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RESEARCH PAPER

The application of genetics and nutritional genomics in practice: an international survey of knowledge, involvement and confidence among dietitians in the US, Australia and the UK

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Abstract As a result of expanding scientific understanding of the interplay between genetics and dietary risk factors, those involved in nutritional management need to understand genetics and nutritional genomics in order to inform management of individuals and groups. The aim of this study was to measure and determine factors affecting dietitians' knowledge, involvement and confidence in genetics and nutritional genomics across the US, Australia and the UK. A cross-sectional study was undertaken using an online questionnaire that measured knowledge and current involvement and confidence in genetics and nutritional genomics. The questionnaire was distributed to dietitians in the US, Australia and the UK using email lists from the relevant professional associations. Data were collected from 1,844 dietitians who had practiced in the previous 6 months. The main outcomes were knowledge of genetics and nutritional genomics and involvement and confidence in undertaking clinical and educational activities related to genetics and nutritional genomics. Mean scores for knowledge, involvement and confidence were calculated. Analysis of variance and χ^2 analysis were used to compare scores and frequencies. Multivariate linear regression was used to determine predictors of high scores. The results demonstrated significant differences in involvement ($p < 0.001$) and confidence ($p < 0.001$) but not knowledge scores ($p = 0.119$) between countries. Overall, dietitians reported low levels of knowledge (mean knowledge score 56.3 %), involvement (mean number of activities undertaken 20.0–22.7 %) and confidence (mean confidence score 25.8–29.7 %). Significant relationships between confidence, involvement and knowledge were observed. Variables relating to education, experience, sector of employment and attitudes were also significantly associated with knowledge, involvement and confidence. Dietitians' knowledge, involvement and confidence relating to genetics and nutritional genomics remain low and further investigation into factors contributing to this is required.

Keywords International · Nutrigenetics · Nutrigenomics · Dietitian

Introduction

The Human Genome Project has precipitated remarkable advances in our understanding of the genetic associations of a range of diseases (Wellcome Trust Case Consortium 2007). Greater understanding about individualised responses to environmental factors such as drugs and nutrients due to genetic variation has resulted in the emerging disciplines of pharmacogenomics and nutritional genomics. Nutritional genomics considers how nutrients or dietary constituents influence gene expression (nutrigenomics) and how genetic variation influences metabolic response to nutrients or dietary constituents (nutrigenetics) (McCarthy et al. 2008), thus potentiating dietary interventions that are personalised to a patient's genomic

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profile. Translating this science to practice is crucial to ensure the potential benefits for disease prevention and management are realised. In view of the established and emerging role for genetics and nutritional genomics in health care, there is impetus to provide a genetics-led health service in many countries (DH 2008; NCHPEG 2001).

In 2001, Guttmacher et al. described how genomics-based medicine would trend towards delivery by non-genetics specialists who 'bring different knowledge bases, talents and emphases to genetic care' (Guttmacher et al. 2001). The successful application of nutritional genomics necessitates cohesive action from multiple professionals from different fields working across the spectrum from 'bench to bed' in research, education and healthcare environments. Previous research has addressed the opportunities and barriers relating to genetics and genomics among various workforces including public health, medicine, primary care, nursing, pharmacy, occupational therapy and dietetics (Chen and Goodson 2007; Emery et al. 1999; Kirk et al. 2008; Ferro et al. 2012; Kyler and Thomas 2000; DeBusk et al. 2005). One group of health professionals who will be involved in the application of nutritional genomics are dietitians, who have expertise in biomedical and nutritional sciences and are well positioned to translate and deliver health messages to the public.

The current role of the dietetic profession in the application of genetics and nutritional genomics has not been extensively investigated. A study in the United States (US) interviewed 2,052 health professionals, of whom 372 were dietitians, and found variation in genetics service provision, genetics education and a desire for continuing professional development in this area (Lapham et al. 2000; Gilbride and Camp 2004). In a study of 390 dietitians in the United Kingdom (UK), involvement, confidence and knowledge of genetics and nutrigenomics were generally low (Whelan et al. 2008). In both of these studies, dietitians with more genetics education had greater confidence and knowledge (McCarthy et al. 2008; Lapham et al. 2000; Gilbride and Camp 2004). Limited knowledge and confidence about genetics and nutritional genomics is likely to be a major barrier preventing the application of these concepts (Rosen et al. 2006).

As the science of genetics and nutritional genomics is advancing at a rapid pace and impacting profoundly on how disease is prevented and managed, health professionals including dietitians need to embrace and integrate nutritional genomics into their practice. The aim of this study was to measure and investigate factors associated with knowledge, involvement and confidence in genetics and nutritional genomics among an international sample of dietitians in the US, Australia and the UK.

Methods

Study design

This international cross-sectional study investigated dietitians' knowledge, involvement and confidence in genetics and nutritional genomics. The study was approved by the institutional review boards of East Carolina University (US), Monash University (Australia) and King's College London (UK). Informed consent was obtained from all participants, and data were collected anonymously.

Questionnaire

The questionnaire was developed using a previously validated survey instrument (McCarthy et al. 2008; Whelan et al. 2008) and refined using the results of seven focus groups conducted with clinical ($n = 12$), academic ($n = 16$) and newly graduated ($n = 6$) dietitians. The focus groups ensured that the questionnaire addressed contemporary issues in genetics and nutritional genomics in international practice, and covered preparedness, perceived opportunities, benefits and barriers of nutritional genomics in dietetics. Once refined, face validity and online usability were determined through a pilot survey of 16 dietitians, and minor modifications were made based upon feedback, adapted by language and context of practice for each country and then administered online.

The final questionnaire included four sections surveying (1) knowledge; (2) confidence; (3) involvement and (4) demographics. The knowledge section had 16 multiple choice questions measuring knowledge of basic terminology and concepts relating to genetics (12 questions; 1–12) and nutritional genomics (4 questions; 13–16) (Table 1). The involvement and confidence sections related to a series of 11 clinical and 3 educational activities about genetics and nutritional genomics (Table 2). The genetics activities were taken from the clinical and educational activities included in the HuGEM study (Lapham et al. 2000) and were only collected from respondents who worked in the clinical or educational sector for a substantial amount of time. Involvement in each activity was measured using a dichotomous response set (involved, not involved), and confidence was measured using a 5-point Likert scale (0 'very low confidence' to 4 'very high confidence'). The demographic section surveyed dietetic employment, qualifications and experience.

Participants

Registered Dietitians who had practiced in the US, Australia or UK in the last 6 months were eligible to participate. To ensure relevance to the widest context of dietetics,

Table 1 Correct responses to questions to measure dietitians' knowledge of genetics and nutritional genomics [*n* (%)]

	Multiple choice questions	Overall $n = 1844$	US $n = 461$	Australia $n = 390$	UK $n = 993$
1	A 'gene' is?	1560 (84.6)	391 (84.8)	344 (88.2)	825 (83.1)
2	A 'chromosome' is?	1661 (90.1)	422 (91.5)	345 (88.5)	894 (90.0)
3	An 'allele' is?	796 (43.2)	159 (34.5)	194 (49.7)	443 (44.6)
4	'Genotype' is?	1330 (72.1)	307 (66.6)	288 (73.8)	735 (74.0)
5	'Phenotype' is?	1173 (63.6)	260 (56.4)	268 (68.7)	645 (65.0)
6	A 'polymorphism' is?	733 (39.8)	174 (37.7)	156 (40.0)	403 (40.6)
7	A 'mutation' is?	1399 (75.9)	334 (72.5)	314 (80.5)	751 (75.6)
8	'PCR' means?	850 (46.1)	176 (38.2)	231 (59.2)	443 (44.6)
9	What condition is not associated with the MTHFR 677C → T defect?	346 (18.8)	104 (22.6)	55 (14.1)	187 (18.8)
10	Which of the following is not a multi-factorial disease?	1039 (56.3)	226 (49.0)	207 (53.1)	606 (61.0)
11	Which of the following statements about genetic defects/disorders is false?	1131 (61.3)	313 (67.9)	241 (61.8)	577 (58.1)
12	In which condition is a genetic test regularly used?	1652 (89.6)	393 (85.2)	353 (90.5)	906 (91.2)
13	'Nutrigenetics' is?	600 (32.5)	163 (35.4)	139 (35.6)	298 (30.0)
14	'Nutrigenomics' is?	618 (33.5)	198 (43.0)	131 (33.6)	289 (29.1)
15	Which of the following applications is not part of nutritional genomics?	1262 (68.4)	343 (74.4)	259 (66.4)	660 (66.5)
16	Which of the following defects interacts with dietary fat intake to influence the risk of CVD?	457 (24.8)	140 (30.4)	92 (23.6)	225 (22.7)

Adapted from McCarthy et al. (2008) and Whelan et al. (2008)

all domains of practice were eligible (e.g. clinical, public health, education and industry). Exclusion criteria were nutritionists, registered dietetic technicians, dietetic assistants and student dietitians.

Recruitment

Participants were recruited through the "Find A Dietitian" search function on the Academy of Nutrition and Dietetics (AND) website and through the membership database of the national professional bodies in Australia (Dietitians Association of Australia, DAA) and the UK (British Dietetic Association, BDA). All registered dietitians listed on the AND website ($n = 4{,}066$), and all members of the DAA ($n = 4{,}720$) and the BDA ($n = 5{,}500$) where email addresses were available (total of 14,286 dietitians) were invited to participate. Potential participants received an invitation email with a weblink to the online survey (Survey Monkey®, Palo Alto, California, US, research version licensed to Monash Nutrition and Dietetics). There are a number of advantages of survey distribution via the Internet, notably including global reach, ease and timeliness of follow-up, low administration cost and burden and convenience for responders (Evans and Mathur 2005). In order to maximise response rate, reminder emails were sent to all potential participants after 1–2 weeks and an incentive to win small gift vouchers was offered to participants in the UK and Australia but not in the US (Edwards et al. 2009).

Statistical analyses

Statistical analysis was performed using SPSS version 17.0 (SPSS Inc., Chicago, Illinois). Mean (SD) scores were calculated for knowledge, involvement and confidence in clinical and educational activities. Knowledge scores were calculated as the percentage of correct answers for the genetics section, the nutritional genomics section and in total. An involvement score was calculated from the sum of clinical or educational activities undertaken in the last 6 months, while confidence scores were determined from the sum of confidence levels (0 'very low confidence' to 4 'very high confidence') for each activity, and this was presented as percentage of total possible scores for clinical or educational activities, respectively.

One-way analysis of variance (ANOVA) with Bonferroni post hoc correction was used to compare knowledge, involvement and confidence scores between countries. χ^2 analysis was used to compare the n (%) of dietitians involved in educational and clinical activities between countries.

Multiple linear regression was used to explore the associations between high scores for knowledge, involvement and confidence and their predictor variables. Univariate analysis was initially undertaken to identify relevant factors. These factors related to education (postgraduate dietetics qualification, having a PhD), practice (years of experience, sector of dietetics, e.g. clinical, public

Table 2 Dietitians' involvement in genetics and nutritional genomics clinical and educational activities (by country) [n (%)]

Clinical activities (11 activities)	All $n = 1357$	US $n = 319$	Australia $n = 280$	UK $n = 758$	p value (x^2)
Collecting genetic information as part of a family or disease history	478 (35.2)	120 (37.6)	119 (42.5)	239 (31.5)	0.003
Discussing the genetic basis of a disease with patients	590 (43.5)	165 (51.7)	145 (51.8)	280 (36.9)	<0.001
Advising a patient to go to a specialist genetic service	93 (6.9)	32 (10.0)	20 (7.1)	41 (5.4)	0.023
Providing guidance to patients with genetic disorders about what impact it may have on their future development	320 (23.6)	96 (30.1)	69 (24.6)	155 (20.4)	0.003
Providing counselling to patients regarding genetic disorders	226 (16.7)	89 (27.9)	66 (23.6)	71 (9.4)	<0.001
Obtained written informed consent to release genetic information to a third party	23 (1.7)	13 (4.1)	9 (3.2)	1 (0.1)	<0.001[a]
Discussing with patients the genetic and dietary basis of a disease	678 (50.0)	192 (60.2)	157 (56.1)	329 (43.4)	<0.001
Discussing with patients how diet may interact with genes to influence the risk of disease	361 (26.6)	141 (44.2)	75 (26.8)	145 (19.1)	<0.001
Providing nutrition advice to patients which is specific to the genetic nature of their condition	428 (31.5)	141 (44.2)	83 (29.6)	204 (26.9)	<0.001
Using the information in a pedigree diagram/family history diagram	101 (7.4)	19 (6.0)	32 (11.4)	50 (6.6)	0.016
Preparing a pedigree diagram/family history diagram	36 (2.7)	9 (2.8)	14 (5.0)	13 (1.7)	0.014
Educational activities (3 activities)	**Overall $n = 638$**	**US $n = 134$**	**Australia $n = 93$**	**UK $n = 411$**	**p value (x^2)**
Providing training or education to students or other health professionals on human genetics	43 (6.7)	23 (17.2)	7 (7.5)	13 (3.2)	<0.001
Providing training or education to students or other health professionals on diseases that have both a dietary and a genetic component	294 (46.1)	77 (57.5)	46 (49.5)	171 (41.6)	0.005
Developing documents related to the training or education of students or other health professionals about human genetics	26 (4.1)	13 (9.7)	4 (4.3)	9 (2.2)	0.001

[a] Some cells (<20 %) used to calculate the p value have an expected frequency <5

health) and attitudes (perceived importance of genetics). Knowledge, involvement and confidence scores were also included as independent variables as appropriate. Years of experience and scores were entered as continuous data, and all other variables were dichotomous. Those that were statistically significant ($p < 0.05$) on univariate analysis were entered into multivariate linear regression models. Five regression models were developed to investigate each outcome (knowledge, involvement in clinical activities, involvement in educational activities, confidence in clinical activities and confidence in educational activities).

Preliminary analyses were conducted to assess the data's compliance with assumptions. The dependent variables were non-normally distributed; however, logistic regression could not be undertaken due to small groups and extensive exclusion of cases with incomplete data. The majority of independent variables did not show a strong association with the dependent variables ($r < 0.3$) with the notable exception of a high correlation between clinical and education confidence scores ($r = 0.737$). Nevertheless, there was no evidence of multicollinearity, supported by tolerance and variance inflation factor (VIF) results within normal limits. Outliers existed but these cases remained in the analysis as there was no overall effect on the model with the maximum value of Cook's distance < 1.0. Exp (B) and the 95 % confidence interval (CI) were reported for linear models to identify the strength, direction and significance of the association. p values of <0.05 was considered statistically significant.

Results

Of the 14,286 questionnaires distributed, 2,287 were accessed (actual response rate 16 %) by 568 (14 %) of dietitians in the US, 507 (11 %) in Australia and 1212 (22 %) in the UK. Among these participants, 179 did not consent or meet the inclusion criteria and 264 withdrew before commencement. Of the remaining 1,844 (valid response rate 13 %) who submitted a questionnaire and on whom data were analysed, 461 (25 %) were from the US, 390 (21 %) from Australia and 993 (54 %) from the UK. A further 158 responses were incomplete.

Demographic characteristics

The majority of respondents worked in clinical dietetics, had a bachelor- or masters-level degree and had worked as a dietitian for an average of 13.3 (10.6, SD) years (Table 3). There were statistically significant differences between countries for some demographic characteristics including years of experience and highest degree (all $p < 0.001$) (Table 3).

Knowledge

Dietitians answered approximately half the questions correctly, with the percentage of correct responses ranging substantially between questions (Table 1). There was no differences between countries in total knowledge scores (Table 4). The multivariate model containing 14 predictor variables was statistically significant, although it explained only 13.9 % of the variance of high knowledge scores ($r^2 = 0.139$, F (14,492) = 5.657, $p < 0.001$) (Table 5). The strongest predictor of high knowledge scores was confidence in undertaking educational activities in genetics and nutritional genomics ($\beta = 0.26$, 95 % CI = 0.13–0.45). Knowledge scores were the highest among those with fewer years of experience and those who perceived an understanding of genetics to be important (Table 5).

Involvement

The majority of respondents who reported working in clinical dietetics ($n = 1{,}357$) or education ($n = 638$) lacked involvement in clinical and educational activities relating to genetics and nutritional genomics (Table 2). Of the 11 clinical activities, on average, dietitians were involved in 2.5 (2.3, SD), and of the three educational activities, educators were involved in 0.6 (0.7, SD) (Table 4). At most, 50 % of clinical dietitians had *'discussed with patients the genetic and dietary basis of a disease,'* while 46.1 % of educators had *'provided training or education to students or other health professionals on diseases that have both a dietary and genetic component'* (Table 2). Multivariate models predicted 40 % of the variance associated with high involvement scores for clinical activities ($r^2 = 0.397$, F (13,493) = 24.971, $p < 0.001$) and 42 % for educational activities ($r^2 = 0.423$, F (11,495) = 33.053, $p < 0.001$) (Table 6). The strongest predictor of high involvement for both clinical and educational activities was high confidence.

Confidence

The majority of clinical dietitians and educators reported low confidence in clinical and educational activities relating to genetics and nutritional genomics (Table 4). Respondents were most confident in their ability to *'discuss with patients the genetic and dietary basis of a disease'* (54.6 % reporting moderate/high confidence) (not shown). Approximately 66 % of the variance associated with high confidence for clinical activities ($r^2 = 0.655$, F (15,491) = 62.151, $p < 0.001$) and 68 % for educational activities ($r^2 = 0.677$, F (12,494) = 86.429, $p < 0.001$)

Table 3 Demographic characteristics of respondents [n, %]

	All	US	Australia	UK
Sector of dietetics where respondents worked for a substantial amount of time				
	$n = 2669$[a]	$n = 415$	$n = 367$	$n = 904$
Clinical dietetics	1394 (82.7)	331 (79.8)	302 (82.3)	761 (84.2)
Educating students or other health professionals	533 (31.6)	113 (27.2)	76 (20.7)	344 (38.1)
Research	169 (10.0)	26 (6.3)	57 (15.5)	86 (9.5)
Food service/food industry	100 (5.9)	43 (10.4)	34 (9.3)	23 (2.5)
Public health/policy	236 (14.0)	56 (13.5)	66 (18.0)	114 (12.6)
Professional dietetic body/government agency	35 (2.1)	8 (1.9)	8 (2.2)	19 (2.1)
Managing dietetic services	161 (9.5)	31 (7.5)	36 (9.8)	94 (10.4)
Media	41 (2.4)	21 (5.1)	4 (1.1)	16 (1.8)
Number of years experience as a dietitian				
	$n = 1686$	$n = 415$	$n = 367$	$n = 904$
0–2	210 (12.5)	15 (3.6)	80 (21.8)	115 (12.7)
3–5	312 (18.5)	50 (12.0)	85 (23.2)	117 (19.6)
6–10	342 (20.3)	60 (14.5)	80 (21.8)	202 (22.3)
11–20	395 (23.4)	93 (22.4)	67 (18.3)	235 (26.0)
21 or more	427 (25.3)	197 (47.5)	55 (15.0)	175 (19.4)
Highest academic degree				
	$n = 1686$	$n = 415$	$n = 367$	$n = 904$
Bachelor	794 (47.1)	130 (31.3)	179 (48.8)	485 (53.7)
Masters	800 (47.4)	252 (60.7)	169 (46.0)	379 (41.9)
Doctorate	74 (4.4)	24 (5.8)	17 (4.6)	33 (3.7)
Other qualification	18 (1.1)	9 (2.2)	2 (0.5)	7 (0.8)

[a] Not mutually exclusive

was identified (Table 7). The greatest predictor of confidence in clinical activities relating to genetics and nutritional genomics was confidence in educational activities and vice versa. Involvement in clinical and educational activities was also significantly associated with confidence in those respective activities.

Discussion

This study was undertaken to measure and identify factors that are associated with knowledge, involvement and confidence of genetics and nutritional genomics among dietitians from three countries: the US, Australia and the UK. Despite substantial variation, overall knowledge was low, with respondents answering just over half of the knowledge questions correctly, and there were similarly low levels of involvement and confidence.

Knowledge

Despite low levels of knowledge overall, dietitians scored higher on the genetics section and lower on the nutritional genomics section, perhaps reflecting the latter being a newer, emerging concept.

The final regression model was only able to explain a very small amount of the variance in dietitians' knowledge of genetics and nutritional genomics, and there are a number of potential explanations for this. First, the majority of knowledge scores were tightly clustered around 50 %, contributing to the inability of the model to find associations. Second, knowledge was measured using multiple choice questions, which although previously validated may not measure the totality of knowledge in this area. Third, some factors that may significantly predict knowledge were not measured here. For example, surveys (McCarthy et al. 2008; Oosthuizen 2011) and an intervention study (Cragun et al. 2005) indicate that knowledge of genetics and nutritional genomics increases with university training or professional development in these areas. However, from the data presented, high levels of confidence in educating others in genetics activities are predictive of high knowledge scores, which reinforces that teaching requires expert knowledge and skills.

Involvement and confidence

Involvement and confidence were considerably higher for clinical tasks such as *'discussing the genetic basis of a disease with patients'* than more specialist activities such

Table 4 Knowledge, involvement and confidence of genetics and nutritional genomics among dietitians, mean (95 % CI)

Knowledge	All $n = 1844$	US $n = 461$	Australia $n = 390$	UK $n = 993$	p value (ANOVA)
Total score, % (16 qu)	56.3 (55.5–57.1)	55.6 (54.0–57.3)	58.0 (56.2–59.8)	55.9 (54.8–57.1)	0.119
Genetic score, % (12 qu)	61.8 (60.9–62.6)	58.9 (57.2–60.6)[a]	64.0 (62.2–65.9)[b]	62.2 (61.0–63.4)[b]	<0.001
Nutritional genomics score, % (4 qu)	39.8 (38.5–41.1)	45.8 (43.2–48.3)[a]	39.8 (36.9–42.8)[b]	37.1 (35.3–38.8)[b]	<0.001
Clinical activities (11 activities)	$n = 1357$	$n = 319$	$n = 280$	$n = 758$	p value (ANOVA)
Involvement (number of activities)	2.5 (2.3–2.6)	3.2 (2.9–3.5)[a]	2.8 (2.6–3.1)[a]	2.0 (1.9–2.2)[b]	<0.001
Confidence score, %[d]	29.7 (28.7–30.8)	38.4 (36.2–40.7)[a]	33.0 (30.8–35.3)[b]	24.9 (23.7–26.1)[c]	<0.001
Educational activities (3 activities)	$n = 638$	$n = 134$	$n = 93$	$n = 411$	p value (ANOVA)
Involvement (number of activities)	0.6 (0.5–0.6)	0.8 (0.7–1.0)[a]	0.6 (0.5–0.8)[b]	0.5 (0.4–0.5)[c]	<0.001
Confidence score, %[d]	25.8 (24.1–27.5)	37.4 (33.6–41.3)[a]	30.4 (25.2–35.6)[b]	21.0 (19.1–22.0)[c]	<0.001

Mean values with different superscripts ([a, b, c]) were statistically significantly different following ANOVA and Bonferroni post hoc correction

[d] The confidence score was calculated by the sum of confidence (0 'very low confidence' to 4 'very high confidence') for each activity, and this was presented as percentage of total possible score for clinical or educational activities. Therefore, 0 % is 'very low confidence' and 100 % is 'very high confidence'

Table 5 Factors associated with high scores for knowledge of genetics and nutritional genomics among dietitians (Model 1)

	B ± SE (95 % CI for B)	β	p value
Years of experience	−0.04 ± 0.01 (−0.07 to −0.02)	−0.16	0.001
PhD	0.45 ± 0.26 (−0.13 to 2.51)	0.08	0.076
Graduated via a postgraduate degree	0.45 ± 0.26 (−0.07 to 0.96)	0.07	0.088
Perceive genetics to be important	1.56 ± 0.63 (0.32 to 2.81)	0.11	0.014
Employed by the public health service	0.20 ± 0.29 (−0.37 to 0.77)	0.03	0.496
Clinical dietitian	−0.39 ± 0.37 (−1.11 to 0.33)	−0.05	0.291
Education dietitian	0.30 ± 0.27 (−0.24 to 0.84)	0.05	0.280
Research dietitian	0.07 ± 0.46 (−0.83 to 0.97)	0.01	0.875
Government dietitian	0.80 ± 0.87 (−0.91 to 2.52)	0.04	0.359
Food service/industry dietitian	0.53 ± 0.55 (−0.54 to 1.60)	0.04	0.333
Clinical confidence score	−0.01 ± 0.02 (−0.06 to 0.04)	−0.04	0.599
Education confidence score	0.29 ± 0.08 (0.13 to 0.45)	0.26	<0.001
Clinical involvement score	0.07 ± 0.07 (−0.07 to 0.21)	0.06	0.309
Education involvement score	0.01 ± 0.23 (−0.45 to 0.47)	0.00	0.956

By multivariate linear regression

as *'obtaining written informed consent to release genetic information'* that may be perceived to be beyond the professional boundaries of a dietitian.

There was an association between involvement and confidence, which is consistent with previous findings (Whelan et al. 2008; Oosthuizen 2011). Dietitians who were more confident in undertaking clinical or educational activities relating to genetics and nutritional genomics were more likely to be involved in them, and this relationship is likely to be bidirectional.

Dietitians may avoid involvement in activities where they lack confidence as there is a danger in working beyond competency limits while being involved and therefore experienced in an activity is likely to increase confidence in undertaking it. As confidence grows through education and training, undertaking genetics and nutritional genomics activities may become more frequent. While confidence contributes to competence, the two are not the same. Competence in genetic and nutritional genomic activities may be of greater importance as this describes integrated, holistic attributes required for a task, rather than particular skills in isolation. Additionally, high confidence scores for educational activities made the greatest unique contribution to high confidence scores for clinical activities and vice versa. Interestingly, knowledge was not significantly associated with involvement, despite the previous research

Table 6 Factors associated with high scores for involvement in undertaking activities related to genetics and nutritional genomics among dietitians

	B ± SE (95 % CI for B)	β	p value
Model 2: Clinical activities (11 activities)			
Years of experience	0.01 ± 0.01 (−0.01 to 0.02)	0.03	0.371
PhD	−0.11 ± 0.43 (−0.95 to 0.74)	−0.01	0.806
Graduated via a postgraduate degree	0.08 ± 0.17 (−0.25 to 0.41)	0.02	0.629
Perceive genetics to be important	−0.06 ± 0.41 (−0.87 to 0.75)	−0.01	0.887
Employed by the public health service	0.10 ± 0.18 (−0.26 to 0.46)	0.02	0.596
Research dietitian	−0.04 ± 0.28 (−0.60 to 0.52)	−0.01	0.887
Health promotion/public health dietitian	0.29 ± 0.23 (−0.16 to 0.74)	0.05	0.199
Food service/industry dietitian	0.35 ± 0.35 (−0.33 to 1.03)	0.04	0.306
Media and press dietitian	0.05 ± 0.53 (−0.98 to 1.09)	0.00	0.921
Knowledge score	0.03 ± 0.03 (−0.03 to 0.08)	0.04	0.347
Clinical confidence score	0.15 ± 0.01 (0.12 to 0.17)	0.55	<0.001
Education confidence score	−0.15 ± 0.05 (−0.25 to −0.04)	−0.17	0.006
Education involvement score	1.01 ± 0.14 (0.73 to 1.29)	0.31	<0.001
Model 3: Educational activities (3 activities)			
Years of experience	0.00 ± 0.00 (0.00 to 0.01)	0.09	0.014
PhD	0.13 ± 0.13 (−0.12 to 0.39)	0.04	0.312
Perceive genetics to be important	0.25 ± 0.12 (0.01 to 0.50)	0.07	0.040
Employed by the public health service	−0.09 ± 0.06 (−0.20 to 0.02)	−0.06	0.100
Clinical dietitian	−0.19 ± 0.07 (−0.32 to −0.05)	−0.10	0.009
Education dietitian	0.14 ± 0.05 (0.03 to 0.24)	0.09	0.010
Research dietitian	0.02 ± 0.09 (−0.15 to 0.20)	0.01	0.811
Knowledge score	−0.00 ± 0.01 (−0.02 to 0.01)	−0.01	0.760
Clinical confidence score	−0.01 ± 0.01 (−0.02 to 0.00)	−0.06	0.267
Education confidence score	0.10 ± 0.02 (0.07 to 0.13)	0.39	<0.001
Clinical involvement score	0.09 ± 0.01 (0.07 to 0.12)	0.30	<0.001

By multivariate linear regression

relating practical and theoretical knowledge of genetics and genetics services with physicians' genetic-based clinical activities (Acton et al. 2000; Hunter et al. 1998).

Other significant factors

The number of years of experience was significantly associated with dietitians' knowledge, involvement in educational activities and confidence in clinical activities (Tables 5, 6, 7). Notably, knowledge and confidence actually decreased with increasing years of experience, a potential effect of the length of time since formal university education on these topics. However, it is also likely that those with greater years of experience undertook their training when genomics and nutritional genomics were not a focus in dietetics curricula.

Dietitians' perception of the importance of an understanding of genetics to the dietetics profession was positively associated with knowledge and involvement, confirming previous reports in small studies (McCarthy et al. 2008). Those who value genetics may be more likely to seek out information and opportunities to be involved.

Differences over time

Low levels of knowledge, involvement and confidence in genetics and nutritional genomics have previously been reported, but only in isolated, single-country surveys of <400 dietitians (Gilbride and Camp 2004; Whelan et al. 2008). Comparing the performance of UK dietitians in this and a past survey is possible as a similar survey instrument was used (Whelan et al. 2008). In that study, mean total knowledge scores in the UK were 41 % and here were 55.9 %. Additionally, in the current study, more dietitians reported involvement in genetics activities and fewer reported 'low' levels of confidence. As improvements over time in dietitians' knowledge, involvement and confidence are observable in the UK, similar changes may have occurred in the US and Australia. However, future studies are required that will measure secular trends, and this research provides the first international data set to compare findings with.

Preparedness of health professionals

The findings that knowledge, involvement and confidence relating to genetics and nutritional genomics are limited

Table 7 Factors associated with high scores for confidence in undertaking activities related to genetics and nutritional genomics among dietitians

	B ± SE (95 % CI for B)	β	p value
Model 4: Clinical activities (11 activities)			
Years of experience	−0.05 ± 0.02 (−0.09 to 0.00)	−0.06	0.044
PhD	−3.81 ± 1.22 (−6.21 to −1.41)	−0.09	0.002
Graduated via a postgraduate degree	0.44 ± 0.48 (−0.51 to 1.38)	0.03	0.362
Perceive genetics to be important	1.77 ± 1.16 (−0.51 to 4.06)	0.04	0.128
Employed by the public health service	−0.71 ± 0.53 (−1.75 to 0.34)	−0.04	0.187
Clinical dietitian	1.11 ± 0.71 (−0.28 to 2.50)	0.05	0.116
Research dietitian	−0.16 ± 0.84 (−1.80 to 1.49)	−0.01	0.853
Health promotion/public health dietitian	0.95 ± 0.68 (−0.38 to 2.27)	0.04	0.161
Dietetics manager	1.27 ± 0.79 (−0.28 to 2.82)	0.04	0.109
Food service/industry dietitian	−0.59 ± 1.00 (−2.55 to 1.38)	−0.02	0.558
Media and press dietitian	4.33 ± 1.49 (1.41 to 7.25)	0.08	0.004
Knowledge score	−0.05 ± 0.08 (−0.22 to 0.11)	−0.02	0.508
Education confidence score	2.12 ± 0.12 (1.89 to 2.35)	0.66	<0.001
Clinical involvement score	1.16 ± 0.12 (0.92–1.39)	0.31	<0.001
Education involvement score	−0.43 ± 0.43 (−1.27 to 0.41)	−0.04	0.316
Model 5: Educational activities (3 activities)			
Years of experience	0.01 ± 0.01 (0.00 to 0.03)	0.05	0.079
PhD	1.78 ± 0.36 (1.07 to 2.49)	0.14	<0.001
Graduated via a postgraduate degree	0.17 ± 0.14 (−0.11 to 0.46)	0.03	0.234
Employed by the public health service	−0.43 ± 0.16 (−0.74 to −0.12)	−0.08	0.007
Clinical dietitian	−0.10 ± −0.20 (−0.50 to 0.30)	−0.01	0.624
Education dietitian	0.39 ± 0.15 (0.10 to 0.69)	0.07	0.009
Research dietitian	0.47 ± 0.25 (−0.02 to 0.96)	0.05	0.059
Food service/industry dietitian	0.45 ± 0.30 (−0.14 to 1.04)	0.04	0.133
Knowledge score	0.08 ± 0.02 (0.04 to 0.13)	0.09	0.001
Clinical confidence score	0.19 ± 0.01 (0.17 to 0.21)	0.61	<0.001
Clinical involvement score	−0.11 ± 0.04 (−0.18 to −0.03)	−0.09	0.005
Education involvement score	0.86 ± 0.12 (0.62 to 1.10)	0.23	<0.001

By multivariate linear regression

among dietitians mirror results of studies conducted with other non-genetic health professionals such as physicians, nurses, midwives and allied health professionals (Metcalfe et al. 2002; Skirton et al. 2012; Godino and Skirton 2012; Benjamin et al. 2009; Lapham et al. 2000; Long et al. 2001). Efforts to increase the awareness and competence of health professionals in relation to genetics and genomics have been addressed via multiple approaches. Competency guidelines have been developed for health professionals (e.g. NCHPEG 2007; ANA 2011; RCGP 2006) and educational centres and networks have been set up in a number of countries (e.g. National Genetics Education and Development Centre, UK; Genetics/Genomics Competency Centre for Education, US). Strategies for tertiary education and continuing professional development are advancing, with introduction of genetics and genomics into undergraduate curricula and emergence of novel teaching strategies such as digital-based learning (Busstra et al. 2007) and an interdisciplinary approach focusing on lived experience (Kirklin 2003). In the dietetics field, the Academy of Nutrition and Dietetics has released a proposed position concept on the 'Importance of nutritional genomics in dietetics' (ADA 2010), and tertiary curriculum frameworks in the US and UK have been updated to include genetics and nutritional genomics, respectively (ACEND 2012; BDA 2008). Undoubtedly, further work is still required to prepare dietitians for the nutritional genomic revolution.

Limitations, strengths and opportunities for future research

This survey was conducted with a volunteer sample recruited from three countries. The sampling methodology, response rate and some demographic characteristics differed by country. The survey response rate (13 %) was poor, which may have been a result of the length of the survey, degree of difficulty and lack of perceived relevance. However, the response rate compares favourably with the only other electronic survey (Oosthuizen 2011) undertaken with dietitians on this topic. On the other hand, it was much lower than that achieved in a previous postal survey (McCarthy et al. 2008). Electronic surveys tend to achieve lower response rates than postal surveys, but undoubtedly have a much greater reach (Shih and Fan 2009). Follow-up to determine characteristics of non-responders was not possible; therefore, the effect of any potential selection bias remains unknown. These limitations result in a lack of generalisability of the findings from this study to the wider dietetics profession.

Knowledge is a notoriously difficult concept to measure. Although this study tested knowledge objectively, it was limited to 16 questions and focused only on the theory of genetics and nutritional genomics and, as such, was not measured exhaustively. There is an opportunity to develop new tools for measuring knowledge that capture the practical and applied aspects of genetics and nutritional genomics. This study did not survey involvement and confidence in genetics and nutritional genomics outside the clinical and educational domains of dietetics. Future research may focus on activities in other areas of dietetic practice (e.g. public health, research and industry) as the application of nutritional genomics increases. The exploratory nature of qualitative research makes it a useful method to thoroughly investigate knowledge, involvement and confidence among dietitians, and the associated determinants, as demonstrated in a recent study (Li et al. 2012). Thus, a mixed methods approach to future research may delve deeper into this topic.

The strength of this study is that it reports on the largest international survey of the dietetics profession ever undertaken, encompassing three countries making major contributions to dietetics practice, education and research.

Conclusions

Scientific and technological advancements have resulted in greater focus on the role genetics and nutritional genomics play in pathogenesis of disease and management. The delivery of genomics focussed health care will require involvement by many professionals, including dietitians. Dietitians' knowledge, involvement and confidence relating to genetics and nutritional genomics were low, and the interaction between these factors was demonstrated. For health care to make the most of these opportunities in genetics and nutritional genomics, improvements in each of these areas are recommended. This international study provides a contribution to enable genetics and nutritional genomics in dietetic practice to be evaluated longitudinally.

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Conflict of interest The authors of this paper; Jorja Collins, Brenda Bertrand, Veronica Hayes, Sherly (Xueyi) Li, Jane Thomas, Helen Truby and Kevin Whelan declare that they have no conflict of interest.

Ethical standard All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional) and with the Helsinki Declaration of 1975, as revised in 2000 (5). consent was obtained from all patients for being included in the study.

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