with each participant. An interview guide was developed to span over the two interviews (see Supporting information, Table S1). This was piloted with experienced dietetic colleagues of the author resulting in minor modifications to the wording and sequence of the questions. The first interview was designed to: (i) build rapport with participants; (ii) gain insight into the participants practice context; and (iii) gain in-depth responses from participants about how they make clinical decisions and what influences this process. In keeping with the interpretative research paradigm, second interviews explored concepts that warranted further dialogue given participant responses in the first interviews. These concepts were identified from an initial reflection and interpretation of the first interviews. The second interview was also designed to gain participants' views around: (i) how their decision-making expertise developed over time; (ii) the role of clinical judgement in decision-making; and (iii) the role of professional artistry in CDM. To access participants' tacit understanding of CDM, the technique of using memorable incidents of patient care was used during interviews to assist participants' in exploring their decision-making experiences [33]. Each interview lasted approximately 60 min (range 45–75 min). All participants within driving distance from the researcher had their first and second interviews conducted (separated by one month) before travelling to the other side of Australia to conduct interviews with the remaining three participants. These three participants had three nonwork days separating their first and second interviews. Many participants indicated that the elapsed time between interviews prompted a shift in understanding of their own CDM around the concepts introduced and explored in the first interview. This resulted in a more rich and deep portrayal of meaningful concepts around the phenomenon of dietitian CDM.

The reference focus group provided an additional data collection method after participants had been provided with initial analysis and had time to reflect on their first and second interviews, as well as a participant checking process to enhance rigour and credibility of the research process [34]. Participants were presented with key words that represented emerging themes and were invited to represent their perspectives of the nature of their CDM as a concept map. The reference focus group lasted for 95 min.

Data analysis and synthesis

Guided by philosophical hermeneutic principles, data analysis was a fluid and nonlinear process occurring throughout the research process [35] including during data collection, subsequent to data collection and data analysis when writing (i.e. the author's doctoral thesis). Data analysis was undertaken via five main steps including: (i) immersion; (ii) recording ideas; (iii) collating and labelling; (iv) categorising labels into groups; and (v) testing ideas. In keeping with philosophical hermeneutics, researchers played an active role in the discovery of insights and interpretation while engaging in a question and answer dialogue with the data [6]. Throughout the whole interpretation process researchers immersed themselves in the data through listening, reading and re-reading each part (e.g. individual transcript, individual participant), moving back and forth with the whole (e.g. emerging interpretation, new understanding) in an iterative process [36]. Data analysed included interview and reference focus group transcripts, reflexive diary entries and the participant concept map from the reference focus group.

The final analysis was confirmed by the research team.

Quality

Strategies to ensure quality in the present study involved consideration for three main criteria, including rigour, transparency and credibility [37]. Reflexivity served as a means to help maintain coherence between the hermeneutic approaches used, the methods used to collect the data, as well as the interpretive actions that helped reveal new meaning. This was enacted by keeping a journal during the data collection and analysis phases as evidence and a point of reference with respect to the role that the researchers' pre-understandings, reasoning and opinions were playing in the process. These reflections were used as the basis to provide a systematic and transparent account of the actual method used to generate findings. Peer review with doctoral supervisors occurred frequently and focused on research actions, data analysis and determining the direction of upcoming interviews. Adequate time spent with participants along with member checking via the reference focus group supported the process of identifying resonance between the researchers' emerging interpretations and the perspectives and experiences of participants. This coincided with use of verbatim participant quotes from transcripts in the reporting process, thereby illustrating the connection between participant voice and interpretation.

Results

The CDM of 10 experienced dietitians was explored and analysed leading to the development of *A Model of the Multidimensional Nature of Dietitian CDM in the Acute Setting* (Figure 1). This model diagrammatically reflects the nature of making decisions for patient care through the synergistic relationship between five key dimensions: tasks (prioritising, assessing, care planning, implementing and monitoring); interactions; reasoning (including clinical judgement); practitioner factors; and context. These five dimensions are incorporated in a situation-dependent manner as determined by the higher-order reasoning process of the dietitian's clinical judgement.

Tasks

Dietitians in the acute setting focus on the core tasks of prioritising, assessing, care planning, implementing care plans, and monitoring patients throughout hospital admission. Within each of the above five tasks, a broad range of information from multiple sources and practitioner knowledge is gathered, used and interpreted through various reasoning processes feeding into the decision-making process. These five core tasks are sequential and iterative as dietitians make decisions about timing and frequency of patient contact and care.

> 'A lot of the time, there's more patients that I can physically see in a day that I have on my list to see and so I'll go through a process of working out how much I could fit in in the day and culling where required' (Sally)

Although these tasks are routine in patient care, they are incorporated into CDM in a highly fluid manner as part of a bigger holistic problem identification and solving approach concerned with the individual patient's current and predicted health and nutrition needs.

> 'I make an assessment of what their nutrition needs are and what they should be doing but I don't necessarily recommend everything or bombard them with information at that initial assessment or the next one' (Alice)

These core tasks are located in the middle of the model (Figure 1) signifying their central place in CDM.

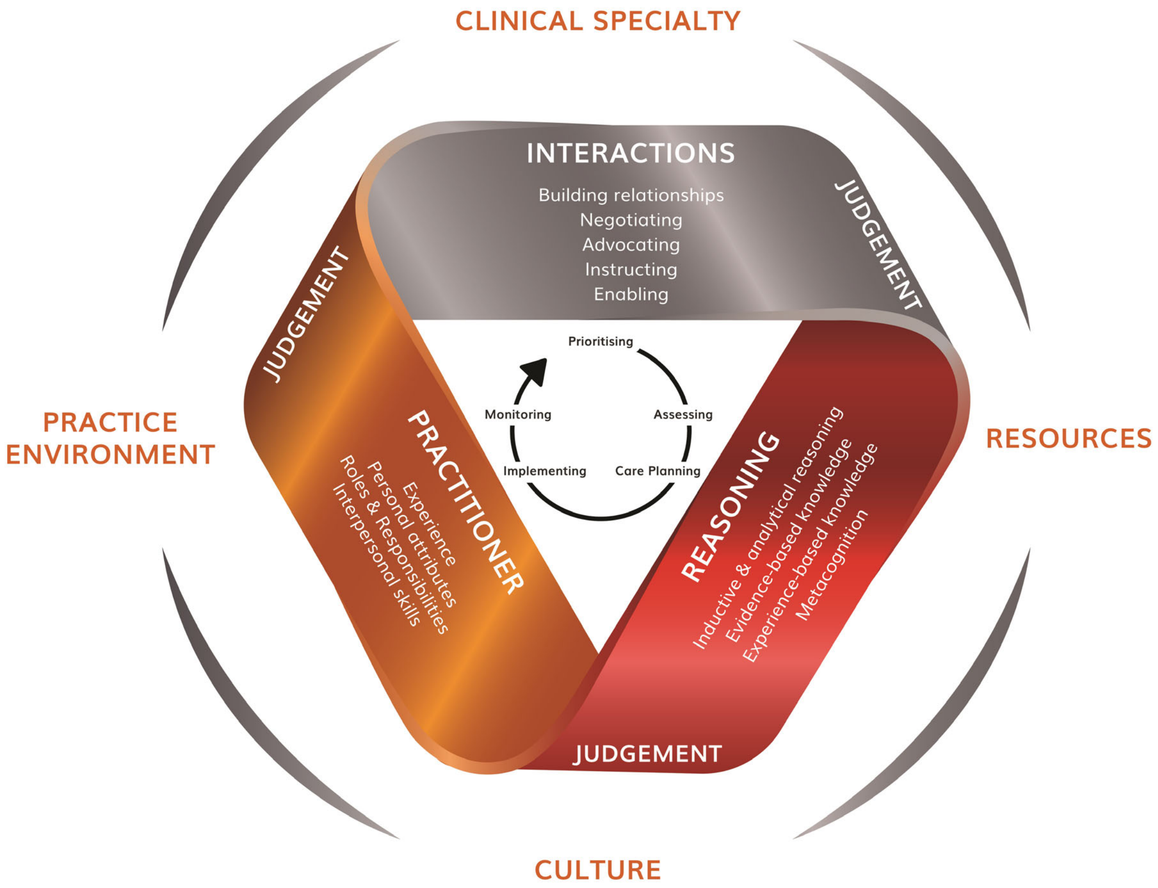

Figure 1 A model of the multidimensional nature of dietitian cdm in the acute care setting.

Interactions

The study also revealed a social dimension of dietitian CDM including a strong dependence on effective interactions with and other professionals such as medical practitioners, nurses, other allied health professionals, as well as patients and their carers. These interactions are strongly characterised by power relations which dominate dietitian CDM at multiple stages throughout the core decision-making tasks. The nature of this power is dependent on individual personalities, beliefs, values and preferences as well as group dynamics within healthcare teams.

> 'We don't have the power to implement best practice ... [Due to] all the things under scope of practice, the professional identity, the autonomy, the culture, the hierarchy in organisational structure, the way that the doctors were trained, the way that we are trained' (Penny, Ref. Focus GP)

The power relations between dietitian and medical practitioner are of particular significance given the greater authority medical practitioners have within decision-making hierarchies in hospital settings [38,39]. Dietitians respond to these power relations by building supportive relationships, negotiating and advocating, instructing and enabling. Building relationships with multidisciplinary team members were considered particularly important as it enabled the dietitian to build rapport and establish a reputation that highlights the dietitian's professional value for patient outcomes.

> 'I think it goes back to the relationship that you have with the rest of the team members as well, and if you are quite distant, I think it's hard to then be able to approach them and stand up for the patient's nutritional needs or make a recommendation' (Mary)

The participants viewed advocating and negotiating with medical practitioners concerning nutrition interventions as key strategies underpinning interprofessional work. Instructing nursing staff and in certain circumstances, patients and carers facilitate implementation and sharing of care plans. Some participants revealed how enabling patients through collaborative decision-making approaches that empower the patient about their own nutrition and health care are ideal and important strategies that were underpinned by empathy and patient-centredness. Although the patient is central to dietitian CDM, interaction in decision-making is not always with the patient on account of varying degrees to which the patient can communicate as a result of their clinical status.

Reasoning

Experienced dietitian reasoning processes were often highly complex with the meta process of clinical judgement interwoven throughout. The participants highly valued sound clinical judgement given the constant changing, often ambiguous and subjective nature of patient care in the acute setting. The participants' clinical judgement was characterised by fluid use of complex knowledge structures developed from specific clinical experience and efficient incorporation of the patient context including weighing up the relevance of information in order to decide on the best course of action at the time. Clinical judgement plays a critical role in the management of complexity, individualisation of care plans, interactions with others concerning patient care and the complex reasoning process used to synthesise information and different types of knowledge.

> 'Anyone can get the evidence and figure out what you would do for someone that's post lap band or had bowel surgery. A patient could get that information but I suppose your clinical judgement is then applying it with considering the patient's whole case, other diseases, other things that might be impacting on them ... that's what makes us the professional' (Lila)

Experienced dietitians' clinical reasoning is highly tacit, automatic and complex involving significant use of inductive reasoning approaches that involve pattern recognition, sensing, intuition and 'gut feeling'. Analytical reasoning, particularly hypothetico-deductive reasoning guides the nutrition assessment process which is focused on identifying relevant nutritional issues. A multifaceted knowledge base of both evidence and highly tacit experience-based knowledge is used often without explicit awareness of the dietitian at the time.

> '... it's just my gut feeling that I would do this in this situation and I can't necessarily explain the thought process I have to get to there, it is just the right thing to do' (Kate)

Dietitians move between different reasoning processes in a fluid way that is influenced by the dietitian's knowledge, expertise and the nature of particular CDM tasks for individual patients. Metacognition, in the form of reflecting on and during patient care as well as to be aware of and alter their own thinking was an important skill and process to engage in for decision-making. Reflection facilitated being able to evaluate self and external influences on the decision-making and how their reasoning should alter to assist with delivering greater quality of care.

Practitioner factors

The dietitians' individual experience (both amount and type), personal attributes, roles and responsibilities and interpersonal skills were found to significantly shape the nature of the individual's CDM. Participants with more experience and time spent specialising conveyed greater confidence to engage in advocating and negotiating and overall greater sense of autonomy in CDM.

> 'With experience, I think you become a bit more certain about yourself and confident about your judgement as well. I think that just came with time' (Mary)

Personal attributes of the individual dietitian such as confidence, empathy, patient-centredness and intrinsic motivation influenced how practitioners enact decision-making and develop from ongoing experience.

> 'I think it's because I'm the sort of person that likes to understand an area in its totality. I don't just look at the evidence-based guidelines. I want to understand why do they do this particular therapy. That's where I fit in' (Theresa)

The specific and current roles and responsibilities of the dietitian including those that weren't directly related to patient care (e.g. management, research, administration, meetings, supervision) also influenced the day-to-day nature of CDM, particularly prioritisation decisions. Interpersonal skills such as assertiveness, compromise, and social and emotional awareness were considered crucial to effectively and professionally navigate the power relations that were prominent in most interactions in the acute setting.

Context

Factors such as resources, culture, practice environment and clinical specialty shape and influence what and how decision-making occurred for the five core tasks. The practice environment, that is, the individual wards and units in which the participant carried out their clinical roles and responsibilities, are both similar and distinct in their defining characteristics and thereby their respective influence on the CDM occurring within them. A dietitian's managers, and other personnel and policies specific to the practice environment, informed participant CDM.

> 'Whatever decision we make, it's about where do we think we sit in that power hierarchy within the team, the ward, the hospital' (Sarah, Ref. Focus GP)

The acute setting as a whole presents a fast and dynamic routine that influence the nature of CDM. In particular, there is need for efficient CDM and for the dietitian to be able to adapt to change effectively. The resources (time, budget, therapies available) available to the dietitian by the healthcare system and or hospital enables and or limits thereby impacting what and how decisions are made for patient care.

> 'In acute hospitals you go in to see them and you never know whether they are well enough to talk to you, whether they in a bad mood, whether they just have just had an emergency' (Belinda)

The clinical specialty within which a patient was located and thereby the multidisciplinary team of health professionals belonging to it were a constant influence on how the dietitian engaged in CDM. Each clinical specialty could have nutritional and medical problems, knowledge and processes that were unique to the specialty. Participants indicated that each clinical specialty, multidisciplinary team and practice environment had a culture that influenced how nutrition was valued and hence the role of the dietitian.

Discussion

The present study aimed to deepen our understanding of the nature of CDM of experienced dietitians in the acute care setting revealing the complex, fluid and multidimensional nature of CDM. New defining elements are the interprofessional and contextual nature that build on well established cognitive and practitioner factors evidenced in the CDM literature [40–42]. The study also brings to the forefront the essential role the metaprocess of clinical judgement has in dietitian CDM in the acute setting, offering perspectives on clinical judgements' characteristics and function in patient care. The key findings of this study have been conceptualised in *A Model of the Multidimensional Nature of Dietitian CDM in the Acute care Setting* (Figure 1).

These findings are consistent with other clinical reasoning and CDM models in other professions underpinned by an argument for a multidimensional nonlinear portrayal of CDM [7,43]. For the most part, the cognitive tasks involved in prioritising, assessing, care planning, implementing care plans and monitoring patients found in the present study are similar to the general steps included in the Nutrition Care Process Model's (NCPM) [9] description of critical thinking and the British Dietitians Association Model and Process 'critical reasoning' [8]. The present study extends on the NCPM by offering an understanding of how interactions, reasoning, practitioner factors and context influence dietitian CDM. As depicted in the model (Figure 1), the relationship between these dimensions is continuous with no boundaries depicting a constant interlocking that is managed by the dietitian's clinical judgement.

Findings support previous research about reasoning and cognitive frameworks that attest to CDM involving a range of reasoning approaches that range from highly analytical to intuitive and pattern recognition [40,44] and that these are often used in an integrated way depending on the nature of the task or decision [45]. The present study compares broadly to expert CDM in other disciplines that have found intuitive and pattern recognition to be dominant reasoning approaches used in CDM in the process of routine care [46–52]. Clinical judgement in this study was described as the overarching reasoning strategy that facilitated this integration of the necessary cognitive strategies thereby positioning dietetics alongside disciplines such as medicine, nursing and more established allied health professions [4,53,54].

The present study revealed that, in the acute care setting, dietitian CDM is an interactive phenomenon that engages interpersonal elements together with technical and cognitive elements integrated to suit the needs of the task in a specific context. These findings have placed interprofessional interactions not at the periphery of influence on CDM, but as one of the main influences on the nature of dietitian CDM in the acute care setting. Successfully navigating power relations was considered essential for effective patient care. Most discussions in the literature revolve around power between patient and dietitian (e.g. the focus of collaborative decision-making) or are gender-focused [55]. The present study has highlighted the role of power in interprofessional relationships involved in dietitian CDM and how CDM sits on a spectrum of autonomy, a view shared by interprofessional practice literature [56]. Croker *et al.* [57] argue different settings have different needs for collaboration and with power accounting for the different ways collaboration can occur in different contexts. Although interpersonal communication and collaboration is highlighted as important in dietetic practice [58], the dietitian–client interaction is what dominates the research and dialogue around the emotional and relational elements of practice [9,59,60]. Therefore, quality CDM requires dietitians to develop interpersonal communication and social awareness capabilities that enable effective interactions with other health professionals that involve power imbalances.

The capabilities that underpin the interpersonal interactions needed for navigating power relations revealed in the present study can be understood in light of research on interpersonal influence and power [61], which are considered to be facilitated through emotional intelligence capabilities [62]. Descriptions of emotional intelligence capabilities in the literature overlap with descriptions in the present study of metacognition, empathy and intuition, suggesting that emotional intelligence is inter-related with reasoning dimensions in dietitian CDM [63–66]. Therefore, dietitians encountering medical dominance and the acute care setting's inherent complexity are likely to be more capable of engaging in influential communication if they possess adequate emotional intelligence and interpersonal skills.

The present study offers a deeper understanding of how context affects the nature of dietitian CDM in the acute care setting. The multiple processes involved in dietitian CDM are embedded in the context in which they are occurring and therefore context is an essential factor for consideration when making and implementing a decision. The need to manage time effectively and the limited and varied resources available to the dietitian varied for both clinical and nonclinical roles and responsibilities. This indicates how context-dependent a dietitian's CDM can be, highlighting the considerations at play that can demand context-specific knowledge and expertise. To develop and support dietetic practice that will meet the demands of the setting and situation, the role of context needs to be emphasised in discussions about how CDM is carried out.

Strengths and limitations of the present study

The use of an interpretive approach has revealed insights not obtained using a positivist paradigm, thereby being a strength of this research at the same time as contributing to the broader understanding of dietitian CDM. The informational power and the thematic saturation that researchers considered to be achieved with the 10 participants, combined with the length of time spent with participants, provided for a deep and rich exploration of experienced dietitian perspectives on their CDM. The findings may be less transferable outside Australia, though eminently transferable to at least to the UK, Canada and New Zealand, where acute care clinical dietetics resembles that in Australia. The scope of the present study was limited to adult acute care dietetics in medium to large metropolitan hospitals. As such, less transferability may be possible to dietetic practice in smaller regional and rural hospitals, community outpatient, private practice, paediatric or rehabilitation settings, or outside usual working hours. Although there could be an argument that the present study could have been extended to more sites and practitioners, the in-depth interviews generated a substantial amount of data. The final numbers of participants were guided by the researchers' conclusion that a level of saturation, redundancy and adequacy had been reached in relation to text construction.

Conclusions

A deeper and more nuanced understanding of CDM in dietetics and its breadth to include strong contextual, judgement and interpersonal dimensions supports the conclusion that clinical dietetics is placed to offer patient care that is sophisticated and situation-dependent, moving it further away from a simply technical profession.

Quality and effective dietetic care in the acute care setting rely on practitioner and interpersonal dimensions given the embedded nature of context, relationships and complexity in practice supporting the conclusion that the nature of dietitian CDM cannot be reduced to a stepwise process. These findings can help educators, managers and clinical supervisors in the areas of interprofessional practice and education, workforce preparation, and professional development.

Transparency declaration

The lead author affirms that this manuscript is an honest, accurate and transparent account of the study being reported. The lead author affirms that no important aspects of the study have been omitted and that any discrepancies from the study as planned have been explained. Reporting was in line with Standards for Reporting Qualitative Research (SRQR) guidelines [67].

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Conflict of interests, source of funding and authorship

The authors declare they have no conflicts of interests.
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RV was responsible for the study conception. RV and MS were responsible for the study methodology. RV was responsible for the formal analysis. RV was responsible for the investigation. RV was responsible for the data curation. RV was responsible for the writing the original draft. RV, MS and NP were responsible for writing, reviewing and editing. RV was responsible for visualisation. MS and NP were responsible for supervision. RV was responsible for project administration. All authors critically reviewed the manuscript and approved the final version submitted for publication.

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Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Supplementary material S1. Questions guide used for in-depth, semi-structured interview with experienced acute care dietitians.

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LOW- AND MIDDLE-INCOME COUNTRIES

Zinc deficiency in low- and middle-income countries: prevalence and approaches for mitigation

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Abstract

This review addresses the prevalence of zinc deficiency in Low- and Middle-income Countries (LMICs) and assesses the available strategies for its alleviation. The paucity of national-level data on the zinc deficiency in LMICs is partially a result of the lack of a reliable biomarker. Zinc deficiency appears to be a public health problem in almost all the LMICs, irrespective of the recommended indicators (plasma zinc concentration, dietary zinc adequacy and stunting prevalence) used. Based on plasma/serum zinc concentration (PZC), which is the most appropriate indicator at present, the prevalence of zinc deficiency in LMICs is of concern. Among the 25 countries for which national PZC data were available, 23 had a zinc deficiency prevalence of >20% for at least one physiological group. Zinc supplementation is largely restricted as an adjunct therapy for diarrhoea management in children, and the best platform and the most effective way of preventive zinc supplementation delivery remains to be established. Impact assessment for current zinc fortification programmes in LMICs and the effectiveness of zinc supplementation as part of a multi-micronutrient powder is to be determined. Dietary diversification, though promising for LMICs, is in the nascent stages of development at present. Inclusion of meat and animal products can be an important way of improving zinc status. Programmatic experience with the promotion of home processing techniques to increase absorbable zinc in the diet is lacking. Conventional biofortification techniques are gaining recognition in LMICs; however, transgenic biofortification as a strategy remains controversial.

Introduction

Zinc is ubiquitous to all biological systems and plays an exceptionally versatile role. Participation of zinc in various vital functions at cellular and subcellular levels can be classified under catalytic, structural and regulatory roles[1], which are attributable to its physicochemical properties, including redox-inertness, as well as a flexible and dynamic coordination geometry[2]. Zinc is a component of more than 300 enzymes and numerous other proteins, and plays multiple roles in optimal nucleic acid and protein metabolism, cell growth and differentiation[3,4]. It is also involved in cell-mediated immunity[5,6]. The universal involvement of zinc in all life processes makes it essential for human health and wellbeing. Functional consequences of zinc deficiency are well known and encompass compromised physical growth, immune competence, reproductive function and neurobehavioural development (although the exact mechanisms are not yet fully elucidated)[7]. These functional consequences have the greatest impact in settings with low intakes of absorbable zinc, such as in low- and middle-income countries (LMICs), where they are associated with impaired childhood growth, increased child morbidity and mortality, and adverse maternal health and pregnancy outcomes. Supplementation with zinc in populations at-risk of deficiency have shown a reduction in the incidence of premature delivery, decreased morbidity from diarrhoea and acute lower respiratory tract infection, reduced duration and severity of diarrhoeal episodes, and improved linear growth and weight gain in children less than 5 years of age[(8,9,10,11,12,13)]. Despite the known detrimental consequences of zinc deficiency and recognised benefits of supplementation in zinc-deficient populations, there have been limited attempts to specifically map the prevalence and severity of deficiency, particularly in LMICs, at a national level to help the development and evaluation of zinc intervention programmes. This could partly be a result of the high financial burden, operational challenges and the lack of a robust biomarker.

Recommended indicators for the estimation of the prevalence of zinc deficiency in a population are: (i) plasma or serum zinc concentration (referred to henceforth as PZC) in a representative sample of all relevant subpopulation groups; or (ii) assessment of intake by employing 24-h dietary recall or other locally validated quantitative dietary assessment methods. Ideally both the above approaches should be used together to derive reliable conclusions [(7,14)]. However, because of paucity of such data, proxy indicators (such as stunting among children <5 years of age and dietary zinc intake using national food balance sheets) have been suggested for the assessment of at-risk populations and to initiate programme planning for zinc interventions [(3,7,14,15,16)]. The suggestive evidence indicates that zinc deficiency is widespread in LMICs and it is estimated to cause substantial morbidity and mortality among children. Approximately 4.4% of childhood deaths could be prevented by addressing zinc nutrition alone [(17)].

This aim of this review is to reflect on the prevalence of zinc deficiency in LMICs using suggestive evidence, as well as reports from the countries that have recently incorporated assessment of zinc status into their periodic nutrition monitoring programmes/surveys, and presenting data from observational studies or trials where zinc assessment was carried out specifically. This review further examines various ongoing as well as possible intervention strategies to address zinc deficiency in LMICs.

Causes of zinc deficiency

The main causes of zinc deficiency include insufficient intake, increased requirements, malabsorption, increased losses and impaired utilisation [(18)]. Inadequate intake of zinc is considered to be one of the most significant determinants for the development of zinc deficiency [(14)]. A daily adequate intake is essential because the body has no specialised storage system for zinc. However, millions of people in LMICs have inadequate levels of zinc in the diet as a result of limited access to foods that are rich in zinc, such as animal products, oysters and shellfish, because of economic, cultural and/or religious reasons [(19)]. Plant-based sources of zinc include wholegrains, nuts and beans. However, zinc assimilation in such sources depends on the soil zinc content. Beside the intake, the absorption of zinc from the diet is another important factor that needs to be considered. Bioavailability of zinc is known to be greatly influenced by the presence of several inhibitors, including phytic acid, calcium and perhaps polyphenols [(20,21,22)]. If diets are rich in inhibitors (as is the case with plant-based diets), even at the acceptable intake levels of zinc, the absorption may be insufficient. Phytate is accepted as the most potent inhibitor of zinc absorption and a meta-analysis of 30 studies by Bel-Serrat *et al.* [(23)] revealed an overall lowering of fractional zinc absorption by 45% of the control values when the phytate: zinc molar ratio of the test meal or diet was greater than 15. Phytic acid forms an insoluble complex with zinc in the small intestine, rendering it unavailable for absorption from cereal-pulse-based phytate rich diets. [(3,19,20)]. Calculation of zinc bioavailability from diets is a challenge mainly because (i) there are constraints to conducting large-scale dietary assessments in LMICs such as cost, time burden, technical difficulty and restricted investment in dietary research infrastructure, including the necessary tools and databases required to collect individual-level dietary data in large surveys (ii) even when dietary intake data are available, information on zinc content and its bioavailability in local foods is fragmentary.

Zinc requirement is often exacerbated by physiological conditions such as during pregnancy and periods of rapid growth, which may precipitate overt zinc deficiency especially when the zinc intake is marginal [(18)]. Conditions that impair intestinal integrity not only reduce absorption, but also result in increased endogenous losses of zinc, particularly in the presence of marginal dietary intakes [(24)].

Faecal excretion of zinc has been shown to increase during acute diarrhoea; however, there is a lack of clarity on the contribution to this loss from unabsorbed dietary zinc and endogenous zinc. Because zinc deficiency increases the susceptibility to childhood diarrhoea and diarrhoeal diseases are common in LMICs, such an infection may further deplete the body zinc and trap the child in a vicious cycle of zinc malnutrition.

Prevalence of zinc deficiency

Recommended indicators for estimating zinc deficiency at a community or population level are: (i) percentage of population with PZC below an appropriate cut-off; (ii) prevalence of dietary intake of zinc below the estimated average requirement; and (iii) percentage of children <5 years of age with height-for-age *Z* scores below −2 SD of the World Health Organization (WHO) reference as a proxy [14]. Because the data on PZC zinc and 24 h recall for assessment of dietary zinc intake are rarely available for LMICs, investigations using the amount of absorbable zinc from national food supplies have been recommended to evaluate the prevalence of zinc deficiency. Apart from PZC, the analyses/studies using proxy indicators, such as height- for- age (only for under 5-year-olds) and dietary intake of zinc using national food balance sheets (FBS) were also considered for this review. The two proxies (absorbable zinc from national food supplies and stunting), if used synergistically or in combination with PZC, appear to be of value until specific assessments are undertaken.

Walker *et al.* [17] showed that zinc deficiency results in a sizable disease burden among children less than 5 years of age, who are predominantly affected by diarrhoea, malaria and pneumonia. In three regions of the world (Latin America, Africa and Asia), they reported that zinc deficiency was responsible for up to 453 207 deaths (4.4% childhood death) and 1.2% of the burden of disease (3.8% in children 6 months to 5 years). This amounts to over 16 million disability-adjusted life years (DALY). Africa had the highest prevalence of zinc deficiency, followed by Asia and Latin America. In India, Nigeria, Democratic Republic of Congo, Ethiopia and Afghanistan, zinc deficiency accounted for 47% of all deaths. Globally, diarrhoea was responsible for approximately half of deaths related to zinc deficiency, and thus is a leading cause of zinc-deficient deaths in each region/subregion. For the above analysis, prevalence of zinc deficiency among children under 5 years of age was assessed using stunting rates and the risk of inadequate zinc intake based on the estimated absorbable zinc in the diet. The fraction of disease-specific morbidity and mortality attributable to zinc deficiency was then estimated based on reductions in both morbidity and mortality as observed from randomised controlled supplementation trials. Finally, the attributable fraction was applied to the earlier estimates for disease-specific deaths and DALYs among children aged 1–59 months to generate an estimate of the total number of deaths and DALYs that could be prevented if zinc deficiency were eliminated in the age group of 6–59 months.

An analysis by Wessells and Brown [16] aimed to estimate global and regional prevalence of zinc deficiency by exploiting two proxies: zinc availability in national food supplies and the prevalence of stunting among children. This combination of the indicators was assumed to be complementary because the national food balance sheets are expected to represent food intake by adults, whereas stunting can be an indirect indicator for risk of deficiency among children. Based on the zinc intake data, approximately 17–29.6% of the population in South and South-East Asia, Sub-Saharan Africa and Central America were at the risk of inadequate zinc intake. The risk was highest (>25%) for south Asia and Sub-Saharan Africa. Country-wise estimated risk of inadequate zinc intake was found to decrease significantly with increasing energy content ($r = -0.62$; $P < 0.01$), zinc content ($r = -0.60$; $P < 0.01$) and percentage of zinc obtained from animal food ($r = -0.90$; $P < 0.01$) which is also a rich source of zinc with no inhibitory phytate. The total dietary phytate and phytate:zinc molar ratio positively correlated ($r = 0.03$ and 0.92, respectively, $P < 0.01$) with the zinc inadequacy. Stunting in children <5 years significantly correlated with the estimated prevalence of inadequate zinc intake ($r = 0.48$, $P < 0.001$), although there was much variance around the best fit line. Approximately 60% (84 of 114) of LMICs had a stunting prevalence of >20% and 32 of the countries were classed as being at high risk of inadequate zinc intake when the composite index (prevalence of stunting >20% and prevalence of inadequate zinc intake >25%) of both indicators was used. A suggested explaination for this discrepancy was that the high prevalence of zinc deficiency using stunting as an indicator was the result of a high requirement and rate of infection among children living in the LMICs.

The major limitation of two above mentioned studies is the use of stunting rates for estimating zinc deficiency. Because stunting is also caused by factors other than zinc deficiency, it is therefore assumed to overestimate the zinc deficiency prevalence. However, an assessment of zinc deficiency based on PZCs from 19 national-level surveys and its comparison with stunting and FBS methods concluded that the stunting prevalence is a better proxy because the two indicators (i.e. plasma zinc and stunting) resulted in similar categorisation of countries into high versus low risk groups, with a few exceptions, whereas the FBS underestimated the prevalence [25]. Although plasma zinc may not be always reliable for making individual diagnoses, it has been recommended as an indicator of population zinc status and can be used to assess the impact of supplementation programmes at the population level because PZCs normally respond to zinc supplementation, especially in individuals with a low, or moderately low baseline [14,26]. Low plasma zinc prevalence in LMICs for various physiological groups (cut-offs used by each country for defining zinc deficiency based on low plasma zinc prevalence are included in Table 1), updated in the light of recent national surveys, is presented in Table 1. Plasma zinc data were available for only 25 LMICs, with a focus on women of reproductive age and children. Surveys from these countries (other than Fiji) invariably included an assessment of PZC among young children (<5 years of age) and a few countrywide surveys also covered older children in the age range 5–14 years. The prevalence of low plasma zinc was >20% for children from all the countries except Azerbaijan, Afghanistan, China, India, Iran, Maldives and Sri-Lanka. Nigeria was at borderline risk with approximately 20% of young children with serum zinc concentration below the defined cut-offs. However, the cut-offs used by Afghanistan, Pakistan and Maldives for defining low PZC were lower, and, for Nigeria, these cut-offs were higher than the International Zinc Nutrition Consultative Group (IZiNCG) cut-off (65 μg dL^{-1}) that has been used by most countries. Therefore, it is possible that the prevalence in Afghanistan, Pakistan and Maldives has been underestimated.

Out of the 25 countries for which PZC data were disaggregated by physiological groups, 18 countries reported PZC for women of reproductive age. Irrespective of the physiological status, these women were at a high risk of zinc deficiency in all the countries (except Fiji). The prevalence of low PZC ranged from 23% in Afghanistan to as high as 82% in Cameroon. A prevalence of 50% or more was common in approximately half of the countries for which the data on PZC were available for women. PZC among adolescents were available for only five countries and varied considerably (11% for Iran; 27–32 % for India, Mexico and Philippines; 68% for Malawi). Surprisingly, the prevalence of low PZC in men (reported by four countries) was approximately 66%, 77%, 42.6% and 31% for Malawi, Kenya, Mexico and Philippines, respectively. This zinc deficiency prevalence rate was comparable with that of women. The high prevalence found in men, along with gender-disaggregated data for adolescent groups, suggests that zinc deficiency is not limited to children and women of reproductive age. However, in contrast to women and children, there is a paucity of evidence relating zinc deficiency to health outcomes in adult men. Studies understanding the consequences of zinc deficiency and assessment of prevalence in males are warranted.

The prevalence of zinc deficiency appears to be further augmented by the economic status. A much higher estimate (43.8%) of low plasma zinc prevalence among children belonging to low socio-economic index was reported in study (n = 1655) from five provinces in India [27] as compared to the findings from national survey (20%). The national survey from India reported a prevalence difference of 4% among the poorest (20%) and richest (16%) households. Similarly, the surveys from Nepal, Sri-Lanka and Cameroon reported zinc deficiency to be associated with low socio-economic status. A recent study using the secondary data from 2010 Colombian National Nutrition Survey for children aged between 12 and 59 months found that zinc deficiency is associated with household income [very poor, odds ratio (OR) = 1.48; poor OR = 1.39] food security (OR = 0.75) and enrolment in nutritional support programmes (OR = 0.76) [28].

The prevalence of low PZC for various countries by rural or urban residence is presented in Fig. 1. Overall, a greater % prevalence of low PZC was observed in rural households across all the population groups, except for a few groups which include- children from Pakistan (5–59 months), Malawi (6–14 years) and Mexico (1–11 years); Indian and Irani adolescents; women from Kenya, Malawi and Iran, as well as Mexican adults. It was interesting to observe a distinct opposite trend for Malawi, non-pregnant females, who had a prevalence of 85% among urban compared to 60% in the rural area. Also, there were regional variations in low PZC prevalence among various countries. These differences were greatest for India, with a low of 1% in Nagaland to a high of 41% in Himachal Pradesh among children aged 1–4 years[29]. Among children aged 5–9 years, zinc deficiency ranged from 2% in Nagaland to 38% in Himachal Pradesh and, among adolescents aged 10–19 years, from 4% in Nagaland to 55% in Gujarat. In Nigeria, the prevalence of zinc deficiency among women and children in Kwara state (highest prevalence) was 54–70% higher with respect to Osun or Edo (lowest prevalence) [30]. Englestone *et al.* [31] reported that living in the northern region, and in rural areas are risk factors for low PZC among children and women in Cameroon. It could be worthwhile analysing such data aiming to determine whether the composition of the diet can explain this or whether there are additional factors influencing the prevalence. Understanding these factors may help to inform the development of nutritional programmes to address zinc deficiency in the local regions.

Zinc deficiency is expected to co-exist with iron deficiency in LMICs because of an overlap of food sources and dietary factors inhibiting or facilitating the absorption of the two nutrients. A very recent cross-sectional study among children from Guatemala reported that 56% of infants and toddlers (<24 months) were anaemic, in contrast to 12% of anaemia prevalence in the preschool group (36–60 months) [32]. Iron and zinc deficiencies were high in these anaemic infants and toddlers. The odds of being anaemic were 3.4 times higher among the infants and toddlers who were zinc deficient (PZC) compared to those who were not. Such an association between anaemia and zinc was not observed for the preschoolers. This indicates that multiple micronutrient deficiencies exist among younger children from rural south-west Guatemala who may have higher dietary

Table 1 Prevalence of zinc deficiency in the Low- and Middle-income Countries based on assessment of plasma/serum zinc concentration in national surveys

Country	Year of the survey	Children sample	Children % Prevalence	Women sample	Women % Prevalence	Adolescent sample	Adolescent % Prevalence	Men sample	Men % Prevalence	Cut-offs used	Reference
Afghanistan	2013	6–59 months (*n* = 950)	15.1	15–49 years (*n* = 950)	23.4	–	–	–	–	<60 µg dL^{-1}	(103)
Azerbaijan	2013	6–59 months (*n* = 1040)	10.7	–	–	–	–	–	–	IZiNCG cut-offs†	(104)
Bangladesh	2011–2012	6–59 months (*n* = 662)	44.6	15–49 years, non-pregnant non-lactating (*n* = 1073)	57.3	–	–	–	–	IZiNCG cut-offs†	(105)
Cameroon	2009	12–59 months (*n* = 845)	82.6	15–49 years, (*n* = 879)	81.6	–	–	–	–	IZiNCG cut-offs†	(31)
China	2013	36–72 months (*n* = 1483)	4	–	–	–	–	–	–	<70 µg dL^{-1}	(25)
Colombia	2008–2010	12–59 months (*n* = 4279)	43	–	–	–	–	–	–	IZiNCG cut-offs†	(25)
Cambodia	2014	6–72 months (*n* = 656)	67.5	15–49 years, non-pregnant (*n* = 720)	62.8	–	–	–	–	<65 µg dL^{-1}	(106)
Ecuador	2011–2012	12–59 years (*n* = 2045)	28	12–49 years (*n* = 8186)	56	–	–	–	–	IZiNCG cut-offs†	(25)
Ethiopia	2015	6–59 months (*n* = 1143)	35	15–49 years, Non-pregnant (*n* = 1625)	33.8	–	–	–	–	< 70 µg dL^{-1}	(107)
		5–14 years (*n* = 1569)	35.8	–	–	–	–	–	–		
Fiji	2010	–	–	15–45 years, Non-pregnant (*n* = 869)	0	–	–	–	–	IZiNCG cut-offs†	(108)
Guatemala	2009–2010	12–59 months (*n* = 1196)	35	–	–	–	–	–	–	< 70 µg dL^{-1}	(25)
India	2016–2018	1–4 years (*n* = 8662)	18.9	–	–	Girls 10–19 years (*n* = 5737)	28.4	–	–	IZiNCG cut-offs†	(29)
	2016–2018	5–9 years (*n* = 11 556)	16.8	–	–	Boys 10–19 years (*n* = 5638)	35.1	–	–		
Iran	2011–2015	15–23 months (*n* = 4372)	19.1	Only pregnant women (*n* = 4395)	28	Girls 14–20 years (*n* = 4685)	13.3	–	–	Pregnant women < 65 µg dL^{-1}; Other age groups < 70 µg dL^{-1}	(109)

Table 1 Continued

Country	Year of the survey	Children sample	Children % Prevalence	Women sample	Women % Prevalence	Adolescent sample	Adolescent % Prevalence	Men sample	Men % Prevalence	Cut-offs used	Reference
	2011–2015	6 years (*n* = 4577)	13.6	–	–	Boys 14–20 years (*n* = 4508)	9.5	–	–		
Kenya	2011	6–59 months (*n* = 771)	81.6	15–49 years non-pregnant women, (*n* = 617)	79.9	–	–	–	–	IZiNCG cut-offs†	(110)
	2011	5–14 years (*n* = 901)	79	15–49 years, pregnant women (*n* = 109)	67.9	–	–	15–54 years (*n* = 239)	77.4		
Malawi	2015–2016	6–59 months (*n* = 1086)	60.4	15–49 years, non-pregnant women (*n* = 757)	62.5	Girls 11–14 years (*n* = 183)	69	15–54 years (*n* = 218)	65.7	IZiNCG cut-offs†	(111)
	2015–2016	6–14 years (*n* = 765)	60.2	–	–	Boys 11–14 years (*n* = 162)	66	–	–		
Maldives	2007	6–59 months (1255)	16	15–49 years (*n* = 1282)	27	–	–	–	–	<60 μg dL^{-1}	(25)
Mexico	2006	1–11 years (*n* = 1127)	26.6	>20 years (*n* = 1932)	33.8	Girls 12–19 years (*n* = 1 019)	28.1	>20 years (*N* = 924)	42.6	For children and adults IZiNCG cut-offs†; Adolescents < 65 μg dL^{-1}	(112,113,114)
	2006	–	–	–	–	Boys 12–19 years (*n* = 734)	24.5	–	–		
Nepal	2016	6–59 months (*n* = 1709)	20.7	15–49 years (*n* = 2144)	24.3	–	–	–	–	IZiNCG cut-offs†	(115)
Nigeria	2001	<60 months (*n* = 2725)	20	Mothers of participating children (*n* = 3779)	28.1	–	–	–	–	<80 μg dL^{-1}	(30)
	2001	–	–	Pregnant women (*n* = 795)	43.8	–	–	–	–		
Pakistan	2011	6–59 months (*n* = 6847)	36.5	15–49 years, non-pregnant mothers (*n* = 5953)	41.6	–	–	–	–	<60 μg dL^{-1}	(116)
	2011	–	–	15–49 years, pregnant mothers (*n* = 791)	48.3	–	–	–	–		

Table 1 Continued

Country	Year of the survey	Children sample	Children % Prevalence	Women sample	Women % Prevalence	Adolescent sample	Adolescent % Prevalence	Men sample	Men % Prevalence	Cut-offs used	Reference
Philippines	2008	6–59 months (*n* = 2370)	21.6	20 < 60 years (*n* = 2892)	31.2	Girls 13–19 years (*n* = 986)	20.6	20 < 60 years men (*n* = 2905)	30.7	IZiNCG cut-offs†	(117)
	2008	6–12 years (*n* = 3789)	30.8	>60 years (*n* = 678)	24.5	Boys 13–19 years (*n* = 1208)	32.2	>60 years men (*n* = 574)	33.6		
	2008	–	–	Pregnant women (*n* = 461)	21.5	–	–	–	–		
	2008	–	–	Lactating women (*n* = 836)	39.7	–	–	–	–		
Senegal	2010	12–59 months (*n* = 1151)	50	15–49 years (*n* = 1082)	59	–	–	–	–	IZiNCG cut-offs†	(25)
South Africa	2005	1–3 years (*n* = 154)	51	–	–	–	–	–	–	IZiNCG cut-offs†	(25)
Sri-Lanka	2012	6–59 months (*n* = 4463)	5.1	–	–	–	–	–	–	IZiNCG cut-offs†	(118)
Vietnam	2010	6–75 months (*n* = 563)	51.9	15–49 years, non-pregnant (*n* = 1522)	67.2	–	–	–	–	IZiNCG cut-offs†	(119)

†Cut-offs suggested by International Zinc Nutrition Consultative Group (IZiNCG): <65 μg dL^{-1} in the morning, and <57 μg dL^{-1} in the afternoon for children below 10 years of age; <70 μg dL^{-1} for fasting status in the morning, <66 μg dL^{-1} for non-fasting in the morning, and <59 μg dL^{-1} non-fasting in the afternoon for non-pregnant females aged ≥10 years; <56 μg dL^{-1} in the first trimester, and <50 μg dL^{-1} in second or third trimester for pregnant women aged ≥10 years; <74 μg dL^{-1} for fasting status in the morning, <70 μg dL^{-1} for non-fasting in the morning, and < 61 μg dL^{-1} non-fasting in the afternoon for non-pregnant males aged ≥10 years [7].

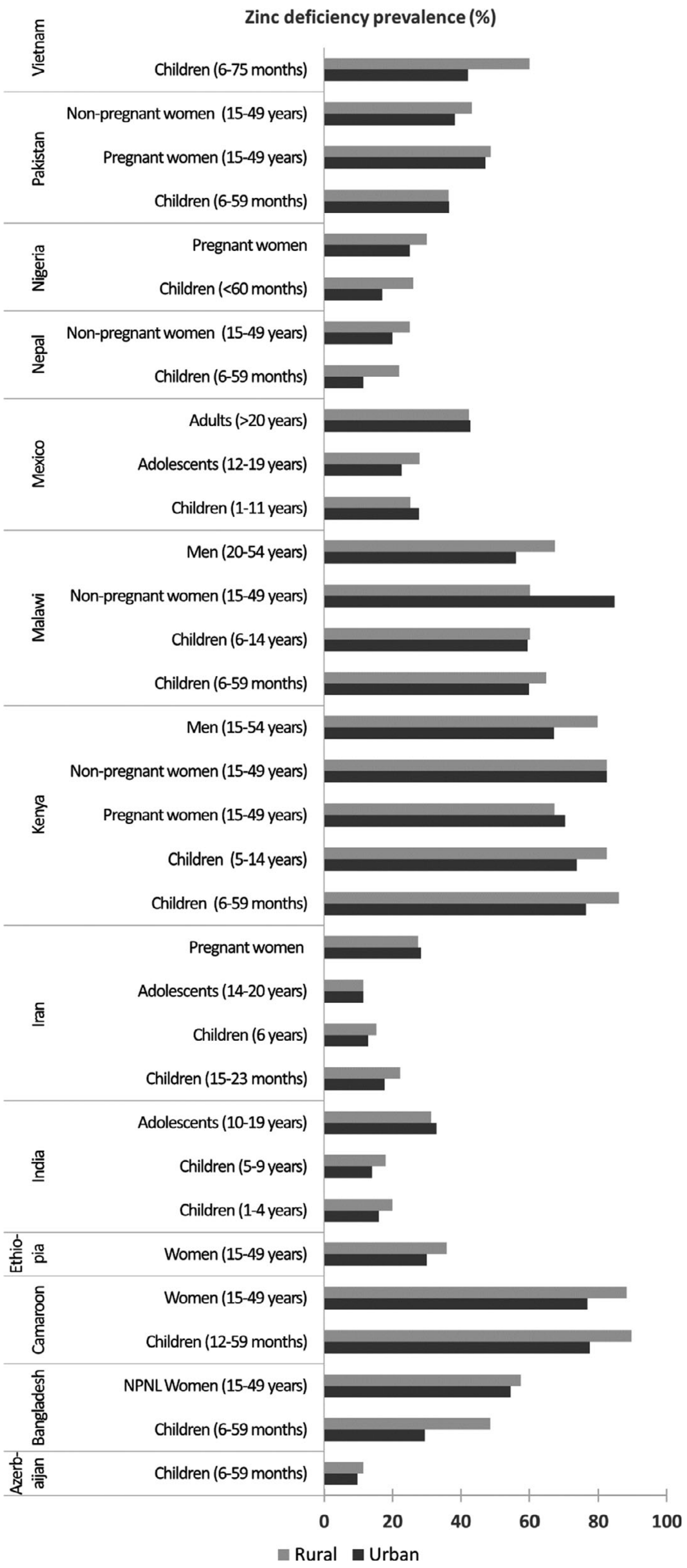

Figure 1 Prevalence of zinc deficiency by urban or rural residence in low- and middle-income countries. Prevalence of zinc deficiency is based on the assessment of plasma/serum zinc concentration in national surveys. Cut-offs used by the countries are provided in Table 1. NPNL, non-pregnant non-lactating.

requirements to support growth, lower dietary diversity and an increased susceptibility to infection compared to the preschoolers. This may call for examining and improving complementary feeding practices, access to animal sources of food and multiple micronutrient supplements. By contrast, it is interesting to note that a high prevalence of zinc (PZC) but not iron-deficiency among women was reported in rural Malawi in a study by Siyame *et al.* [33] that aimed to understand zinc deficiency in relation to selenium and iron intake. Zinc deficiency (>90 %) was greater than iron deficiency anaemia (6%) or iron deficiency (5%) and this was attributed to diets low in zinc (median 5.7 mg day^{-1}) with high phytate:zinc molar ratios (20.0) but high in iron (21.0 mg day^{-1}) from soil contamination. However, PZC in the referred study was found to be a determinant of haemoglobin and is in-agreement with previous findings from the other LMICs where zinc deficiency has been found to be associated with anaemia in young children. Although the study did not account for malaria and genetic haemoglobin disorders and was limited by use of a convenience sample, it suggests the importance for micronutrient assessment and understanding the factors relating to the regional context.

The latest Global Nutrition Report has emphasised the estimation of micronutrient deficiencies, highlighted the paucity of information relating to zinc from LMICs [34]. Although there are numerous regional small-scale studies from LMICs for various physiological groups, the national-level data are scant. The available data, irrespective of the indicators employed, suggest that zinc deficiency is a public health problem in LMICs. The prevalence data that are available for 25 countries highlight the gravity of the zinc deficiency issue not only particularly among women and children, but also possibly among other groups such as male adults and adolescents. Therefore, there is an urgent need to assess zinc status among various physiological groups for all LMICs. IZiNCG has committed to conduct key informant interviews with survey representatives from the countries where a recent national nutrition survey included plasma/serum zinc or omitted it. This would help to identify the factors that enable plasma/serum zinc assessment along with the challenges that persist to facilitate availability and utilisation of such data.

Strategies for addressing zinc deficiencies

The past two decades have witnessed an increasing awareness of zinc nutrition in LMICs. Several zinc intervention (supplementation) trials in settings with inadequate intake have shown beneficial effects on various aspects of human health. However, as mentioned earlier, large-scale intervention programmes have been impeded partially by a lack of reliable biomarkers. Presently, the approaches suggested for tackling zinc deficiency are identical to that in place for iron deficiency and include supplementation, fortification, dietary diversification and the emerging area of biofortification. The choice of intervention will be influenced by the urgency with which the situation needs to be addressed, the resources available to develop and maintain the infrastructure, and/or technology necessary to deliver and sustain the interventions and evidence in the support of the intervention type [7]. Preferably, the above-mentioned approaches should be integrated not only to derive maximum effects, but also to facilitate a smooth transition from short term strategies such as supplementation to the most sustainable strategy of dietary diversification. In addition, complementary approaches should be combined with ongoing national food, nutrition and health programmes, and promoted using nutrition education and social marketing techniques to enhance their effectiveness and sustainability. The success of programmes and policies requires harmonisation and integration of the work of various sectors, such as government, education, public health and industry, as well as international and consumer organisations [35].

Supplementation

Supplementation programmes are particularly valuable for targeting vulnerable population subgroups whose nutritional status needs to be improved within a relatively short period and are often looked upon as a short-term strategy. A strong argument in support of zinc supplementation in LMICs arises not only because supplementation has been shown to reduce ill effects associated with zinc deficiency, but also it appears to be a viable strategy for reaching specific target groups that do not have access to processed food or whose requirement for zinc (such as young children with frequent episode of diarrheal infections) cannot be met even with a fortification and/or dietary diversification program.

The potential of zinc supplementation programmes in LMICs as a protective approach against diarrhoea, pneumonia, respiratory tract infection, mortality among children and adverse pregnancy outcomes among women is widely documented [9,10,13]. A recent double-blind study has confirmed the beneficial effects of a 6-month zinc supplementation intervention on the length increment among rural young Iranian children (6–24 months) [36]. This study, along with a meta-analysis by Imdad and Bhutta [37] that concluded a significant positive effect of zinc supplementation on stunting reduction in children <5 years of age in LMICs, has brought some clarity to the contrasting findings of the previous meta-analyses by two independent groups. Among these, two meta-analyses by Brown *et al.* [9,38] concluded that zinc supplementation produces a highly significant positive effect on height gain in prepubertal children and is in contrast to a finding by Ramakrishnan *et al.* [39] where no such association was observed among children <5 years.

In LMICs, supplementation programmes are often expensive, rely heavily on donor support and on individual compliance, which may require an alteration in usual behaviour. In such a setting, a health system capable of providing a consistent supply, distribution, and delivery of the supplement to the targeted group is a prerequisite [35], alongside effective compliance monitoring and support. Accordingly, despite the evidence, implementation of preventive zinc supplementation remains a challenge. Zinc supplementation is generally restricted to therapeutic purposes and an increasing number of LMICs have introduced national policies for zinc in the treatment of diarrhoea among children <5 years, based on recommendations by WHO and United Nations Children's Fund [40]. These recommendations were made in response to a growing body of evidence showing a reduction in the duration and severity of diarrhoeal episodes, as well as reduced incidence in the subsequent months. According to the guidelines, 10 mg Zn day^{-1} for 10–14 days for children under 3 years and 20 mg for older children should be administered. However, the coverage for this zinc supplementation as an adjunct therapy for the treatment of diarrhoea remains low in the absence of effective scale-up efforts [41]. Also, this approach appears to be suboptimal for the prevention of zinc deficiency because children only have access to supplemental zinc after they become ill, and if their caregivers actively seek treatment for diarrhoea.

Public health experts, government and donors may be reluctant to scale up a preventive programme that requires daily zinc supplementation, especially when several micronutrient deficiencies often co-exist [42]. The use of the existing supplementation platforms, such as those for iron and folic acid, is suggested with respect to reducing the cost of zinc supplementation. Multiple micronutrient interventions such as multiple micronutrient powders (MNP) that often include zinc have attracted attention [43,44]. However, evidence supporting the beneficial impact of MNP on zinc status and on health and growth outcomes is inconsistent compared to preventative zinc supplementation provided in the form of a single micronutrient [45,46,47,48]. Furthermore, there are some concerns about the potential risks of MNP, which include altered gut microbiota, intestinal inflammation and an increased risk of morbidity in some studies, possibly related to the provision of supplemental iron in MNP and possibly modified by individuals' underlying iron status [47,49,50]. Zinc is absorbed most effectively when taken between meals, and in the absence of other micronutrients. However multiple micronutrient supplementation taken with a meal may dilute the inhibitory effect of other micronutrients on zinc and vice versa. Interactions between zinc and other minerals including copper, calcium and non-haem iron have been reviewed elsewhere[20,23]. The exact mechanisms underlying these interactions are not clearly known. Shared absorptive pathways for iron, copper and zinc through DMT-1 (divalent metal transporter 1), CRT1 (copper tansporter1) and individual pathways in the apical membrane of the intestinal cell are possibly implicated [4,51,52,53,54]. Calcium alone has no inhibitory effect on zinc absorption but, in the presence of phytate, may form insoluble calcium-zinc-phytate complexes that cannot be absorbed [4,20]. Thus, additional research is needed to not only to determine the efficacy of MNP as a preventive zinc supplement, but also to further understand the benefits and risks associated with it [55,56]. A different approach for fostering zinc supplementation (by increasing cost-effectiveness) could be through intermittent/weekly zinc supplementation [57]; however, more robust evidence is required [56,58].

A chemical form that is high in bioavailability, does not evoke a metallic taste, is safe, and yet is cheap, is central to the supplementation programme in any LMIC. Different chemical forms of zinc that can be used as supplements include acetate, chloride, citrate, gluconate lactate, methionine, zinc oxide, zinc stearate and heptahydrate/anhydrous zinc sulphate. Studies conducted to assess the absorption of different chemical forms of supplemental zinc have provided varying results and sometimes conflicting data in terms of their relative absorption. In general, water-soluble compounds, such as zinc acetate, zinc gluconate and zinc sulphate, are considered more readily absorbable than compounds with limited solubility at neutral pH [7]. Based on limited human studies, it appears that zinc gluconate, zinc acetate, zinc citrate and zinc sulphate are absorbed to a similar extent and that zinc oxide is slightly less well absorbed when given without food [7,59,60,61,62]. Zinc methionine/histidine may have enhanced absorption than zinc sulphate because of the facilitation of zinc absorption by the amino acid ligands [63,64]. However, the possible benefit of improved zinc absorption from these compounds may not justify their higher costs. WHO recommends the use of the water-soluble compounds zinc sulphate (23% zinc), zinc acetate (30% zinc) or zinc gluconate (14% zinc) in the form of syrups or dispersible tablets for diarrhoea management in infants based on randomised placebo-controlled trials reporting similar efficacy [40]. However, zinc sulphate and zinc acetate have a strong metallic, bitter and astringent taste that needs to be masked, whereas the low zinc content of zinc gluconate makes this compound more expensive. Wegmüller *et al.* [59] used the double-isotope tracer method to compare zinc absorption in humans from zinc citrate with zinc gluconate and zinc oxide using a randomised, double-masked, three-way crossover design. The group concluded that zinc citrate (which is odourless and has a relatively lower cost), given as a supplement without food, is as well absorbed by healthy adults as zinc gluconate and could serve as a useful alternative. However, further studies using zinc citrate are required to confirm the efficacy.

Fortification

Food fortification is the addition of one or more nutrients to a food during processing to increase the intake for the correction or prevention of micronutrient deficiencies [65]. Being cost effective and safe, this strategy has gained popularity among developed countries, and is attracting the attention of LMICs. Hess and Brown [66] have set forth a case in favour of zinc fortification, largely based on the clear evidence that zinc fortification enhances dietary zinc intake. However, it was uncertain whether zinc fortification has an impact on PZC or functional indicators of zinc status. Das *et al.* [67] reported that zinc fortification is associated with an increased serum concentration, although overall evidence of the effectiveness of fortification remains inadequate. A relatively recent systematic review attempted to assess the beneficial and adverse effects of fortification of staple foods with zinc on health-related outcomes and biomarkers of zinc status in the general population from middle-income countries where zinc deficiency is expected to be a public health problem [68]. It was found that foods fortified with zinc increased the PZC levels in comparison with foods without added zinc [mean difference (MD) 2.12 μmol L^{-1}], although participants consuming foods fortified with zinc versus participants consuming the same food without zinc had a similar risk of stunting (relative risk = 0.88). Furthermore, the group expressed ambiguity with respect to the effect of zinc fortification, as a result of the very small difference in PZC among the participants consuming foods fortified with zinc plus other micronutrients, compared to participants consuming the same foods with micronutrients but no added zinc (MD 0.03 μmol L^{-1}). Because most of the studies included in the above review had a small number of participants and there were inconsistencies in the results across different studies, a further synthesis of evidence is required in support of the effectiveness of zinc fortification.

The vehicles for zinc fortification include cereal flours and products such as porridge, edible fats, sugar, condiments, seasonings, milk and beverages, bread and infant formulae [67,68]. WHO has given an interim consensus statement on wheat and maize flour fortification with a variety of micronutrients including zinc (for both low and high extraction flour)[69]. Chemical forms of zinc used for fortification purposes are mainly the cheapest ones (i.e. zinc sulphate and zinc-oxide), although several compounds mentioned under the supplementation section may be exploited. MNP also referred to as 'point of use fortificants' (generally added to food at a single point of time in a day) have been suggested for zinc fortification to enhance the cost-effectiveness in settings where several micronutrient deficiencies co-exist. Lipid-based nutrient supplements are semi-solid pastes usually prepared from vegetable oil, groundnut paste, milk and sugar, and may include zinc simultaneously with other micronutrients, serving as yet another form of zinc fortification [70,71]. The concerns with regards to the use of multiple micronutrients/MNP for improving zinc nutrition has been discussed earlier in this review.

Although food fortification appears to be a feasible approach in lower-income countries, there are several underlying determinants that critically impact the successful implementation of fortification programmes in these regions, including government commitment, legislation, education, awareness and cost of fortification. Despite the potential for a positive impact on zinc nutriture, national-level zinc fortification programmes in LMICs are rudimentary. Cereal flours are attractive vehicles for fortification programmes in LMICs and have been shown to have positive impact on zinc nutrition [72]. Mass fortification of cereal flour with zinc was initiated in Mexico and China. At present, there are 24 LMICs that have regulations for mandatory, and another six for voluntary wheat and/or maize flour fortification (Table 2), although evidence on programme effectiveness is scant. Large-scale fortification programmes with robust impact assessment need to be carried out to cover larger populations in all age groups for informed decisions. Cameroon has recently evaluated the impact of mandatory flour fortification with iron, B12, folic acid and zinc (1 year of intervention) through a nationwide survey and reported greater post-fortification mean PZC for both women and children. A significant reduction in the prevalence of low PZC was reported in women by 18% ($P < 0.001$) and children by 19% ($P < 0.001$) [73]. Very few countries have an ongoing voluntary/mandatory rice fortification programme (Table 2). Apart from cereal flour, roots and tubers could be explored as a potential vehicle for zinc fortification. Recently, Vergara Carmona *et al.* [74] demonstrated post-harvest priming of potato tubers with zinc solution could enhance the zinc content. An improved bioavailability of zinc from the uncooked

Table 2 Regulations on wheat flour, maize flour and rice fortification with zinc in the Low- and Middle-income Countries

		Wheat flour fortification		Maize flour fortification		Rice fortification	
Region	Country	Category	Levels (ppm)	Category	Levels (ppm)	Category	Levels (ppm)
Central Africa	Cameroon	Mandatory	95	–	–	–	–
East Africa	Burundi	Mandatory	88	Mandatory	49	–	–
	Djibouti	Mandatory	40	–	–	–	–
	Kenya	Mandatory	40	Mandatory	30	–	–
	Uganda	Mandatory	60	Mandatory	30	–	–
	Tanzania	Mandatory	40	Mandatory	22.5	–	–
South Africa	Malawi	Mandatory	80	Mandatory	40	–	–
	Mozambique	Mandatory	30	Mandatory	20	–	–
	South Africa	Mandatory	15	Mandatory	15	–	–
	Zimbabwe	Mandatory	40	Mandatory	40	–	–
	Eswatini	Voluntary	20	–	–	–	–
West Africa	Ghana	Mandatory	28.3	–	–	–	–
	Liberia	Mandatory	95	–	–	–	–
	Nigeria	Mandatory	50	Mandatory	50	–	–
	Togo	Mandatory	55	–	–	–	–
	Sierra Leone	Voluntary	28.3	–	–	–	–
East Africa	Rwanda	–	–	Voluntary	49	–	–
East Asia	Fiji	Mandatory	30	–	–	–	–
	Indonesia	Mandatory	30	–	–	–	–
	Kiribati	Mandatory	30	–	–	–	–
	Mongolia	Mandatory	18.7	–	–	–	–
	Solomon Islands	Mandatory	30	–	–	Mandatory	45
	Vietnam	Mandatory	101.3	–	–	–	–
	China	Voluntary	25	–	–	–	–
Central Asia	Kazakhstan	Mandatory	25	–	–	–	–
West Asia	Jordan	Mandatory	20.08	–	–	–	–
South Asia	Afghanistan	Voluntary	50	–	–	–	–
	Bangladesh	–	–	–	–	Voluntary	40
	India	Voluntary	12.5	–	–	Voluntary	12.5
Mexico and Central America	Costa Rica	–	–	–	–	Mandatory	7.5
	Guatemala	–	–	Mandatory	15	–	–
	Mexico	Mandatory	40	Mandatory	40	–	–
	Nicaragua	–	–	–	–	Mandatory	25
	Panama	–	–	–	–	Mandatory	25
South America	Peru	–	–	–	–	Voluntary	32

Data source: Food Fortification Initiative[120]; ppm, parts per million.

potato was suggested, based on a lowered phytate:zinc ratio (<5) in primed compared to non-primed (Zn: phytate ratio 5–15). Further studies are necessary to substantiate the effectiveness of this method on biofortification and bioavailability of zinc *in vivo* and using the cooked/processed form.

An increase in PZC when zinc was taken in the form of a supplement between meals, but not when the same amount was provided in form of fortified food, is intriguing [4]. One of the probable reasons could be the difference in the absorption. Because the diets in LMICs are generally low in animal food and high in phytate, it may be worthwhile to investigate the feasibility of co-fortification with promoters of zinc absorption such as ethylenediaminetetraacetic acid, or the use of phytase to derive maximum benefits from fortification [22]. A recent randomised controlled cross-over trial in young Gambian children (aged 18–23 months) reported that the addition of exogenous phytase to small-quantity lipid-based nutrient (SQ-LNS) supplements enhanced the fractional and total absorption of zinc from a millet-based porridge consumed with SQ-LNS by around two-fold compared to the meal containing SQ-LNS without phytase [75].

Diet diversification/modification

Dietary diversification/modification (DDM) is a more sustainable, long-term, economically-feasible and culturally-acceptable strategy. It is highly suited for the needs of LMICs because it does not rely on a constant financial support/infrastructure, which is the case with supplementation and fortification, and it can be used to alleviate several micronutrient deficiencies simultaneously without any risk of antagonistic interactions [19]. It entails both enhancing zinc intake as well as its absorbability, in contrast to fortification that addresses only intake.

The potential of DDM strategies to improve zinc intake and absorption has been reviewed in-depth by Gibson and Anderson [76]. These DDM strategies at the community/household level include (i) agricultural interventions; (ii) production and promotion of animal-source foods through animal husbandry or aquaculture; and (iii) processing strategies at the commercial or household level to enhance zinc absorption from plant-based diets that have potential to improve zinc nutrition. Agricultural interventions can increase the production, accessibility and consumption of plant-based foods and hence have the potential to improve intake of several micronutrients including zinc. However, the evidence regarding specifically improving zinc intakes and bioavailable zinc is missing because the agriculture interventions in the past have been conducted largely for the improvement of vitamin A nutrition. An issue with the above approach is that agricultural interventions, focussed on plant-based foods, may only have a small impact on the intake of bioavailable zinc. Because the diets in LMICs are largely plant-based, a combination of dietary strategies involving the increased consumption of animal-source foods and phytate reduction is a preferred method for enhancing both the content and bioavailability of zinc in the household diets. Besides animal foods being rich sources of readily available zinc, there is evidence that the inclusion of even a small amount of animal protein, such as fish, poultry, guinea fowl, rabbit, goat and eggs, increases zinc absorption from a plant-based diet [77]. This effect may be attributable to amino acids, released from animal protein, which keep the zinc soluble and counteract the inhibitory effect of phytate in the meal [20]. Promoting animal foods thus appears the best strategy for enhancing the zinc content of household diets [19]. Fish flour can be used to enrich cereal-based porridges for feeding infants and young children [78]. The cost-effectiveness may be further enhanced by exploring fish powder from cheaper fish and by-products [79]. This source of zinc has the additional advantage of not requiring refrigeration and can be consumed by economically weaker sections and communities in which cultural/religious factors prevent meat and poultry consumption. Nutrition education has been shown to impact the intakes of animal-source foods and thus bioavailable zinc and therefore appears to be a crucial component of DDM [76].

Several household/commercial food preparation and processing methods can be used to reduce the phytate content of foods based on cereals and legumes. Milling is the most commonly used method for removing phytic acid from grains. This technique removes the phytic acid but has a drawback that it also removes minerals including zinc [80]. Other household techniques, including soaking, germination and fermentation, have been reviewed in detail elsewhere [81]. Soaking followed by decanting can also be used to reduce the phytate content of cereal and legume flours by passive diffusion of the water-soluble sodium, potassium and magnesium phytates and may activate endogenous phytase under optimal conditions. Phytic acid degradation during germination and fermentation is based on the enzymic hydrolysis of phytic acid to lower inositol phosphates. Germination may also reduce the content of inhibitory tannins and other polyphenols in some legumes [82]. Organic acids produced during fermentation also have the potential to enhance zinc absorption via the formation of soluble ligands with zinc. However, human studies examining the beneficial effect of fermentation on zinc bioavailability are missing.

The extent of phytate degradation depends on the method and conditions used. Although, with household processes, phytate can be reduced by approximately 50%, almost a complete degradation can be achieved by commercial phytases [76]. WHO has evaluated certain phytases from *Aspergillus niger* for use with food and found it safe for human consumption; however, acceptable daily intake has not been specified [83]. It is of interest that fermentation of germinated pearl millet sprouts with mixed pure cultures of *Saccharomyces diasticus*, *Saccharomyces cerevisiae*, *Lactobacillus brevis* and *Lactobacillus fermentum* at 30 °C for 72 h led to 88.3% reduction in phytate content[84]. Recipes combining germination and fermentation need to be formulated and investigated for the bioavailability of zinc.

Although promising, the promotion of food-based strategies remains in its nascent stages of development in LMICs. Despite evidence for the improvement of zinc absorption from cereal-based foods prepared with a reduced phytate content, programmatic experience with the promotion of home processing techniques to increase absorbable zinc in diet is limited. Information on locally available, low-cost, culturally acceptable zinc-rich foods and identification of best approach to promote their consumption by those who are at risk of zinc deficiency is required for developing such programmes.

Biofortification

Biofortification involves increasing the nutrient levels in edible plants during the period of growth through (i) Agricultural, (ii) Agronomic and (iii) Transgenic (genetic modification) means, either alone or in combination.

Targeting staple foods for biofortification is appropriate for improving the diet quality in LMICs because it is sustainable and highly cost-effective, and also does not require any changes/modification in the existing practices of food preparation and consumption. Furthermore, it can cover the communities that are hard to reach, who subsist only on staples as a result of the unaffordability of diverse food, where food is grown and consumed locally, and it is applicable to all family members including women and children [85].

The transgenic approach involves inserting genes needed for the accumulation of a micronutrient that would not otherwise exist in that crop. This method provides exciting opportunities not only for making dramatic increases in the contents, but also has the potential to increase bioavailability. Crops including rice, wheat, maize have been genetically engineered to enhance zinc content [86]. Furthermore, bioavailability can also be improved through genetic engineering by decreasing inhibitors or possibly improving the synthesis of enhancers [87]. It has also been possible to accumulate zinc in edible germ through this technique. Despite these benefits and time-effectiveness compared to conventional plant breeding, transgenic crops have limited acceptability among consumers and regulatory bodies [88,89].

Agronomic bio-fortification can be achieved by applying zinc fertilisers to soil, or leaves, or by priming seeds. Although this requires an appropriate infrastructure, it can be successful in regions where mineral fertilisers are used to increase crop yields and zinc is added to these at the point of manufacture or distribution. As reviewed by Cakmak and Kutman [90], agronomic biofortification with zinc has proved to be effective for crop fortification and has additional benefits such as enhanced yields depending on the extent of soil zinc deficiency, improved seed and seedling vigour, as well as reduced root and shoot accumulation of cadmium. A recently published multicentric study across six LMICs revealed that the seeds biofortified with zinc enhanced crop (rice, wheat and common beans) productivity at many locations with different soil and environmental conditions [91]. The use of nanofertilisers offers a new paradigm for biofortification. This method has the potential to significantly improve the efficiency of micronutrient application to crops, reducing nutrient waste and subsequent environmental contamination [92]. It is interesting to note that a very recent study investigating the effect of different agronomical methods for biofortification on human zinc absorption reported no difference in zinc absorption (fractional zinc and total absorbed zinc) between the food prepared from wheat biofortified by foliar application or through the root (hydroponic). At the same time, absorption from the biofortified foods, regardless agronomic-biofortification methodology used, was greater compared to the control [93].

A synergistic usage of application of zinc fertiliser along with breeding/genetic modification is a key to effective biofortification. For enhanced accumulation by conventional breeding or molecular engineering, it is imperative that the soil/vegetative tissues have sufficient zinc for translocation into grain. Although agronomic biofortification has shown a definitive increase in zinc concentration, evidence of the translation of this increase to benefit human health is uncertain [94,95].

Conventional breeding is the most accepted technique for the production of new biofortified crop varieties. Using this strategy, parent lines with high nutrient content are crossed with a recipient line of desirable agronomic traits over several generations to produce plants with the desired nutrient and agronomic traits. As reviewed by Lockyer *et al.* [96], biofortified zinc wheat has been released in China, India, Pakistan and Bolivia; rice in China and Bangladesh; and iron-zinc enriched lentils in India, Nepal and Bangladesh. Among the three small studies conducted to assess the effectiveness of conventionally-bred biofortified cereals, two studies (one with wheat and another maize) found a greater net absorption of zinc from the biofortified crop. The study with rice failed to show any increase in total or in fractional zinc absorption. A study carried out in India aiming to determine the absorption of iron and zinc among children (<2 years) from biofortified pearl millet concluded that the biofortified pearl millet, when consumed as a major food staple, is more than adequate for meeting the physiological requirements for these micronutrients [97]. In addition to cereals and millets, there is some evidence of improved zinc absorption from biofortified beans (high iron and zinc) [98]. Biofortified beans were released in Colombia in 2016. Its acceptability has been tested to understand the feasibility of incorporation of biofortified beans into the national school-feeding programme [99]. Larger studies are needed to draw a more definitive conclusions with regard to the effectiveness of biofortified crops. A large-scale effectiveness study on the potential of biofortified wheat (Zincol-2016) to improve zinc and iron status among adolescent girls and children living in Pakistan is underway (Trial registration No. ISRCTN17107812).

Furthermore, there is some evidence that plant breeding techniques can be applied to improve the bioavailability of zinc. Previously, low phytate content maize, produced through plant breeding techniques, has been shown to improve the fractional absorption of zinc (single day) [100,101]. However, a longer-term study in which low-phytate maize was supplied to school-aged children in Guatemala for 10 weeks failed to demonstrate any improvement in zinc absorption compared to control maize [102]. The reason for such unexpected findings is uncertain. Confirmation of the efficacy of long-term consumption of low-phytate hybrids is warranted because this strategy has the potential to conveniently improve the absorbable zinc intake of populations subsisting on plant-based diets. At present, further exploration of this novel approach to enhance mineral absorption from plant-based diets has been hindered by the association of the low-phytate trait with reduced yields, as well as by technical and cultural constraints such as the need for long-term breeding projects specifically devoted to the low-phytate trait [81].

Conclusions

The UN Sustainable Development Goal for zero hunger and good health and wellbeing for all cannot be met without alleviating zinc malnutrition. There is paucity of information on zinc deficiency for various physiological groups at a national level in LMICs and the lack of a reliable biomarker is one of the underlying factors that has impeded the assessment of zinc status in national monitoring and surveillance. Zinc deficiency appears to be a public health problem in almost all LMICs, irrespective of the indicators used for assessment (prevalence of low height- or length-for-age >20% among children under 5 years of age; prevalence of low plasma zinc among the population >20%; prevalence of insufficient zinc intake >25%). Using the PZC, which appears to be the most appropriate indicator at present, the prevalence rate of zinc deficiency in LMICs is of concern. Among 25 countries for which the national data was available for PZC, 23 were found to have a prevalence of zinc deficiency greater than 20% for at least one of the physiological groups. Our review suggests that zinc deficiency is common not only among women and children, but also presumably among adolescent and adult males. Because there is a wide intra-regional variation in the prevalence of zinc deficiency, with those belonging to the poorer sections and living in rural areas mostly affected, regional identification of the underlying factors is necessary to devise context-specific strategies and delivery platforms for improving the intake of bioavailable zinc.

Various approaches can be used simultaneously to achieve the improvement in zinc status. Although there is evidence to support zinc supplementation, this approach has been largely restricted as an adjunct therapy for diarrheal management in children. Optimisation of delivery platforms, zinc formulations, and frequency of supplementation are needed to enhance the cost-effectiveness of preventive zinc supplementation. Regulations for mandatory/voluntary zinc fortification are in place for many LMICs, although there is a dearth of impact assessment. Because zinc has been mostly found to be effective when supplemented alone, the effectiveness of MNP and point of use fortificants needs to be ascertained. Dietary diversification, although promising, is still in the nascent stages of its development. Programmes targeting the inclusion of animal products can be an important way of improving zinc status, particularly in children. Programmatic experience with the promotion of home processing techniques to increase absorbable zinc in the diet is lacking.

Supplementation, fortification and dietary diversification are feasible strategies for enhancing zinc status among various population groups; however, conventional breeding and agronomic biofortification techniques are gaining recognition in LMIC settings and point toward a brighter future with respect to a sustainable solution to the global challenge of zinc deficiency.

Transparency Declaration

The lead author affirms that this narrative review is an honest, accurate and transparent review of some key publications in this field. It does not claim to be a comprehensive Systematic Review of all literature published on this topic.

Conflict of interests, source of funding and authorship

The authors declare that they have no conflicts of interests.

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NL conceived the structure of the review. SG undertook the literature search and wrote the draft. AB contributed to the initial literature search on zinc deficiency prevalence and the editing of the tables. NL critically reviewed, revised and finalised the manuscript. All the authors read, revised and approved the final manuscript submitted for publication.

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PREGNANCY

DASH (Dietary Approaches to Stop Hypertension) dietary pattern and maternal blood pressure in pregnancy

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Keywords
blood pressure, blood pressure in pregnancy, DASH diet, dietary approaches to stop hypertension, dietary intervention, hypertension, ROLO study, sodium diet.

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Abstract

Background: High blood pressure (BP) in pregnancy is associated with significant adverse outcomes. In nonpregnant populations, the DASH (Dietary Approaches to Stop Hypertension) diet is associated with reductions in blood pressure. The present study investigated the relationship between the DASH dietary pattern and maternal BP in pregnancy.
Methods: This is an observational study of 511 women who participated in the ROLO study (Randomized cOntrol trial of LOw glycaemic index diet for the prevention of recurrence of macrosomia), 2007–2011, Dublin, Ireland. Auscultatory blood pressure, systolic blood pressure (SBP) and diastolic blood pressure (DBP) measurements were taken. Mean arterial pressure (MAP) was calculated. Dietary intakes were recorded using 3-day food diaries in each trimester. DASH scoring criteria were used to score and rank participants from low to high intakes of foods recommended in the DASH diet. Statistical analysis using analysis of variance and multiple linear regression were used to determine the relationship between maternal BP and DASH scores.
Results: Dietary intake more closely resembling the DASH dietary recommendations throughout pregnancy was associated with a lower DBP (mmHg) in trimesters 1 [B: −0.70; 95% confidence interval (CI) = −1.21 to −0.18] and 3 (*B*: −0.68; 95% CI = −1.19 to −0.17), as well as lower MAP (mmHg) in trimesters 1 (*B*: −0.78; 95% CI = −1.33 to −0.25) and 3 (*B*: −0.54; 95% CI = −1.04 to −0.04), controlling for body mass index, age, education, energy intake and intervention grouping.
Conclusions: The DASH dietary pattern was associated with lower maternal BP in pregnancy among healthy women without hypertensive disorders of pregnancy. Despite the observational nature of these findings, the results demonstrate the potential for healthcare professionals to intervene to promote cardiovascular health in pregnancy.

Introduction

Physiological changes within the cardiovascular system in normal pregnancy are significant because systolic, diastolic and mean arterial pressure (MAP) decrease in the first trimester, increasing back to the prepregnancy values towards delivery [(1–4)]. Blood pressure can be used as a clinical health marker in the prediction of hypertensive disorders of pregnancy (HDP); chronic hypertension, gestational hypertension, pre-eclampsia and white coat hypertension [(5,6)]. Hypertension (HTN) occurs in 6% of pregnancies [(7)], and increases the risk of hypertension in subsequent pregnancies [(8)].

In nonpregnant populations, weight reduction and DASH (Dietary Approaches to Stop Hypertension) dietary intakes are lifestyle modifications with the greatest reduction in systolic blood pressure (SBP) [9]. Because weight reduction during pregnancy is not recommended [9], the DASH diet appears to be the most suitable modifiable factor to target as a method of controlling blood pressure in a pregnant population [9]. The DASH diet is high in fruit, vegetables, nuts, seeds, legumes, low-fat dairy products, wholegrains, lean meat and fish, with reduced intakes of saturated fat and total fat, and with sodium restricted to 2300 mg per day [10,11]. Previous studies suggest that dietary intervention using the DASH diet as a complement to weight loss [12–14], as well as a reduced daily intake of sodium <2300 mg [15,16], lowers blood pressure in healthy, nonpregnant populations. However, many of these studies have been limited by a small sample size, and food provision, which may not be generalisable to a normal population.

It is well known that blood pressure disorders during pregnancy can have significant adverse effects on both the mother and the fetus [6,17,18]. However, only one study to date has examined the DASH dietary pattern and blood pressure during pregnancy, with null findings for the risk of HDP or third trimester blood pressure [19]. Further examination of detailed maternal dietary intakes using food diaries and repeated blood pressure measurements throughout pregnancy is required.

During pregnancy, women are in regular contact with healthcare professionals and are motivated to make dietary changes for the benefit of their infant [20], and so it is an ideal time for dietitians and healthcare professionals to intervene to improve cardiovascular health. An understanding of the effect of dietary patterns on blood pressure in pregnancy could identify potential future maternity and public health strategies. Given the potential for the DASH diet to improve outcomes, as well as the relative dearth of knowledge in pregnancy, compared to nonpregnant populations, an examination of the DASH diet and maternal blood pressure is warranted. Thus, the primary aim of the present study was to describe the diet in a sample of healthy pregnant women and compare it with the DASH recommendations. The secondary aim was to investigate the relationship between the DASH dietary pattern and maternal blood pressure at multiple time points in pregnancy, among healthy women without HDP.

Materials and methods

Study design

This was an observational study of 511 women who participated in the ROLO (Randomized cOntrol trial of LOw glycaemic index diet for the prevention of recurrence of macrosomia) study, in the National Maternity Hospital, Dublin, Ireland, 2007 to 2011 [21]. The ROLO study originally focused on reduced consumption of high glycaemic index foods, aimed at preventing fetal macrosomia, reducing gestational weight gain and improving maternal glucose tolerance [21]. Detailed methods and descriptions of the study have been outlined elsewhere [21,22]. Participants were recruited during their second pregnancy, and were included based on previous macrosomia (infant birth weight > 4 kg) [21]. Exclusion criteria were: any underlying medical disorders, a history of gestational diabetes, being on medication, unable to give full consent, aged under 18 years old, greater than 18 weeks of gestation, or multiple pregnancies [21]. Inclusion criteria for this analysis were: completed and returned 3-food diaries, food diaries with plausible dietary reporting (between 500 and 3500 kcal day^{-1}), available blood pressure measurements, and women without HDP (Figure 1).

Ethical approval was granted by the National Maternity Hospital ethics committee, Dublin, Ireland. The exposure of interest in this analysis was the DASH dietary pattern, using a DASH score as an index of dietary quality. The outcome of interest was maternal blood pressure (systolic, diastolic and MAP) across the three trimesters of pregnancy.

Data collection

Body weight and blood pressure were obtained at booking (week 13) and at weeks 28 and 34 of gestation. Each participant had their height and weight measured using standardised protocols and instruments; body weight was measured using a calibrated SECA weighing scales (SECA GmBH & CO. KG., Hamburg, Germany), to the nearest 0.1 kg without shoes, in minimal clothing; height was measured, without shoes, on first hospital visit, using a wall mounted stadiometer to the nearest 0.1 cm. Body mass index (BMI) was calculated as kg m^{-2}. All anthropometric measures were performed by a midwife or researcher. Primary outcome variables were maternal blood pressure; SBP and DBP, measured in early (week 13), mid (week 28) and late (week 34) pregnancy. Auscultatory blood pressure measurements (mmHg) were obtained by the doctors and/or midwife, using a mobile Trimline aneroid sphygmomanometer (Hillrom, Chicago, IL, USA), in accordance with the institutional protocol for routine antenatal care. After the participant had rested, sitting with arm at heart level, the observer measured blood pressure in the right arm, using an appropriately sized cuff (according to mid-arm circumference). MAP was calculated as $[DBP + 1/3 \times (SBP - DBP)]$ [23]. Dietary intakes were assessed at trimester 1 (pre-low glycaemic index diet intervention), trimester 2 and trimester 3, using 3-day food diaries [21]. Women were asked to include the type and amount of all foods and drinks consumed over three consecutive days [21]. The dietary data from the food diaries were entered into NetWISP

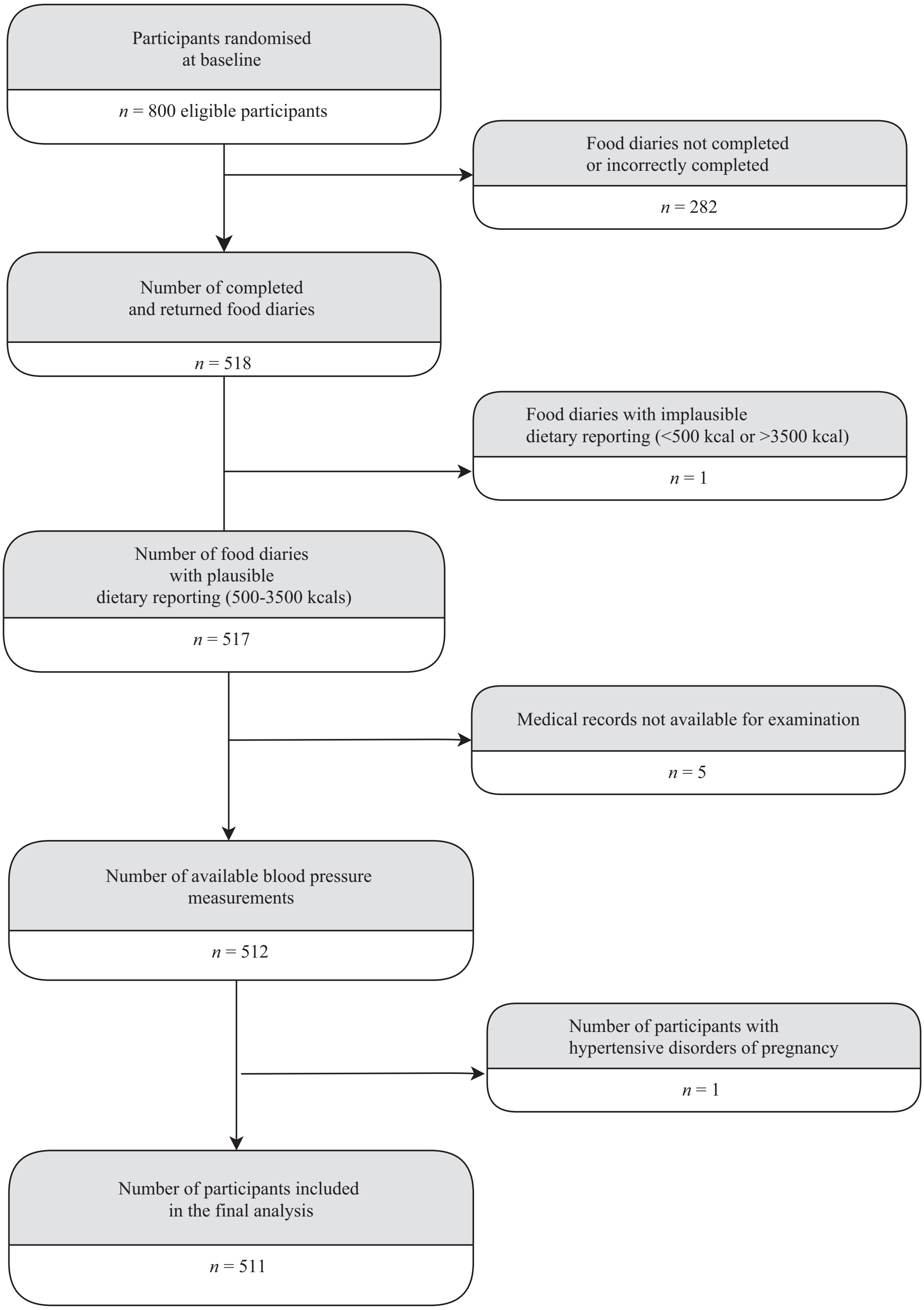

Figure 1 Flow diagram of the step by step participant randomisation, selection and inclusion for analysis within the present study.

food composition database, version 3.0 (Tinuviel Software, Llanfechell, Anglesey, UK), derived from the McCance and Widdowson food composition tables (6th edition) [24]. Implausible mean dietary energy intakes (<500 kcal day^{-1} or > 3500 kcal day^{-1}), which could be a result of misreporting, or measurement errors, were excluded from the analysis (n = 1) [25]. These cut-off values were previously reported in a pregnant population [26]. Questionnaires distributed during pregnancy assessed patient's activity, smoking status, education, well-being, alcohol and supplement intakes. Other maternal characteristics (age and race) were self-reported in pregnancy.

DASH adherence score

Adherence to the DASH diet was examined using a modified version (by Fung *et al.*[25]) of the DASH scoring criteria (eight components); fruit, vegetables, nuts/seeds/legumes, wholegrains, low-fat dairy, red lean/red processed meat, sweet snacks and sodium. An additional ninth food group; salty snacks was included, previously used in a nonpregnant Irish cohort [16]. Three-day food diaries assessed maternal dietary intakes during pregnancy. The 1730 foods reported in the food diaries were (i) grouped into one of nine food groups as per the DASH recommendations (n = 1079) or (ii) not grouped (n = 651) for foods that fall outside DASH food groups (e.g. white bread). A portion size (grams) was assigned to each food using the Food Pyramid food portion sizes (e.g. 200 mL of milk, 75 g of lean meat)[27]. However, some foods were not specifically represented as a serving size in grams (e.g. one medium apple). These foods were assigned a median gram weight using the '*Irish Food Portion Sizes Database*' [28]. Additional foods were sourced from Nutritics (Nutritics Software 2018, Dublin, Ireland). To calculate the number of servings of each food group consumed, the food intakes for each participant (grams reported in the 3-day food diary) were divided by serving size (grams weight). Servings consumed = reported gram weight of food eaten (mean of 3-day food dairy)/serving size (g). For example: serving of nuts = 45 g as per food diary (mean of 3 days)/40 g serving size as per Food Pyramid = 1.13 servings. Foods that fall into more than one food group (e.g. lasagna) were assigned into all appropriate food groups (meat, vegetable), with the proportion contributed and the serving size (in grams) of the allocated food group. All nine food groups were ranked into quintiles (1 to 5). Five of the nine food groups; fruits, vegetables, nuts/seeds/legumes, wholegrains and low-fat dairy products were positively scored from 1 to 5, based on the intakes of participants. The higher the score, the more frequent the consumption (quintile 1, the lowest consumption received a score of 1; quintile 5, the highest consumption received a score of 5). The remaining four components; sodium, red meat, sweet snacks and salty snacks were scored in reverse because a lower consumption of these foods is recommended (quintile 1 received a score of 5 and quintile 5 received a score of 1). The scores were totalled across the nine food groups to yield the DASH diet adherence score of a minimum of 9 and a maximum of 45 points.

Statistical analysis

Data were assessed for normality using the Kolmogorov–Smirnov tests and through visual inspection of histograms. One-way analysis of variance (ANOVA) and independent-samples t-tests were used to compare mean DASH scores and demographic, lifestyle and behavioural characteristics. Bivariate analysis was carried out to examine correlations between maternal characteristics and blood pressure at trimesters 1, 2, and 3. One-way ANOVA tests compared maternal characteristics with DASH quintile across all three measures of blood pressure (SBP, DBP and MAP). A *post hoc* (Tukey's test) allowed for comparison between DASH quintiles. Independent-samples t-tests were used to identify differences between the participants assigned the ROLO intervention and the control diet. Variables in the bivariate analysis, or ANOVA, with an association with blood pressure ($P < 0.1$) were selected for further analysis. These values were included in the multivariate linear regression models to determine the associations between maternal blood pressure (SBP, DBP and MAP) with (i) the categorical variable DASH quintiles (quintile 1 served as the referent) and (ii) DASH as a continuous variable, examining the change in blood pressure for every 5-unit increase in DASH score. Unadjusted and adjusted models of regression were carried out, with and without confounders, based on earlier literature, and determined *a priori* [16]; adjusted for BMI (kg m^{-2}), age (years), education (greater or less than tertiary), grouping (intervention or control) and energy intake (kcal day^{-1}). Although confounders were decided *a priori* because most of the women were Caucasian and we had a very low smoking rate of approximately 3%, neither were included as confounders. Data analysis was conducted using SPSS, version 24.0 (IBM Corp., Armonk, NY, USA). To reduce bias, all food group allocation, DASH scoring and statistical analysis were conducted blind to the ROLO intervention grouping of participants.

Results

Maternal characteristics

Five hundred and eleven women from the ROLO study were included in this analysis. Table 1 summarises the

Table 1 Maternal characteristics of the ROLO (Randomized cOntrol trial of LOw glycaemic index diet versus no dietary intervention in the prevention of recurrence of macrosomia) participants with blood pressures measurements and returned completed 3-day food diaries (n = 511)

	n		
Demographics			
Age at booking (years)[a]	509	32.2	4.0
Age at childbirth (years)[a]	511	32.7	4.0
Age groups[b]	511		
<30 years[b]	121	23.7%	
>30 years[b]	390	76.3%	
Race/ethnicity:	511		
Caucasian[b]	499	97.7%	
Other[b]	12	2.3%	
Education attainment:	511		
Less than third level education[b]	209	42.8%	
Completed third level education[b]	279	57.2%	
Smoking habits at baseline:	511		
Yes[b]	14	2.7%	
No[b]	497	97.3%	
Supplementation (not specified):	489		
Yes[b]	287	58.7%	
No[b]	202	41.3%	
Alcohol intakes (mL day^{-1})[c]	494	1.4	5.3
Alcohol intakes (mL $week^{-1}$)[c]	494	9.5	37.0
Alcohol intakes (units/week)[c]	494	1.0	3.7
Energy intakes (mean overall pregnancy)[a]	511	1879.8	375.9
Trimester 1[a]	511	1855.2	436.1
Trimester 2[a]	511	1886.6	450.9
Trimester 3[a]	511	1897.7	443.6
Anthropometry			
Weight at booking (kg)[a]	510	72.2	12.4
Height (cm)[a]	509	165.8	6.1
Body mass index (BMI) in early pregnancy[a]	509	26.3	4.3
Body mass index classification:	509		
Underweight (BMI < 18.5 kg m^{-2})[b]	2	0.4%	
Normal weight (BMI 18.49–25 kg m^{-2})[b]	229	45.0%	
Overweight (BMI 25–29.99 kg m^{-2})[b]	194	38.1%	
Obese (BMI > 30 kg m^{-2})[b]	84	16.5%	
Gestational weight gain (kg)[a]	429	13.2	4.2
Gestational weight gain (GWG) IOM categories	511		
Inadequate weight gain[b]	65	15.2%	
Adequate weight gain[b]	154	36.0%	
Excessive weight gain[b]	209	48.8%	
Basal metabolic rate (Henry Oxford)[a]	510	1423.0	142.9
Blood pressure			
Trimester 1			
Systolic (mmHg)[a]	468	112.7	11.5
Diastolic (mmHg)[a]	468	68.0	7.1
Mean arterial pressure (MAP)[a]	468	82.9	7.6
Trimester 2			
Systolic (mmHg)[a]	489	112.4	11.3
Diastolic (mmHg)[a]	489	66.6	7.3
MAP[a]	489	81.9	7.7
Trimester 3			
Systolic (mmHg)[a]	503	112.7	10.3
Diastolic (mmHg)[a]	503	68.1	7.3
MAP[a]	503	82.9	7.2
Gestational diabetes			
GTT Carpenter-Coustan			
Yes (diagnosed)[b]	11	2.2%	
Physical activity			
METs[a]	443	450.8	295.1
Time spent sitting (min day^{-1}):			
Total over week day[a]	443	385.2	180.2
Total over weekend day[a]	439	300.5	139.8
Grouping (Low Glycaemic Index Diet in ROLO Study versus Control)			
Intervention[b]	225	44.0%	
Control[b]	286	56.0%	

Data are presented as: [a]mean (SD), [b]n (%), [c]median (interquartile range). MET, metabolic equivalent; n, number of participants; Supplement not specified within lifestyle questionnaire; unit, unit of alcohol; energy intakes; mean kcal intakes as reported in 3-day food diaries; BMI, body mass index classification per World Health Organization cut-offs; GWG, gestational weight gain per Institute of Medicine (IOM) guidelines of weight gain in pregnancy (underweight 12.5–18 kg, normal weight 11.5–16 kg, overweight 7–11.5 kg, obese 5–9 kg); GTT, glucose tolerance test 50 g glucose tolerance test. 10 mL alcohol = 1 unit of alcohol.

baseline characteristics and demographics of the population. The sample comprised healthy pregnant women with a mean (SD) age of 32.2 (4.0) years, mostly Caucasian (97.7%), with a mean (SD) BMI of 26.3 (4.4) kg m^{-2}. Mean (SD) for blood pressures in trimesters 1 to 3 were: SBP 112.7 (11.5) mmHg, 112.4 (11.2) mmHg and 112.7 (10.3) mmHg, respectively; DBP (68.0 (7.1) mmHg, 66.6 (7.3) mmHg and 68.1 (7.3) mmHg, respectively; and MAP 82.9 (7.6) mmHg, 81.9 (7.6) mmHg and 82.9 (7.2) mmHg, respectively. For analysis, the overall participant DASH scores represented as quintiles were in the range: Q1 (11–22); Q2 (23–25); Q3 (26–28); Q4 (29–32); and Q5 (33–42). Mean (SD) DASH scores in trimesters 1, 2 and 3 were 26.7 (5.2), 26.7 (5.3) and 26.8 (5.2), respectively.

Positive significant associations (bivariate correlations) were identified between blood pressures (systolic, diastolic and MAP) for weight (kg) at booking, as well as basal metabolic rate (Henry Oxford) and BMI at booking (kg m^{-2}) across all trimesters of pregnancy. Negative significant associations between blood pressures were identified for maternal age (years) in trimester 2 for SBP and MAP, as well as physical activity (metabolic equivalents) for DBP in trimester 1.

Table 2 Comparison of DASH (Dietary Approaches to Stop Hypertension) score with DASH diet recommendations: mean number of daily servings of food groups consumed during pregnancy according to overall total DASH score quintile

	DASH Score (quintile)						Meeting DASH?
Food group Overall Pregnancy	Q1 (*n* = 108)	Q2 (*n* = 93)	Q3 (*n* = 98)	Q4 (*n* = 126)	Q5 (*n* = 86)	DASH diet	Yes/No
Fruit and fruit juice	1.1	1.6	2.0	2.4	2.8	4–6 servings day–1	No
Vegetables excluding potatoes and legumes	1.4	1.6	1.9	2.2	2.6	4–6 servings day–1	No
Nuts, seeds, legumes	0.2	0.2	0.2	0.4	0.5	0.57–0.71 servings day–1	No
Wholegrains	0.8	1.1	1.3	1.6	1.8	3 servings day–1	No
Low-fat dairy	0.5	0.7	0.8	1.1	1.3	2–4 servings day–1	No
Sodium (mg day^{-1})	2902.2	2690.9	2619.8	2631.1	2439.1	<2300 mg day–1−1	No
Red and red processed meat	1.2	1.0	0.9	0.8	0.6	<2.26 servings day–1	Yes
Sweet snacks, SSB, desserts	2.7	2.2	2.1	2.0	1.4	<0.71 servings day–1	No
Salty snacks	0.5	0.3	0.2	0.2	0.1	<0.71 servings day–1	Yes
Trimester 1	Q1 (*n* = 93)	Q2 (*n* = 112)	Q3 (*n* = 119)	Q4 (*n* = 92)	Q5 (*n* = 95)	DASH diet	Yes/No
Fruit and fruit juice	1.1	1.5	2.1	2.8	3.0	4–6 servings day^{-1}	No
Vegetables excluding potatoes and legumes	1.2	1.7	2.0	2.3	2.6	4–6 servings day^{-1}	No
Nuts, seeds, legumes	0.2	0.2	0.3	0.4	0.5	0.57–0.71 servings day^{-1}	No
Wholegrains	0.7	1.0	1.2	1.5	1.8	3 servings day^{-1}	No
Low-fat dairy	0.4	0.6	0.8	1.0	1.5	2–4 servings day^{-1}	No
Sodium (mg day^{-1})	2944.1	2591.1	2747.0	2620.8	2389.7	<2300 mg day^{-1}	No
Red and red processed meat	1.2	1.0	0.8	0.8	0.5	<2.26 servings day^{-1}	Yes
Sweet snacks, SSB, desserts	2.7	2.0	2.0	1.6	1.3	<0.71 servings day^{-1}	No
Salty snacks	0.6	0.3	0.2	0.2	0.1	<0.71 servings day^{-1}	Yes
	DASH score (quintile)						Meeting DASH?
Trimester 2	Q1 (*n* = 114)	Q2 (*n* = 84)	Q3 (*n* = 126)	Q4 (*n* = 93)	Q5 (*n* = 94)	DASH diet	Yes/No
Fruit and fruit juice	0.8	1.5	2.1	2.3	2.2	4–6 servings day^{-1}	No
Vegetables excluding potatoes and legumes	1.4	1.6	2.0	2.1	2.6	4–6 servings day^{-1}	No
Nuts, seeds, legumes	0.2	0.2	0.2	0.4	0.5	0.57–0.71 servings day^{-1}	No
Wholegrains	0.8	1.1	1.5	1.7	2.0	3 servings day^{-1}	No
Low-fat dairy	0.4	0.7	0.8	1.1	1.3	2–4 servings day^{-1}	No
Sodium (mg day^{-1})	2954.6	2710.3	2584.3	2610.1	2395.1	<2300 mg day^{-1}	No
Red and red processed meat	1.2	1.1	0.9	0.7	0.6	<2.26 servings day^{-1}	Yes
Sweet snacks, SSB, desserts	2.8	2.3	2.3	1.8	1.3	<0.71 servings day^{-1}	No
Salty snacks	0.5	0.4	0.3	0.2	0.1	<0.71 servings day^{-1}	Yes
Trimester 3	Q1 (*n* = 111)	Q2 (*n* = 82)	Q3 (*n* = 123)	Q4 (*n* = 95)	Q5 (*n* = 100)	DASH diet	Yes/No
Fruit and fruit juice	0.9	1.6	2.0	2.4	2.8	4–6 servings day^{-1}	No
Vegetables excluding potatoes and legumes	1.4	1.7	1.8	1.9	2.6	4–6 servings day^{-1}	No
Nuts, seeds, legumes	0.1	0.2	0.2	0.4	0.6	0.57–0.71 servings day^{-1}	Yes
Wholegrains	0.7	1.2	1.2	1.7	1.9	3 servings day^{-1}	No
Low-fat dairy	0.4	0.6	1.0	1.1	1.4	2–4 servings day^{-1}	No
Sodium (mg day^{-1})	2966.3	2703.0	2623.9	2568.4	2505.2	<2300 mg day^{-1}	No
Red and red processed meat	1.2	1.1	1.0	0.8	0.6	<2.26 servings day^{-1}	Yes
Sweet snacks, SSB, desserts	3.0	2.3	2.0	2.2	1.5	<0.71 servings day^{-1}	No
Salty snacks	0.5	0.2	0.3	0.3	0.1	<0.71 servings day^{-1}	Yes

Q1–Q5, quintile 1 to quintile 5; SSB, sugar sweetened beverages.

Six servings of 1 ounce of cooked meat, 75 g is one serving as per Food Pyramid, 6 ounces = 170 g, 170/75 = 2.26 servings; Salty snacks and sweet snacks < 5 servings/week were divided by 7 = 0.71 servings day^{-1}; Nuts and seeds 4–5 servings week^{-1}, were divided by 7 to obtain 0.57–0.71 day^{-1}, and averaged = 0.64 servings day^{-1}.

Maternal dietary pattern

Table 2 shows the number of servings of each DASH component (2000 kcal energy level) by quintiles (of maternal dietary intake ranked according to the DASH dietary guidelines), for trimester 1, trimester 2 and trimester 3 and, on average, during pregnancy (trimester 1, trimester 2 and trimester 3 summed and divided by 3). It was noted that those in the highest quintile (quintile 5) did not meet the recommended servings for the majority of components within the DASH diet. Consumption of two food groups (red lean/red processed meats and salty snacks) met the daily DASH recommendations of <2.3 and <0.7 servings, respectively. A higher DASH score was positively associated with other health-promoting behaviours; micronutrient supplementation, nonsmoker, healthy BMI, older age, adequate gestational weight gain and tertiary education attainment (Table 3). The ROLO intervention group had significantly higher mean DASH score than the control group. When independent-samples *t*-tests compared maternal blood pressure (systolic, diastolic and MAP) among those in the intervention and control, no differences were observed.

Table 3 The unadjusted mean DASH (Dietary Approaches to Stop Hypertension) score for key maternal demographic and lifestyle factors of the $n = 511$ women during pregnancy

	DASH score			
Demographic and lifestyle factors	*N*	Mean	SD	*P*-value
Race/ethnicity:				
Caucasian	499	27.1	5.7	0.464
Other	12	25.9	5.3	
Education attainment:				
Less than third level education	209	25.6	5.8	**0.000****
Completed third level education	279	28.2	5.2	
Smoking habits at baseline:				
Yes	14	23.6	4.7	**0.020****
No	497	27.2	5.6	
Supplementation*:				
Yes	287	28.1	5.5	**0.000****
No	202	25.8	5.5	
Age groups:				
<30 years	121	25.0	6.2	**0.000****
>30 years	390	27.7	5.3	
Body mass index classification:				
Underweight (BMI < 18.5 kg m^{-2})	2	26.0	1.4	**0.000****
Normal weight (BMI 18.5–25 kg m^{-2})	229	28.1	5.4	
Overweight (BMI 25–29.99 kg m^{-2})	194	26.9	5.5	
Obese (BMI > 30 kg m^{-2})	84	24.9	6.2	
Grouping				
Intervention	225	28.4	5.4	**0.000****
Control	286	26.1	5.7	

BMI, body mass index classification as per World Health Organization cut-offs; Supplement not specified in supplement question within lifestyle questionnaire; Grouping, Participants within the ROLO (Randomized cOntrol trial of LOw glycaemic index diet versus no dietary intervention in the prevention of recurrence of macrosomia) study randomised into either the intervention low glycaemic index diet or the control diet). Bold indicates significant value.
*$P < 0.05$.
**$P < 0.001$.

DASH diet score and maternal blood pressure

Figure 2 shows the difference in SBP, DBP and MAP between the lowest DASH quintile (quintile 1) and the highest DASH quintile (quintile 5) across the three trimesters; SBP differed by 4.0, 1.8 and 1.6 mmHg; DBP differed by 2.1, 1.6 and 1.9 mmHg; and MAP differed by 2.7, 1.7 and 1.8 mmHg, respectively. Greater dietary intake resembling the DASH diet guidelines (higher DASH score) throughout pregnancy was associated with lower DBP in trimesters 1 [DASH Score Coefficient, *B*: −0.70; 95% confidence interval (CI) = −1.21 to −0.18] ($P = 0.008$) and trimester 3 (*B*: −0.68; 95% CI = −1.19 to −0.17) ($P = 0.010$), and lower MAP in trimesters 1 (*B*: −0.78; 95% CI = −1.33 to −0.25) ($P = 0.004$) and trimester 3 (*B*: −0.54; 95% CI = −1.04 to −0.04) ($P = 0.033$) controlling for BMI, age, education, energy intakes and grouping (Table 4). Lower SBP was observed with greater DASH score, in trimester 1 (*B*: −0.94; 95% CI = −1.75 to −0.12) ($P = 0.000$) but not across trimesters 2 or 3. Each 5-unit increase in overall DASH score was significantly associated with an 0.8 mmHg lower DBP in trimester 1 ($P = 0.001$), 0.76 mmHg lower DBP in trimester 3 ($P = 0.05$) and 0.74 mmHg lower MAP trimester 1 ($P = 0.024$), adjusting for the same cofounders (Table 4).

Discussion

Among a cohort of healthy, normotensive, pregnant women recruited in early pregnancy, a higher DASH score was significantly associated with lower blood pressure across the three trimesters. A higher DASH score was associated with higher education, nonsmokers and normal BMI. For each 5-unit increase in DASH score, participants had a 1 mmHg lower DBP and MAP.

This is a novel study, and there is only one known previous study examining the effect of the DASH diet on blood pressure during pregnancy [19]. The positive findings from this analysis differ in many aspects to the research carried out in the USA in 2018 [19], which reported null findings for dietary adherence to the DASH diet during pregnancy on third trimester BP and HDP. The differences between this ROLO cohort and the study by Project Viva lie within the study design. First, the population; data from a cohort of healthy pregnant women

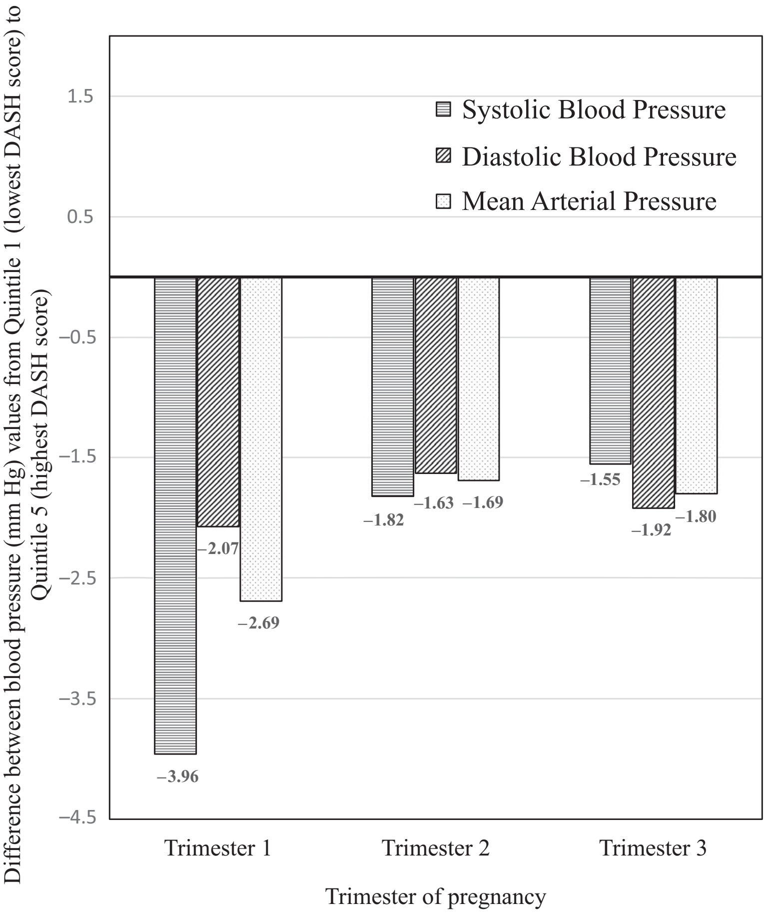

Figure 2 The difference in blood pressure (systolic, diastolic and mean arterial pressure) between the participants in quintile 5 [highest DASH (Dietary Approaches to Stop Hypertension) score] and quintile 1 (lowest DASH score) across the three trimesters of pregnancy (one-way analysis of variance).

(n = 800), compared to pregnant women (n = 1760) with disorders including hypertensive disorders of pregnancy and gestational diabetes (19). Second, the data collection; in the ROLO study, 3-day food diaries were used at each trimester to capture specific foods and allow thorough categorisation into DASH food groups, Project Viva used a semi-quantitative food frequency questionnaire in trimester 1 (19). Third, BP measurements; BP in ROLO was measured at three time points (13, 28 and 34 weeks of gestation) during pregnancy compared to one time point in trimester 1 (19). Finally, the outcomes of interest differed; DASH dietary score and measures of BP (SPB, DBP, MAP) were the primary outcomes in the present study compared to DASH dietary score and the occurrence of gestational diabetes mellitus, HDP and third trimester BP.

This is not the first study to question the adherence to the DASH diet (11,25,29–31). Various methods used to assess DASH compliance include the construction of DASH score based on dietary intake (10,25,30,32–35), self-reported adherence from participant food frequency questionaire or 3-day food record charts(10,25,30,32–35), observation during on-site meal times (10,32), or urinalysis of potassium and sodium to reflect high levels of DASH dietary adherence (10,32,33,36). Previous studies have admitted that participant dietary adherence is poor (30); DASH scores ranged from 4.9 out of 8 (61%) (37), 1.4 to 2.9 out of 9 (16–32%) (29,38,39) and 3.9 to 6 out of 10 (40–60%) (14). Troyer *et al.* (38) defined adherence to the DASH dietary recommendations as a DASH score of >4.5/9 or >50% adherence. The mean DASH score in the present study of 5.3/9 (60%) indicates that our participants, in terms defined by Troyer *et al.*(29,38,39), were compliant, although not meeting the National Institutes of Health National Heart, Lung, and Blood Institute portion requirements (40). Our Mean DASH score 26.7 out of 45 (59%) compared almost exactly to the Pregnancy Infection Nutrition Study DASH score 24.3 out of 40 (58.5%) a larger (n = 4227) American prospective study without intensive feeding, dietary education on the DASH diet or meal provision (37).

Similar to our findings, a higher DASH score was associated with older age, higher education, nonsmokers and normal BMI, in accordance with previous research in a

Table 4 Adjusted multiple linear regression model for association between an increase in DASH (Dietary Approaches to Stop Hypertension) quintile and reduced blood pressure and each 5-unit increase in DASH score and reduced blood pressure during the three trimesters of pregnancy

Increase in DASH score							
Blood pressure	*n*	B	95% CI		r^2 Adj	*P*-value	Model *P*
Systolic blood pressure							
Trimester 1	445	−0.968	−1.788	−0.147	0.075	**0.021***	**0.000****
Trimester 2	465	−0.169	−0.961	0.622	0.041	0.675	**0.000****
Trimester 3	478	−0.268	−0.987	0.451	0.042	0.465	**0.000****
Diastolic blood pressure							
Trimester 1	445	−0.696	−1.211	−0.181	0.043	**0.008***	**0.000****
Trimester 2	465	−0.439	−0.953	0.075	0.053	0.094	**0.000****
Trimester 3	478	−0.680	−1.194	−0.166	0.023	**0.010***	**0.009***
Mean arterial pressure							
Trimester 1	445	−0.787	−1.326	−0.247	0.071	**0.004***	**0.000****
Trimester 2	465	−0.349	−0.883	0.184	0.062	0.199	**0.000****
Trimester 3	478	−0.543	−1.043	−0.043	0.040	**0.033***	**0.000****

5-unit increase in DASH score				
	n	*B*	*P*-value	Model *P*-value
Systolic blood pressure				
Trimester 1	445	−0.880	0.092	**0.000****
Trimester 2	465	+0.005	0.990	**0.000****
Trimester 3	478	−0.330	0.471	**0.000****
Diastolic blood pressure				
Trimester 1	445	−0.804	**0.041***	**0.001****
Trimester 2	465	−0.385	0.236	**0.000****
Trimester 3	478	−0.755	**0.022***	**0.015***
Mean arterial pressure				
Trimester 1	445	−0.740	**0.032***	**0.000****
Trimester 2	465	−0.255	0.451	**0.000****
Trimester 3	478	−0.615	0.055	**0.000****

B, DASH Score Coefficient; r^2 Adj, *r* squared adjusted; variables adjusted for age (years), education (greater than/less than tertiary), BMI (kg m^{-2}), grouping (ROLO Low GI intervention versus control) and energy intake (kcal day^{-1}). Bold indicates significant value.
*$P < 0.05$.
**$P < 0.001$.

nonpregnant population [41]. Although >75% of the women in this study were aged over 30 years, which may be considered a higher age than the general population, the mean age of participants was 32.2 years. This is comparable across recent similar studies, including project VIVA: 31.8 years [42], 32.2 years [19] and 33.2 years [43]. Higher DASH score was previously inversely associated with blood pressure in a nonpregnant population [16]. In our unadjusted model, a higher DASH score in each trimester, and overall during pregnancy, was associated with lower maternal blood pressure (systolic, diastolic and MAP). Those in the highest DASH group (quintile 5) differed in SBP by 1.6–4.0 mmHg, differed in DBP by 1.6–2.0 mmHg and differed in MAP by 1.7–2.7 mmHg compared to those in the lowest DASH group (quintile 1). This concurs with the evidence available from nonpregnant populations because the DASH diet is known to reduce blood pressure by 4.5 mmHg (systolic) and 2.7 mmHg (diastolic) [12]. Similarly, the Joint National Committee guidelines on the Prevention, Detection, Evaluation, and Treatment of High Blood Pressure suggest that the DASH diet can reduce SBP by 3 mmHg in normotensive individuals [44]. Because pregnancy is a stressed state, the response by women to the DASH diet may be exaggerated.

A small, yet significant, decrease in blood pressure, as low as 2 mmHg SBP, reduced the risk of cardiovascular death rates by 4–5%, including a 4% reduction in coronary heart disease and 6% reduction for stroke [45]. The DASH diet compared on par with pharmacological monotherapy in individuals with clinical HTN; those following the DASH diet had greater BP reductions among those with clinical HTN than those with normal BP [32]. Thus, DASH dietary compliance may potentially obviate the need for anti-hypertensive medications and suggests the potential application of DASH dietary recommendations for both the treatment and primary preventative measures within the general population. [32]

Challenges arise in the attainment of low sodium dietary intakes because many foods are high in sodium, with the daily recommended salt allowance of 6 g day^{-1} [46]. Ongoing dietary counselling and support measures may be required to sustain long-term dietary adherence to the DASH diet [47]. Previous studies randomised participants into DASH diet versus control and examined dietary patterns with blood pressure within the general, nonpregnant population, or observed health outcomes of adherence to the DASH diet using a scoring scheme in pregnant, and nonpregnant, populations. Although we cannot ascertain cause and effect from this observational study, these results support the hypothesis that a diet resembling the DASH diet during pregnancy could reduce maternal blood pressure. During pregnancy, women are more receptive to lifestyle changes [20], and so a better understanding of how diet during pregnancy impacts on gestational outcomes could have measurable impacts on population health and also combat hypertension, as well as other diseases that arise from unhealthy dietary patterns. In our adjusted model, a 5-unit increase in DASH score, decreasing DBP and MAP by approximately 1 mmHg, has been previously cited to reduce SBP by 1.9 mmHg in a nonpregnant population [16]. Potentially, a small adjustment in maternal diet to increase the overall DASH score by 5 could potentially reduce blood pressure by 1 mmHg, important for those on the cusp of prehypertension. Pregnancy is considered to act as a stress test for life, and these women may only be diagnosed with hypertension when their blood pressure fails to normalise at delivery [48]. As one of the first studies to examine the DASH diet and blood pressure in pregnancy, further research in this area is needed to confirm these results.

The strengths of the present study include the use of food diaries captured at three time points during pregnancy, which allowed for repeated measurements to obtain long-term overall dietary intakes and therefore reduced measurement error. Unlike food frequency questionaires, food diaries do not rely on memory or recall because they are filled out daily. The ROLO study is a RCT, with a large sample size (n = 511), and the results should be applicable to pregnant women. The scoring system of Fung *et al.* [25] was previously validated as a method for assessing adherence to dietary patterns in relation to health outcomes in pregnant [19] and nonpregnant populations [16]. The DASH diet is a low cost, low risk, simple to follow diet employing foods that are easily accessible and accepted [32]. This is a clinically relevant study and will help to drive research in this area and potentially lead to an RCT in women with HTN in pregnancy. Limitations include the observational study design, the predominately white, educated, nonsmoking population, and the health-conscious nature of women who volunteer to take part in a study. The generalisability of the results may be limited as a result of the specific population studied, including a previous history of macrosomia, recruited on their second pregnancy, without gestational diabetes or HDP. Because participants were recruited at approximately 13 weeks of gestation, prepregnancy blood pressure measurements were unavailable, and it is not clear whether blood pressure was high for some women before pregnancy, although this is unlikely. This is similar to the Generation R study [3], which only included pregnancy blood pressure values, and not baseline values, because women were recruited during pregnancy. The DASH score does not measure adherence to the DASH diet *per se* but, instead, it ranks participants according to their dietary intakes in comparison to the DASH diet. The allocation of the same weight to each dietary component, may dilute the effectiveness of certain components, such as the effect of sodium on blood pressure. Although these women were not prescribed the DASH diet *per se*, the retrospective examination of their usual dietary pattern and the ROLO intervention of low glycaemic diet allowed for dietary intake and comparison with the DASH dietary guidelines. The DASH score does, however, reflect how closely an individual's diet represents the DASH recommendations [40].

The DASH dietary pattern was associated with lower maternal blood pressure in pregnancy among healthy women without HDP. Despite the observational nature of these novel findings, the results demonstrate the potential for dietitians and healthcare professionals to intervene, aiming to promote cardiovascular health, using the DASH diet to reduce blood pressure during pregnancy.

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Conflict of interests, source of funding and authorship

The authors declare that they have no conflicts of interest.
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AC, EOB, RC and FMcA designed the research. All authors conducted the research. All authors helped with data analysis. All authors were involved with writing the paper. FMcA had primary responsibility for the final paper.

Transparency declaration

The lead author affirms that this manuscript is an honest, accurate and transparent account of the study being reported. The reporting of this work is compliant with STROBE guidelines. The lead author affirms that no important aspects of the study have been omitted and that any discrepancies from the study as planned (Clinical Trial Registry number; Current Controlled Trials ISRCTN54392969) have been explained.

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DIETARY PATTERNS

The role of socio-economic status and energy-density in Australian women of child-bearing age

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Keywords
Australia, energy intake, nutrition requirements, obesity, preconception care, socio-economic status.

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Abstract

Introduction: An optimal diet is imperative in preparing women for pregnancy and this may be influenced by socio-economic status (SES). This research aims to investigate the role of SES on the dietary energy density (ED) in Australian women of preconception age.
Methods: A secondary analysis of the Australian National Nutrition and Physical Activity Survey 2011–12 for females aged 18–39 years (n = 1617) was conducted. Dietary intake was assessed by 24-hr recalls and dietary ED by dietary energy per weight (kJ.g^{-1}). ED was further categorised as ED of foods and beverages separately. SES was assessed by three variables: Socio-Economic Indexes for Areas (SEIFA), developed by the Australian Bureau of Statistics; income decile; and level of education. Linear mixed model regressions were used to identify associations between ED and SES.
Results: The median ED for food, beverages and combined food and beverages was 9.38 kJ g^{-1}, 1.02 kJ g^{-1} and 7.11 kJ g^{-1}, respectively. No significant variation was explained by SES variables when analysing combined ED in the adjusted model or ED from foods. Income decile reduced ED of beverages, although with little effect (coefficient: −0.04, P = 0.002). Significant confounders included inactivity, which increased ED in both combined ED and ED foods (coefficient: 0.51, P = 0.001 and coefficient: 0.78, P < 0.001).
Conclusions: SES explained little variation in dietary ED in women of childbearing age. A large proportion of women had high energy-dense diets regardless of their SES. These findings suggest that a large proportion of women, who may become pregnant, have diets that exceed the international recommendations for dietary energy density.

Introduction

Almost half of pregnancies worldwide were unintended during 2010–2014 [(1)]. This highlights the importance of women achieving and maintaining optimal health in childbearing years regardless of pregnancy intentions [(1,2)]. The nutritional status of women prior to and during the period of conception is crucial for foetal development and birth outcomes [(3–5)] because a developing foetus will depend on the mother's stored nutrients throughout pregnancy [(6)]. Deleterious preconception behaviours including sub-optimal nutrition and maternal obesity can negatively influence the quality of a woman's ovum, as well as the subsequent foetal development and birth outcomes [(1,6,7)]. Recent research suggests that sub-optimal maternal nutritional status can lead to the reprogramming of foetal tissues, predisposing the infant to chronic disease later in adulthood [(3,5–10)].

Inadequate maternal nutrition may be influenced by the energy density (ED) of the diet. Foods that are more energy-dense tend to be of poor quality, lack important nutrients for pregnancy and can lead to overweight or obesity [11–13]. ED can be defined as the energy content of the food in kilojoules (kJ) per amount of food (g) (ED = kJ g^{-1}) [11,14]. Foods with a lower ED are typically nutrient-dense, particularly core foods outlined by the Australian Dietary Guidelines (ADG) such as fruit, vegetables and wholegrain cereals [12,13,15]. Lean meat and alternatives and dairy foods and equivalents are also described as core foods by the ADG. Consumption of lower energy-dense foods is associated with decreased risk of overweight and abdominal obesity [11,13]. By contrast, energy-dense foods tend to be nutrient-poor and high in saturated fat, salt and added or refined sugar, also referred to as discretionary foods by the ADG [12,13,15]. The World Cancer Research Fund (WCRF) has recommended that average dietary ED (excluding beverages) be lowered towards 5.23 kJ g^{-1} (125 kcal per 100 g) to prevent weight gain [16].

Globally, the prevalence of obesity has almost tripled from 1975 onward [17]. The prevalence of overweight and obesity has increased in Australia by almost 10% in 20 years, with two-thirds of Australians classed as being overweight or obese in 2014–15 [18]. Being overweight and obese increases the risk of health conditions such as diabetes mellitus, hypertension and cardiovascular disease and, in addition, affects female reproductive health [1,9,19,20]. Obesity is associated with several reproductive disorders, including anovulation, infertility, gestational diabetes mellitus, preeclampsia, preterm delivery, stillbirth delivery and macrosomia in the infant [1,9,19,20]. Evidence suggests that maternal adiposity and weight gain during pregnancy may lead to an intergenerational cycle of obesity, causing increased adiposity and body mass index (BMI) in the offspring [7,21].

Obesity is more likely to occur in women of lower SES within developed nations [22]. People belonging to low SES groups are at greater risk of poor health, experience higher rates of chronic illness, disability and death and have a lower life expectancy than higher SES groups [23,24]. An inverse association exists between obesity status and SES within developed nations, with a stronger association among females than males [22,24,25]. Evidence suggests this inverse association may be partly explained by higher rates of unhealthy behaviours among lower SES groups, including increased rates of smoking, sedentary behaviour and obesogenic diets [22,26]. Consequently, women of low SES may experience higher rates of nutrient deficiencies and poor birth outcomes [10,27].

The relationship between SES and dietary intake has been explored in young Australian adults, assessing both the ED and diet quality [11]. Young Australian adults were found to have poor quality diets that are high in energy-dense foods, highlighting an inverse association between dietary ED and SES [11]. The association between SES, dietary intake and health-related factors has been studied in pregnant Austrian women, with findings highlighting that dietary intake and BMI of pregnant women is strongly predicted by education [5]. Food and nutrient intakes have been investigated in young Irish women of differing SES to identify associations of poorer nutrient intakes among socially disadvantaged women. They found significant nutrient and food group deficits among women of low SES [28]. The relationship between income, SES and dietary intake has previously been investigated in Australia using national data on males and females aged ≥18 years. The findings from the study identified that income influences the variety of the diet, with men and women of low income households having less variety than higher income households [29].

Socio-economic differences in dietary ED have not been investigated in relation to the preparedness of Australian women for pregnancy. Therefore, the present study aimed to investigate the role of SES on the dietary ED of Australian women in their childbearing years.

Materials and methods

Study participants

This analysis uses data from the Australian Bureau of Statistics' Australian Health Survey (AHS) 2011–2013. The AHS was designed to provide a cross-sectional multistage area sample, representative of 97% of the Australian population. Detailed information regarding participant recruitment, data collection and additional measures are available elsewhere [30]. Females aged 18–39 years were selected for inclusion in the study to represent the age range of approximately 95% of women who gave birth in the year 2016 [31]. Preconception was defined as any woman within the specified ages (18–39 years) who was not pregnant, menopausal, post-menopausal or premenarchal. Women whom were breastfeeding and at preconception stages were included.

Demographics describing socioeconomic status

The Australian Bureau of Statistics (ABS) Socio-Economic Indexes for Area (SEIFA) summarises SES factors by using social and economic information including education and occupation from the five-yearly Census. Each geographical area was scored according to SES advantage and disadvantage in comparison to other areas in Australia [32]. The data from the AHS were recorded into SEIFA quintiles, from lowest 20% (first quintile) to the highest 20% (fifth quintile). Income deciles were also included, as was the highest level of non-school qualification. Non-school qualifications ranged from postgraduate degree or graduate diploma through to no non-school qualifications.

Study design

The study uses data collected as a 24-h dietary recall, conducted as part of the Australian National Nutrition and Physical Activity Survey (NNPAS) component of the Australian Health Survey in 2011–13 [30]. The NNPAS collected information regarding food, beverage and supplement intake in the 24 h of the day prior to the interview. Information was collected using the Automated Multiple Pass Method. The initial interview was conducted using Computer Assisted Personal Interview software. Where possible, a second 24-h dietary recall was conducted via telephone interview ≥8 days after the initial interview using a computer-assisted telephone interview [33]. Only data from the initial day were used in the analysis as a result of a lower participation rate for the second day (64%) [30]. AUSNUT 2011–13 food composition database developed by Food Standards Australia and New Zealand was used to analyse the nutritional composition of foods and to reflect the Australian food supply [34].

Dietary energy density

ED was calculated using three methods: (i) considered food only (ED_{food}); (ii) considered beverages only (ED_{bev}), including water; and (iii) combined food and beverages ($ED_{food+bev}$). ED was calculated by dividing the energy content of foods and/or beverages (kJ), by the amount consumed (g) (i.e. ED = kJ g^{-1}). Beverages were analysed separately as the ED of beverages is relatively low in comparison to food, which can obscure the relationship between exposure to energy-dense foods and health outcomes [11,35] Food and beverages can be consumed in combination (e.g. cereal with the addition of milk or sugar added to tea). Food combination codes and meal occasion codes were used to identify these items and classify them as foods or beverages accordingly (see Supporting information, Fig. S1). Meal codes were used to identify ambiguous food and beverages (i.e. meal replacements and supplementary and medical foods). The aforementioned methods for measuring ED have been described in further detail elsewhere [14] and adapted for compatibility with AUSNUT 2011–13 food composition database. The mean ED_{food} was compared with the WCRF guidelines for average dietary ED (excluding beverages) of 5.23 kJ g^{-1} [11,16,36]. The WCRF defines high energy-dense foods as those with an ED of more than 9.4–11.5 kJ g^{-1} (225–275 kcal per 100 g) [16].

Statistical analysis

Participant demographic information was reported using descriptive statistics. Normally distributed data are presented as the mean (SD) and non-normal data are presented as the interquartile range (IQR). Linear mixed model regressions were used to investigate the association between SES variables, ED (food, beverages and combined food and beverages), overall energy intake and overall weight of food. The model was adjusted to account for potential confounders (such as BMI, smoking status and country of birth) and included (based on $P \leq 0.2$ in a multivariate model with SEIFA) education and income if the inclusion of the confounder also improved the model fit ($P < 0.1$). Data were analysed using STATA/IC, version 15.1 (StataCorp LLC, College Station, TX, USA).

Ethics approval

The Australian Bureau of Statistics received ethics approval to conduct the 2011–12 interview components of the NNPAS from the Census and Statistics Act of 1905 [30]. Ethical approval to perform a secondary data analysis on ABS Confidentialised Unit Record Files was obtained from the University of Newcastle Human Research Ethics Committee (Approval number H-2015-0216).

Results

Of the 6451 females in the NNPAS dataset, those <18 years (n = 1345) and >39 years (n = 3341) were excluded. Women also excluded from the analysis were those: who have never menstruated (n = 6); who were currently pregnant (n = 111); who were currently experiencing menopause (n = 7); and who were post-menopause (n = 3). In total, 1638 women aged 18–39 years, which included 102 breastfeeding women, were used in the analysis.

The characteristics of included women can be seen in Tables 1 and 2. Women were predominantly at the lower end of the overweight BMI category (25–29.9 kg m^{-2}), with a mean (SD) BMI of 26.0 (6.1) kg m^{-2}. The mean (SD) waist circumference of 84.2 (14.6) cm was >80 cm, a marker of increased risk of chronic disease for women [37]. A decreasing trend was seen in median waist circumference across SEIFA quintiles.

The most frequently reported income bracket was $AUD 1630–2492 per week ($n$ = 369, 22.5%). In the first- and second-income deciles, approximately half the participants were single parent families with children. Most

Table 1 Demographics describing the sample of Australian women of childbearing age across the SEIFA quintiles (n = 1638), including age, BMI, education and income

SEIFA Quintile	First		Second		Third		Fourth		Fifth		Total	
Characteristics	n	%	n	%	n	%	n	%	n	%	n	%
Females	325	19.8	307	18.7	337	20.6	278	17.0	391	23.9	1638	100
18 years	8	0.5	11	0.7	10	0.6	5	0.3	12	0.7	46	2.8
19-39 years	317	19.4	296	18.1	327	20.0	273	16.7	379	23.1	1592	97.2
Married	117	7.1	130	7.9	172	10.5	136	8.3	191	11.7	746	45.4
Female life stage												
Breastfeeding	16	1.0	25	1.5	23	1.4	18	1.1	20	1.2	102	6.2
Preconception	309	18.9	282	17.2	314	19.2	260	15.9	371	22.7	1536	93.8
BMI category												
Underweight	11	0.8	9	0.6	7	0.5	10	0.7	13	0.9	50	3.5
Normal	120	8.4	127	8.8	158	11.0	130	9.1	208	14.5	743	51.7
Overweight	63	4.4	61	4.3	75	5.2	55	3.8	70	4.9	324	22.6
Obese	86	6.0	72	5.0	58	4.0	42	2.9	61	4.3	319	22.2
Household income (weekly)												
$561	98	6.0	48	2.9	39	2.4	18	1.1	22	1.3	225	13.7
$562-$998	67	4.1	71	4.3	58	3.5	33	2.0	31	1.9	260	15.9
$999-$1629	52	3.2	55	3.4	74	4.5	60	3.7	45	2.8	286	17.5
1630-$2492	55	3.4	67	4.1	71	4.3	64	3.9	112	6.8	369	22.5
$2493	27	1.7	37	2.3	56	3.4	73	4.5	133	8.1	326	19.9
Not stated	3	0.2	9	0.6	6	0.4	8	0.5	8	0.5	34	2.1
Not known	23	1.4	20	1.2	33	2.0	22	1.3	40	2.4	138	8.4
Highest level of schooling												
Year 8 or below[a]	4	0.2	4	0.2	5	0.3	2	0.1	1	0.1	16	1.0
Year 9 or 10	78	4.8	60	3.7	45	2.8	30	1.8	34	2.1	247	15.1
Year 11 or 12	243	14.8	243	14.8	287	17.5	246	15.0	356	21.7	1375	83.9
Highest qualification												
≤High school qualification	135	8.3	106	6.5	110	6.8	56	3.4	95	5.8	502	30.9
Certificate I-IV[b]	95	5.8	96	5.9	74	4.6	59	3.6	73	4.5	397	24.4
Diploma/Adv. Diploma	26	1.6	31	1.9	38	2.3	41	2.5	36	2.2	172	10.6
Bachelor degree	53	3.3	59	3.6	86	5.3	80	4.9	135	8.3	413	25.4
Postgraduate, etc.	14	0.9	14	0.9	28	1.7	38	2.3	49	3.0	143	8.8
Labour force status												
Employed	195	11.9	204	12.5	253	15.5	222	13.6	328	20.0	1202	73.4
Unemployed	19	1.2	13	0.8	11	0.7	10	0.6	15	0.9	68	4.2
Not in labour force	111	6.8	90	5.5	73	4.5	46	2.8	48	2.9	368	22.5

SEIFA quintiles, first (lowest) to fifth (highest).
BMI, Body Mass Index; SEIFA, Socio-Economic Indexes for Areas.
[a]Includes never attended school.
[b]Includes certificate not further defined.

Table 2 Physical characteristics of the sample of Australian women of childbearing age across the SEIFA quintiles (n = 1638)

SEIFA quintile	First	Second	Third	Fourth	Fifth	Total
Physical measures	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)	Median (IQR)
Height n = 1438	163.0 (158.2-167.0)	165.5 (161.4-169.7)	164.0 (159.5-169.2)	164.0 (159.3-168.5)	165.0 (161.0-169.3)	164.5 (160.0-169.0)
Weight n = 1421	68.3 (58.7-84.3)	69.4 (59.2-83.5)	65.7 (58.7-77.0)	64.9 (57.1-76.0)	64.4 (56.8-76.2)	66.2 (58.0-78.9)
BMI (kg/m^2) n = 1416	25.5 (22.5-31.5)	24.9 (21.5-30.8)	24.2 (21.7-28.6)	23.9 (21.4-27.7)	23.6 (20.9-27.6)	24.2 (21.5-29.2)
WC (cm) n = 1407	84.0 (75.6-98.0)	84.0 (74.5-95.5)	82.0 (73.0-92.0)	80.0 (73.0-89.8)	79.0 (72.0-89.3)	81.0 (73.4-93.0)

SEIFA quintiles, first (lowest) to fifth (highest).
BMI, Body Mass Index; SEIFA, Socio-Economic Indexes for Areas; WC, Waist Circumference.

participants (84%) reported their highest level of schooling at year 11 or 12, with almost 70% reporting a non-school qualification. [38].

Energy density results

The median ED_{food}, ED_{bev} and $ED_{food+bev}$ for all participants was 9.38 kJ g^{-1} (IQR 7.63–11.09 kJ g^{-1}), 1.02 kJ g^{-1} (0.64–1.44 kJ g^{-1}) and 7.11 kJ g^{-1} (5.73–8.39 kJ g^{-1}), respectively (Fig. 1). Almost all women (94.8%) were consuming diets with an average ED_{food} that exceeded the WCRF recommendations of 5.23 kJ. The first (lowest) quintile had the highest ED_{food} [9.75 kJ g^{-1} (7.80–11.59 kJ g^{-1})], whereas the second SEIFA quintile had the highest ED_{bev} [1.09 kJ g^{-1} (0.66–1.44 kJ g^{-1})]. The two lowest SEIFA quintiles had the highest $ED_{food+bev}$, with a median value of 7.23 kJ g^{-1} (Fig. 2).

SEIFA, income and education did not explain variance in either the unadjusted or adjusted model of $ED_{food+bev}$. Included in the adjusted model was marital status, BMI, basal metabolic rate, country of birth and whether activity level was sufficient for good health. Significant confounders included being born in a non-English-speaking country, or not married and were more likely to have a reduced $ED_{food+bev}$ (coefficient: −0.57, $P < 0.001$ and coefficient: −0.22, $P = 0.045$ respectively), whereas those that were inactive were more likely to have a more energy-dense diet (coefficient: 0.51, $P = 0.001$).

Similar results were found for $_{EDfood}$, again with SEIFA, income and education showing little explanation for the variation in the unadjusted and adjusted regressions. Confounders such as BMI and age, although significant ($P = 0.008$ and $P = 0.031$ respectively) had little effect on ED_{food} (coefficient: −0.03 and 0.03 respectively). Inactivity, activity levels insufficient for good health and eating much less than usual were all shown to increase ED_{food} (coefficient: 0.78, $P < 0.001$; coefficient: 0.40, $P = 0.015$ and coefficient: 0.54, $P = 0.003$ respectively). Alternately, a non-English-speaking country of birth decreased ED_{food} (coefficient: −0.90, $P < 0.001$) as did the ED_{food} in those that had never smoked (coefficient: −0.452, $P = 0.028$).

Insignificant results were found for SEIFA and education in the unadjusted ED_{bev} model (coefficient: −0.00, $P = 0.984$, coefficient: 0.01, $P = 0.616$ respectively), with little significant effect explained by income (coefficient: −0.04, $P = 0.002$). Similarly, in the adjusted model, income and age had minimal effect (coefficient: −0.02, $P = 0.010$ respectively) and income was no longer significant (coefficient: −0.03, $P = 0.068$).

Education, but not SEIFA or income was significant in the unadjusted model for total energy intake with lower levels of education consuming less total energy (coefficient: −93.80, $P = 0.014$). In the adjusted model, education was no longer significant ($P = 0.245$). Confounders having greater effect were eating much more than usual (coefficient: 620.80, $P = 0.26$) and eating much less than usual (−927.36, $P < 0.001$). Every increase in BMI unit decreased energy intake by 56 kJ (coefficient: −55.67, $P < 0.001$). Energy intake increased in those who were inactive (coefficient: 818.17, $P = 0.001$) and insufficiently active (371.70, $P = 0.048$).

Initial associations were found with education and income and the total weight of dietary intake, with lower non-school education reducing total weight of intake (coefficient: −46.84, $P = 0.002$) and income increasing it (coefficient: 43.95, $P < 0.001$). Neither remained in the adjusted model. Significant confounders that increased the weight of dietary intake included eating much more than usual (coefficient: 216.43, $P = 0.046$), age (coefficient: 21.19, $P < 0.001$) and being taller (coefficient: 15.96, $P = 0.001$). Reduced weight of intake was associated with never smoking (coefficient: −333.55, $P < 0.001$), inactivity (coefficient: −400.21, $P < 0.001$), insufficient activity (coefficient: −217.27, $P = 0.003$) and having children (couple with children, coefficient:

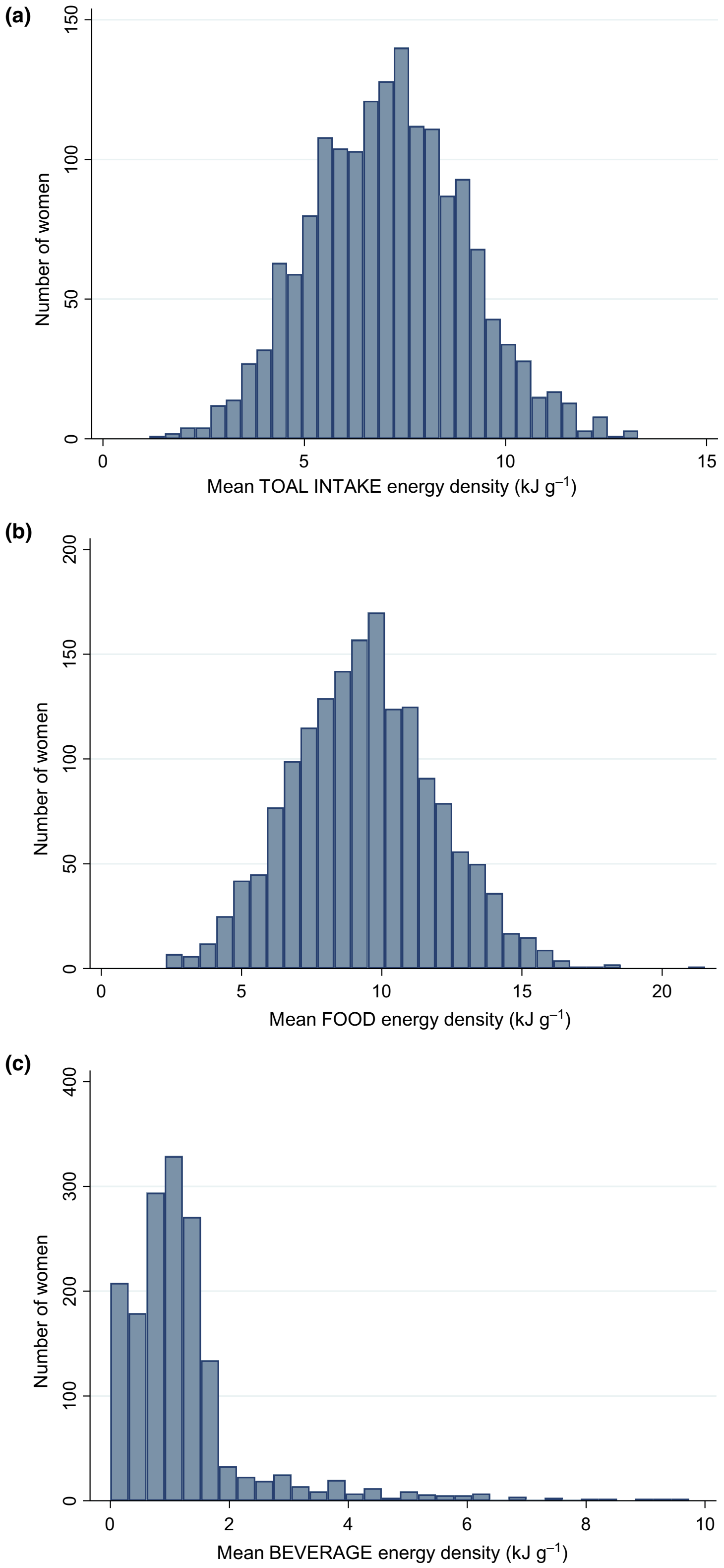

Figure 1 Frequency of mean (a) $ED_{food+bev}$, (b) ED_{food} and (c) ED_{bev} reportedly consumed by Australian childbearing women. ED, energy density.

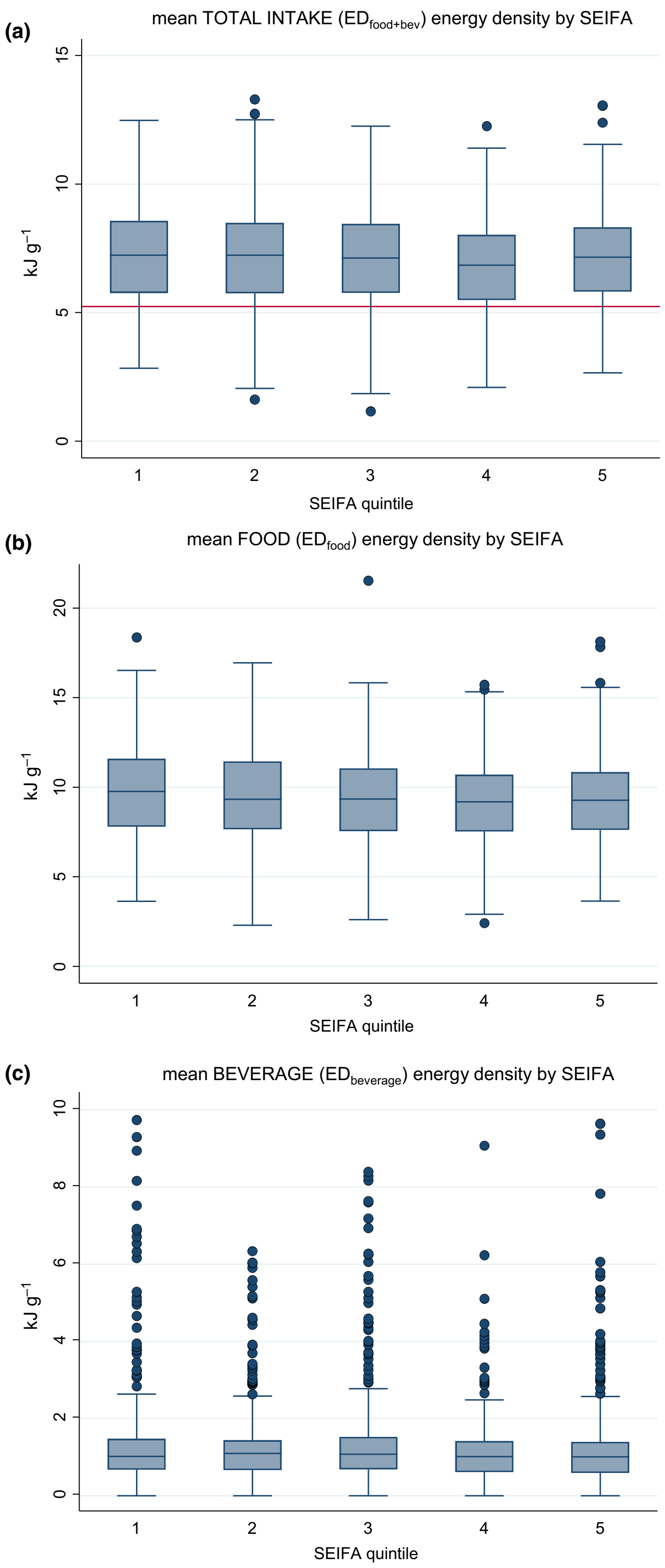

Figure 2 Differences in mean (a) $ED_{food+bev}$, (b) ED_{food} and (c) ED_{bev} across the Socio-Economic Indexes for Areas (SEIFA) quintiles. ED, energy density.

−210.40, $P = 0.046$; sole parent, coefficient: −486.18, $P < 0.001$). High fat foods, concentrated beverages and some commercial or takeaway foods contributed to high ED, energy content and weight analysis (see Supporting information, Fig. S2).

Discussion

Overall, the dietary intakes from this sample of Australian childbearing aged women were of poor quality and high ED, with large disparity from the ADG. SEIFA, income and education showed little effect on ED in any model, with various lifestyle confounders having greater effects. Inactivity and activity levels insufficient for good health, smoking, BMI, country of birth, marital status, whether the woman already had children and eating more or less than usual had greater effect on the ED of the diet reported. These findings suggest that Australian women of childbearing age may not be eating diets of optimum energy density and that lifestyle factors are having a greater effect than SES.

Significant inverse associations have been found between SES and dietary ED in previous research, which differs from the findings reported here [11,25,39,40]. Higher levels of education and income were inversely associated with dietary ED in an American study of male and female participants [41]. ED was found to be positively associated with living below the poverty line among a representative sample of the adult population in Luxembourg ($\beta = 0.125$) [42]. Australian women from lower SES areas have significantly higher dietary ED than those from higher SES groups [11]. Grech, Rangan and Farinelli [11] found a difference of + 0.52 kJ g^{-1} between the highest and lowest SEIFA quintiles in an Australian study of males and females aged 18–34 years. Furthermore, participants with a university education (6.85 kJ g^{-1}) had the lowest dietary ED compared to those with no tertiary education (7.53 kJ g^{-1}) [11]. Small increases in ED can contribute to total energy intake, therefore disturbing energy balance in favour of weight gain [11]. Increases in ED as small as 0.2 kJ g^{-1} can significantly increase the population's energy intake, subsequently leading to weight gain [36]. A systematic review found that low dietary ED decreased body weight and prevented weight regain in obese adults [43]. In comparison with higher energy-dense foods, lower energy-dense foods were found to have similar to higher satiety effects following consumption, with reduced energy intake [43].

The present study found significant decreases in ED in people who were born overseas, compared to those born in Australia or other main English-speaking countries, explaining moderate variation in $ED_{food+bev}$ and ED_{food} (coefficient: −0.57, $P < 0.001$ and coefficient: −0.90, $P < 0.001$ respectively). An Australian study found a significant inverse association ($P < 0.0001$) between those born in non-English-speaking countries (6.77 kJ g^{-1}) compared to those born in Australia and other English-speaking countries (7.36 kJ g^{-1}) [11]. Our research found that the ED_{food} of those who had never smoked was lower (coefficient: −0.452). This relationship between dietary ED and smoking is supported by recent research from the USA, using a national representative sample of adults over 18 years [44]. MacLean *et al.*[44] found that daily and non-daily smokers had significantly higher dietary ED (8.45 kJ g^{-1} and 7.9 kJ g^{-1}, respectively) compared to those who never smoked (7.5 kJ g^{-1}). Despite eating smaller portions, the average difference in ED meant that current daily smokers consumed approximately 840 kJ (200 cal) more per day than those who never smoked [44].

A large proportion of participants across all SEIFA quintiles exceeded the WCRF recommendations for ED_{food} of 5.23 kJ g^{-1} [16]. The present study found an average ED_{food} that was higher than that of other studies [11,45]. The discrepancy between the findings of the present study and other studies could be due to differences in the categorisation of what was considered a food or a beverage (e.g. liquid meal replacement or cereal with milk). $ED_{food+bev}$ was similar to other studies, which found energy-densities of food to range between 7.24 kJ g^{-1} and 7.18 kJ g^{-1} [11,45]. The similarity between the $ED_{food+bev}$ here to the ED_{food} of other studies could be explained by additions to food and beverages influencing the ED. A difference of approximately 2.1 kJ g^{-1} (0.5 kcal g^{-1}) in ED was found between two studies [46,47] in a systematic review, as a result of the exclusion of beverages from the analyses [43]. The insignificant results found for ED_{bev} and $ED_{food+bev}$ could be explained by the effect that beverages has on ED. Beverages have a high water content, and may disproportionately influence dietary ED [48,49]. However, beverages contribute to overall energy intake; therefore, it is important to consider the analysis beverages separately rather than removing them from analyses completely.

The proportion of core foods and discretionary items could explain the high ED of food found across all SEIFA quintiles. The present study found that the majority of foods and beverages contributing the most energy were being consumed in large quantities and were mostly discretionary items. These included takeaway pizzas, deep-fried foods and alcoholic beverages. Studies have found that differences in dietary ED were mostly a result of higher intakes of discretionary foods that were high in sugar, sodium, saturated fat and a lower intake of fruit and vegetables [11,45]. One Australian study using diet quality scores, found that diet quality was inversely associated with dietary ED [11]. Improved dietary quality was associated with higher intakes of fruit and vegetables, with lower intakes of discretionary foods [11,45]. Higher quality diets were associated with higher levels of SES in an American study; however, per approximately 8400 kJ (2000 kcal), they were more costly [41].

By using a sample taken from an Australian national dataset, the findings of the present study are generalisable to the Australian female population who are breastfeeding or in the preconception period. Representative data allow the study to be transferable, although the results may only comparable with those of similar, high-income countries that use similar methodologies to collect their national data. The limitations of the study include the cross-sectional design, which provides an insight into the ED and nutritional adequacy of the diets of childbearing aged women, although it cannot demonstrate causation. Although 24-h dietary recalls are considered a reliable and valid method of dietary assessment, there are several limitations [50]. This analysis only reported on the group average intake relative to a single day because one 24-h dietary recall was used for each participant; therefore, we were unable to derive usual intake. Measurement error is inevitable when data are self-reported as a result of the estimation of food portions, composition of foods and recalling foods consumed the day prior to recall [51]. Low energy reporting and underreporting of high energy-dense and discretionary items is likely a result of recall bias and perceived social desirability.

Overall, our findings suggest that Australian women of childbearing age may not be consuming an optimal diet to ensure nutritional readiness for pregnancy. Given the high dietary ED, it is important to improve dietary quality in this group through a reduction in ED. Further research is needed to identify the factors affecting the nutritional preparedness of childbearing aged women for pregnancy. Identifying these factors may improve the health of Australian childbearing aged women and improve birth outcomes. In addition, additional investigation into the nutrient intakes and the sources of these (supplements, discretionary items, core foods) is needed. The preconception period, irrespective of pregnancy planning, provides an opportunistic period for health care professionals to educate and encourage health promoting behaviours, to improve maternal health, birth outcomes and reduce the risk of chronic disease in offspring.

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Conflict of interests, source of funding and authorship

The authors declare that they have no conflicts of interest.
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RL was responsible for drafting the paper, as well as the analysis and interpretation of the data. TS was responsible for the conception of the study design, drafting the paper, the analysis and interpretation of the data, and critically reviewed the paper. LB was responsible for the interpretation of the data, the conception of the study design and critically reviewed the paper. KR was responsible for interpretation of the data and critically reviewed the paper. MR was responsible for the conception of the study design and critically reviewed the paper. All authors critically reviewed the manuscript and approved the final version submitted for publication.

Transparency declaration

The lead author affirms that this manuscript is an honest, accurate and transparent account of the study being reported. The reporting of this work is compliant with STROBE guidelines. The lead author affirms that no important aspects of the study have been omitted and that any discrepancies from the study as planned have been explained.

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Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Figure S1. Energy density methods flowchart.

Figure S2. Reported foods and beverages with the highest energy density and weight per energy.

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CORRIGENDUM

Understanding the core principles of a 'modified ketogenic diet': a UK and Ireland perspective

K. J. Martin-McGill, B. Lambert, V. J. Whiteley, S. Wood, E. G. Neal, Z. R. Simpson & N. E. Schoeler on behalf of the Ketogenic Dietitians Research Network (KDRN). *Journal of Human Nutrition and Dietetics* 2019, 32, 385–390.

In the article by Martin-McGill *et al.* [1], the authors missed to include the funding statement. The following funding statement should be added: "This work was supported by the NIHR GOSH BRC."

The authors apologize for this mistake.

Reference

1. Martin-McGill KJ, Lambert B, Whiteley VJ *et al.* (2019) Understanding the core principles of a 'modified ketogenic diet': a UK and Ireland perspective. *J Hum Nutr Diet* **32**, 385–390.