Would fortification of more foods with vitamin D improve vitamin D intakes and status of groups at risk of deficiency in the UK?

LONDON SCHOOL of HYGIENE &TROPICAL MEDICINE

Doctor of Public Health (DrPH) Thesis

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DECLARATION

I, Rachel Allen, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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ABSTRACT

Groups of the UK population have poor vitamin D status, particularly those with low sun exposure and/or poor dietary intake. This study looked at the impact of fortifying more foods with vitamin D in the UK on population vitamin D intakes and status. It included:

- A systematic review, which found that consumption of a wide variety of foods (including milk, orange juice and bread) fortified with vitamin D can improve vitamin D status; and that national schemes have been effective at improving status of some, but not all groups of the target population.
- An update of the vitamin D content of fortified foods and supplements within the National Diet and Nutrition Survey (NDNS) Nutrient Databank, which increased current population vitamin D intakes by 3%. Consideration of a standard level of 'overage' applied during fortification increased population intakes by a further 3%.
- A computer-based data processing exercise to simulate the effect of fortifying flour and milk with vitamin D using NDNS data. At 10µg vitamin D per 100g flour, the proportion of 'at risk' groups with vitamin D intakes below the UK Reference Nutrient Intake (RNI) was reduced from a current level of 97% to 53%, without anyone exceeding the European Tolerable Upper Intake Level (UL) for vitamin D. Fortification of flour at this level improved intakes across all socio-economic groups and was found to be more effective than fortification of milk, as well as simultaneous fortification of milk and flour.

Fortification therefore provides an opportunity for improving vitamin D intakes and status in the UK however, there remains much uncertainty surrounding vitamin D, in particular around intake and status levels required for optimum health and the analytical methods used to determine these. Further research is therefore recommended prior to introducing a national scheme to fortify with vitamin D in the UK.

INTEGRATING STATEMENT

I began the Doctor of Public Health (DrPH) course in October 2008. The first module, *Evidence Based Policy and Practice* (EBPHP), was an excellent place to start as it reaffirmed my decision to enrol on the course. At the time, I was working at the Food Standards Agency (FSA), an organisation that takes pride in being a science and evidence based organisation. Having spent most of my academic and working life focusing on science, it was refreshing to look at the wider picture at how this scientific 'evidence' is used in policy and consider other influences on decision making. This module covered systematic reviews, including how to search the literature and evaluate the evidence, providing a firm foundation for skills that were invaluable for the rest of the course and will be throughout my scientific career. I found the systematic review assignment very challenging, but an excellent way to put the skills I had learnt into practice. Part of the assignment involved translating the review into a piece of briefing, an exercise in translating complex research into laymen's terms, a useful skill when working in Government.

I was least looking forward to the second of the compulsory modules, *Leadership Management and Personal Development* (LMPD) as it was the furthest removed from the science. However, it provided core skills required for a career in public health management. I found the personal development retreat especially useful as it provided an insight into the strengths and weaknesses of my own management and leadership styles, which has helped me to identify how I am perceived in the work place, as well being able to better identify with how others prefer to communicate and understand how different personality types influence behaviours. The course provided useful grounding for the organisational changes I was experiencing in my own workplace, as the module fell between a change programme at the FSA and a much larger programme of change across the civil service driven by a new coalition Government. As I carried out my Organisational and Policy Analysis (OPA) project at the FSA, the key learning points of the course, specifically around organisational structure, management, leadership and change management were very useful in understanding the changes happening around me.

I completed three MSc modules as part of the taught element of the course: *Medical Anthropology in Public Health*, *History and Health*; and *Maternal and Child Nutrition.* Having studied natural sciences for most of my life the first two of these modules were my first real introduction to the social sciences. I found *Medical Anthropology in Public Health* very challenging as I was constantly looking for facts within the observations, concepts and theories. This module opened my eyes to the implications of behaviour, perception and culture on the effectiveness and success of public health policies. It highlighted that throughout much of the world behaviour is based on foundations of centuries-old belief systems that dictate a particular way of living. Scientific evidence on its own cannot change behaviour. It is only through understanding the origins of the behaviour that change can ever be brought about. The next module *History and Health* provided a great insight into the use of historic evidence to support public health policy as alluded to in the EBPHP module. In the assignment I considered the rise of public health nutrition in the early 20th century. The final module *Maternal and Child Nutrition* was a delight to complete as it was very closely related to my main area of interest and extremely relevant to my current area of work. Throughout the DrPH course I have been managing the Diet and Nutrition Survey of Infants and Young Children (DNSIYC) at the FSA and the Department of Health (DH) and at the time of completing this module I was carrying out a literature review of the nutritional composition of breast milk. The module therefore strengthened my understanding of the subject area. I had completed a clinically focused Maternal and Child Nutrition module in my previous MSc Nutrition degree, so this module, with a public health focus, complemented and refreshed my learning on this subject. Coincidently I chose the assignment on vitamin D supplementation in Asian children, which turned out to be of direct relevance to my research project, the topic of which I chose 5 months later.

Although we had discussed the OPA in class and heard of other students' experiences, I had little idea of what to expect. I chose to carry out my OPA in my place of work, as the FSA has a unique structure for a Government department, being one-step removed from ministers it is unable to make legislative policy, only recommend proposals to ministers. It therefore aims to work purely in consumers' interests and bases legislative policy proposals, voluntary policies and consumer advice on available evidence. The timing of the OPA coincided with a newly elected coalition Government that made a decision to move the Government's nutrition responsibilities out of the FSA into DH. As part of the OPA project, I had the opportunity to research the background and function of the FSA, interview key people involved in the nutrition policy making process at the FSA, DH and the Scientific Advisory Committee on Nutrition (SACN), accompanied by the experience of a physical move from a non-ministerial Department to a ministerial Department. This enabled me to gain insight into the influences and drivers of policy making in the UK, the importance and reality of evidence based policy making, and look at how the structure and management of an organisation can influence whether the policy is truly evidence based. The project therefore drew on my learning from both the EBPHP and LMPD modules. It was my first experience of carrying out social research in the form of interviews, text analysis and use of quotes as supporting evidence. It was a document unlike any other I had written before, requiring critical assessment of Government structures and processes that I had previously never given a second thought. Although an extremely challenging project it was also very rewarding.

Once I had completed the OPA, the research project felt as though I was back on familiar territory. Having previously been involved in collating data for modelling work to support SACN's folate and iron risk assessments, I was keen to further develop these skills. SACN were in the initial stages of a risk assessment on vitamin D and therefore a project investigating whether the UK could benefit from fortifying more foods with vitamin D seemed an ideal DrPH research project, which could potentially inform UK nutrition policy. I carried out a systematic review quite early in the project and would have been lost without the skills I had learnt in EBPHP. I spent six months preparing for my DrPH review meeting, refining my research question and identifying the potential scope of the project based on the available evidence. As part of this preparation I carried out a piece of work to update the vitamin D content of fortified foods and supplements that was of use to my work in the Food Composition and Diet team at DH. The remainder of the research project built on skills obtained from previous modelling projects, although I had never before carried out the statistical data analysis, so I had to learn how to use SPSS and carry out complex data manipulation. The amount of data I was dealing with was quite overwhelming, but I tried to take it in stages, making sure I could see a picture of the results forming, before deciding what step to take next. As much of our work at DH relies on the use of data analysis, I have learnt skills that will be useful in my future career at DH and beyond.

The complement of different projects involved in the DrPH course, makes it an incredibly challenging, but rewarding course to complete. It has been a turbulent journey, but I have a great deal to show for my efforts. I have made great friends and contacts, learnt valuable skills and gained a wealth of knowledge on a wide range of subjects.

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ACKNOWLEDGMENTS

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ABBREVIATIONS

AHRQ	Agency for Healthcare Research and Quality
AI	Adequate Intake
BMI	Body Mass Index
COMA	Committee on Medical Aspects of Food and Nutrition Policy
DALY	Disability Adjusted Life Year
DH	Department of Health
DEFRA	Department for Environment, Food and Rural Affairs
DEQAS	Vitamin D External Quality Assurance Scheme
DRI	Dietary Reference Intake
DRV	Dietary Reference Value
EAR	Estimated Average Requirement
EFSA	European Food Safety Authority
ESDS	Economic and Social Data Service
EVM	Expert Group on Vitamins and Minerals
IOM	The Food and Nutrition Board of the National Academy of Sciences' Institute of Medicine
LIDNS	Low Income Diet and Nutrition Survey
LRNI	Lower Reference Nutrient Intake
NDNS	National Diet and Nutrition Survey
NS-SEC	National Statistics Socio-Economic Classification
RCT	Randomised Controlled Trial
RDA	Recommended Dietary Allowance (1) Recommended Daily Allowance (2)
RNI	Reference Nutrient Intake
SACN	Scientific Advisory Committee on Nutrition
SCF	European Scientific Committee on Food
UL	Tolerable Upper Intake Level
VDR	The Vitamin D Receptor
25(OH)D	25-Hydroxyvitamin D

CHAPTER 1: INTRODUCTION

1.1. Introduction

Significant proportions of the UK population have poor vitamin D status, and there has been speculation whether the population would benefit from introducing fortification of more foods with vitamin D. There is however, little evidence available as to whether national fortification strategies improve vitamin D intakes of groups most at risk of vitamin D deficiency, let alone whether they improve vitamin D status or have an impact on population health. There is also uncertainty over the potential impact of vitamin D deficiency on bone health and other chronic diseases as well as the recommended minimum and maximum intake and status thresholds. Prior to implementing a strategy to fortify more foods with vitamin D, a full risk assessment of the vehicle, level of fortification, ethical and practical issues would be required due to the potential risk of toxicity from excess vitamin D. This study aimed to provide an assessment of whether introducing fortification of more foods with vitamin D in the UK would improve the vitamin D intakes and status of the UK population, specifically in groups at risk of vitamin D deficiency.

1.2 Background

A number of reviews have been published on vitamin D relevant to UK policy.
In 1991 the Department of Health's Committee on Medical Aspects of Food and Nutrition Policy (COMA) published a report outlining reference daily intakes of all key nutrients including vitamin D, in the form of Dietary Reference Values (DRVs) (3). This report was followed by a review of all aspects relevant to bone health, including the role of vitamin D (4). In 2007, COMA's successor, the Scientific Advisory Committee on Nutrition (SACN), the current UK Government independent advisory committee on all aspects of nutrition, published a position statement on vitamin D to provide an updated review of the evidence to support UK policy (5). SACN began a full risk assessment of vitamin D in May 2011, the conclusions of which are due to be published in 2014 (6). Also worthy of note, the Food and Nutrition Board of the National Academy of Sciences' Institute of Medicine (IOM) published a report in 2011 setting out Dietary Reference Intakes (DRIs) for vitamin D and calcium for use in the United States of America (US) and Canada (1). This report sought to update the DRIs published in 1997 (7) and details a full review of the scientific evidence relating to dietary requirements for vitamin D, based largely on the systematic evidence-based reviews from the Agency for Healthcare Research and Quality (AHRQ), as well as incorporating other evidence identified by

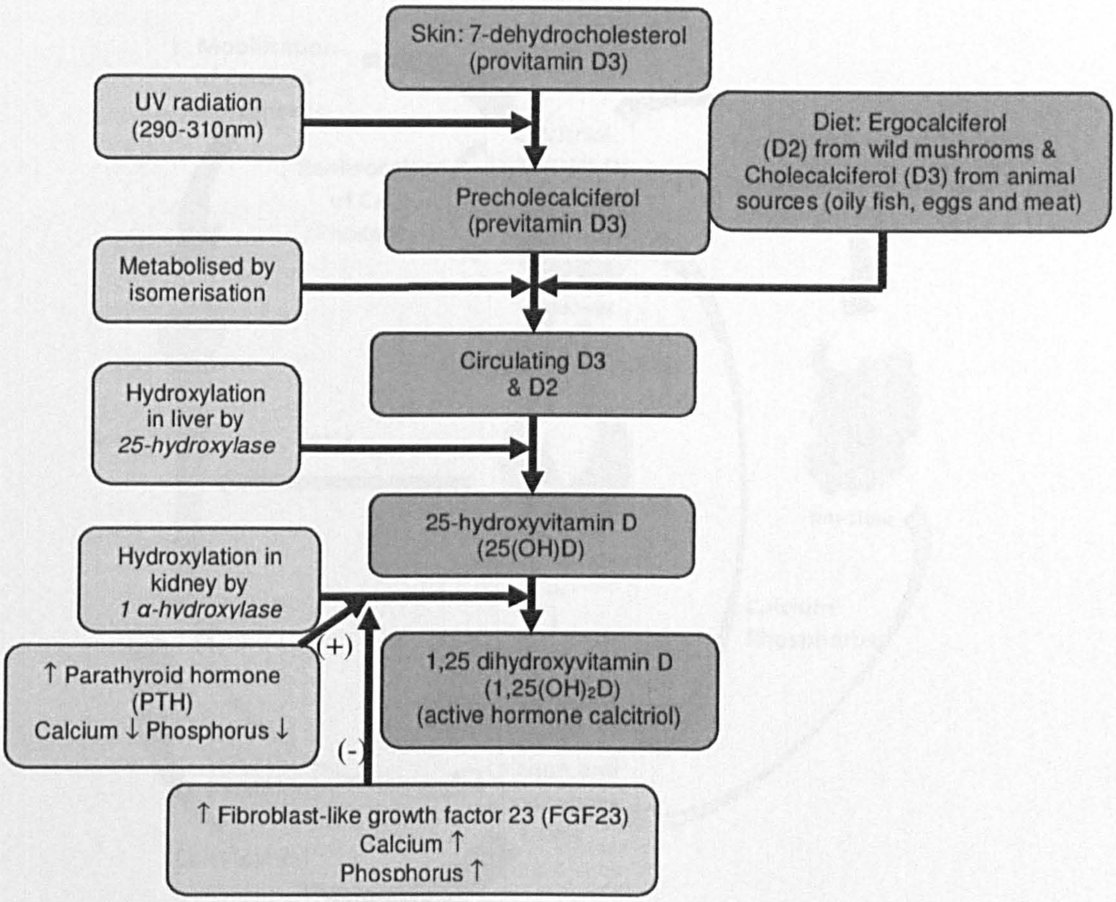
the committee. The first AHRQ review was published in 2007 specifically looking at the role of vitamin D, and vitamin D and calcium, in relation to bone health and included 167 primary articles, of which 112 were randomised controlled trials (RCTs) (8). The second AHRQ review was published in 2009 and looked at the role of vitamin D in relation to a broader range of other health outcomes, including evidence from 165 primary articles and 11 systematic reviews (9). The conclusions of all of these reviews, as well as other relevant literature sources are discussed in this section.

1.2.1 Role of vitamin D

Vitamin D is a prohormone existing in two main forms: vitamin D_2 (ergocalciferol) produced by plants and fungi by exposure to ultra violet (UV) radiation; and vitamin D_3 (cholecalciferol) synthesized by exposure of the skin to UV radiation, also obtained in the diet through consumption of animal foods (1, 7). For the purposes of this report, 'vitamin D intake' refers to the dietary intake of the generic form found in the diet and includes D_2 and D_3. Figure 1 outlines the metabolic pathway for the production of the active hormone, calcitriol ($1,25(OH)_2D$), and figure 2 illustrates the essential role of this hormone in maintaining levels of calcium and phosphorus in the blood required for bone mineralisation.

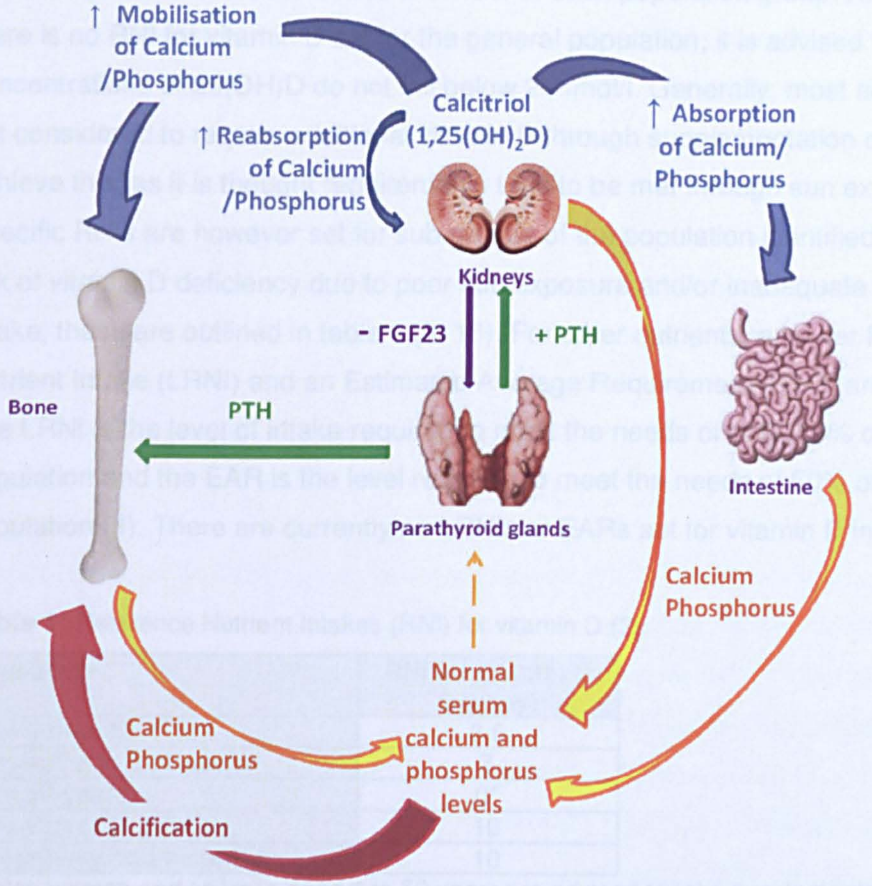
The parathyroid gland acts as a sensor for levels of calcium in the blood and when calcium levels drop, it stimulates the release of parathyroid hormone (PTH) to stimulate calcitriol production in the kidney. Calcitriol then stimulates an increase in calcium by three mechanisms: regulation of absorption from the diet in the small intestine; mobilisation from the bone; and prevention of excretion (i.e. reabsorption) in the kidney (1). This system operates on a feedback loop, so when adequate levels are reached calcitritol production is down regulated by fibroblast-like growth factor 23 (FGF23) and calcium absorption/mobilisation/reabsorption ceases. The production of calcitriol is also regulated by the level of phosphorus in the blood and when levels drop, calcitriol production is stimulated, which in turn stimulates phosphorus absorption in the intestine and reabsorption in the kidneys. Calcium is absorbed by active transport in the intestine, which is dependent on the presence of calcitriol and the vitamin D receptor (VDR) (1). The VDR involved in these processes has been identified in many other tissues independent of the regulation of phosphorus and calcium metabolism, suggesting a potential role for vitamin D in the immune system (10), gene regulation (11) and chronic disease (12).

Figure 1: The chemical conversion pathway of vitamin D to the active hormone. Adapted from (5).



Serum 25-hydroxyvitamin D (25(OH)D) concentration is recognised as the best indicator for determining levels of available vitamin D within the body, i.e. vitamin D status, obtained from both sun exposure and dietary intake including from food and supplements (13). It is therefore considered the best marker to determine biological adequacy of vitamin D in the UK (4, 5).

Figure 2: Role of calcitriol (1,25(OH)$_2$D) in maintaining levels of calcium and phosphorus in the blood required for bone mineralisation, adapted from (14). PTH = Parathyroid hormone; FGF23= Fibroblast-like growth factor 23.



1.2.2 Sources of vitamin D

The main source of vitamin D for the majority of the UK population is sunlight (DH, 1998). Due to the northerly latitude of the UK however, the population only benefits from ultraviolet B (UVB) radiation of the wavelength (290 to 310nm) able to convert 7-dehydrocholesterol to vitamin D in the skin from April to September/October (3). During these months use of sunscreen and covering the skin further reduces the chance of vitamin D synthesis. As there are few natural dietary sources of vitamin D (oily fish, egg yolk, red meat and liver (15)), commercially manufactured forms are often added to foods through fortification, either voluntarily by manufacturers, or enforced at a national level to improve population intakes (see section 1.2.4). In the UK, individuals at risk of poor sun exposure and poor dietary intake are recommended to take dietary supplements of vitamin D (16).

1.2.3 Reference intake values for vitamin D

In the UK, dietary reference intakes for nutrients are defined by the DRVs, which include Reference Nutrient Intakes (RNIs). The RNIs describe the daily level of intake required to meet the needs of 97.5% of each population group. Although there is no RNI for vitamin D set for the general population, it is advised that serum concentrations of 25(OH)D do not fall below 25nmol/l. Generally, most adults are not considered to require additional vitamin D through supplementation of the diet to achieve this, as it is thought requirements tend to be met through sun exposure (3). Specific RNIs are however set for sub-groups of the population identified to be at risk of vitamin D deficiency due to poor sun exposure and/or inadequate dietary intake, these are outlined in table 1 (3, 16). For other nutrients, a Lower Reference Nutrient Intake (LRNI) and an Estimated Average Requirement (EAR) are also set. The LRNI is the level of intake required to meet the needs of only 2.5% of the UK population and the EAR is the level required to meet the needs of 50% of the population (3). There are currently no LRNIs or EARs set for vitamin D in the UK.

Table 1: Reference Nutrient Intakes (RNI) for vitamin D (3).

Age/Stage	RNI for vitamin D (µg/day)
0 to 6 months	8.5
7 months to 3 years	7
4 to 50 years	0*
50+ years	10
Pregnancy and lactation	10

* Asian women and children aged 4 to 50 years are advised to take supplementary vitamin D (3).

In the US and Canada, dietary reference intakes for vitamin D intake are set in the form of the DRIs, including a Recommended Dietary Allowance (RDA), an EAR and an Adequate Intake (AI) level (1). The RDA is comparable to the UK RNI as it is considered the amount sufficient to meet the needs of 97.5% of the population, whereas the EAR is equivalent to the UK EAR and is the amount considered to meet the needs of 50% of the population. The RDA is set at 15µg vitamin D per day for the whole population with the exception of adults aged over 70 years, for whom the RDA is set at 20µg per day (1). The EAR is set at 10µg per day for the whole population above one year of age (1). An AI has been set at 10µg per day for infants as an average intake level, as there were not considered sufficient data to set an RDA and EAR for this age group. These values assume minimal sun exposure. The RDA mentioned here is separate to the European Recommended Daily Allowance (RDA) for vitamin D set for use in food labelling at 5µg vitamin D per day (2).

Guidelines on how best to use the DRIs discourage use of the RDA as a threshold for determining the proportion of a population with intakes below requirements, as the RDA is designed as a value adequate for 97.5% of the population and is therefore considered to overestimate the degree of risk. It is therefore recommended that the EAR is more appropriate for use in determining the dietary adequacy of groups (17). This approach has been supported by analyses of population intake distributions (18).

Dietary intakes are expressed in micrograms (µg), but are often expressed in the literature in International Units (IU), where 1µg is equivalent to 40IU. Serum 25(OH)D concentrations are expressed as nanomoles per litre (nmol/l), but can also be expressed as nanograms per millilitre (ng/ml), where 2.5nmol/l is equivalent to 1ng/ml.

The Department of Health recommends daily vitamin D supplements during pregnancy and lactation (3, 5, 16) (see table 1). Infants born to women not taking vitamin D supplements have been shown to be at a higher risk of hypocalcaemia, hyperparathyroidism and defects of tooth enamel (3, 19). Daily supplements are also recommended for young children unless adequate status can be guaranteed from the diet and/or adequate exposure to sunlight (3-5, 16). The types of foods usually fed to young children, at a stage when bones are rapidly growing requiring the deposition of calcium, are generally low in vitamin D. Women and children living in families on low incomes are entitled to free vitamin D containing supplements as part of the Government's *Healthy Start* scheme (20).

Adults aged over 65 years living in the UK are advised to consume 10µg of dietary vitamin D per day, which may need to be in the form of a supplement if dietary intakes are poor (5, 16), although an RNI is currently set for all adults aged over 50 years (3). As well as having generally reduced sunlight exposure and low dietary vitamin D intake (21), older adults may have a reduced ability to convert vitamin D in the skin. Adults aged 62 to 80 years have been shown to be less than a third as efficient at producing vitamin D in the skin compared to adults aged 20 to 30 years (22).

People who have dark skin, for example those from African, African-Caribbean and South Asian origin living in the UK are also recommended to consider taking a

vitamin D supplement as they are known to be at risk of deficiency (16). Pigmentation is thought to affect the skin's ability to absorb UV light reducing the opportunity for vitamin D production (23, 24).
The Department of Health also recommends that individuals who have poor sun exposure, for example those who cover their skin for cultural or religious reasons, or who are housebound or confined indoors for long periods of time take a vitamin D supplement (3, 5, 16). Individuals with poor sun exposure who do not consume animal products, such as vegans and vegetarians, may be at a greater risk of vitamin D deficiency.

Despite recommendations for these 'at risk' groups to take supplementary vitamin D, supplement uptake in the UK is poor. In a postal questionnaire of over nine thousand mothers of young children, a quarter reported taking vitamins and iron or vitamins only in pregnancy and only a third of breast-feeding mothers reported taking any kind of supplement when their child was 4 to 10 weeks of age, this declined to 24% at 8 to 10 months (25). A review of the Welfare Food Scheme (WFS) published in 2002 identified that uptake of vitamins among children was low, even amongst those entitled to receive free supplements (5). There are currently no published data on the uptake of Healthy Start vitamins. A recent national survey revealed only 12% of children aged 1.5 to 3 years were reported to be taking any sort of supplement (including multivitamins containing vitamin D) over a four day diary period (21). In the same survey, over a third (39%) of adults aged over 65 years were reported to take any sort of supplement. In a survey of the low income population, a sub-group potentially at greater risk of vitamin D deficiency, only 7% of women and 8% of men aged 65 years and over reported taking vitamin D containing supplements (26). There are currently no national data available on supplement uptake by ethnicity.

1.2.4 Enrichment of foods with micronutrients

It is common practice in the UK to add micronutrients to foods for a number of purposes (27):

(a) restoration, to restore nutrients lost during processing e.g. the restoration of white and brown wheat flour with thiamine, niacin and iron to equivalent levels in wholemeal flour (28);

(b) substitution, to ensure a food substituted for another food contains at least the same level of nutrients e.g. the addition of vitamins A and D to margarine (29);

(c) standardisation, to standardise an otherwise variable nutrient content of food e.g. the addition of vitamin C to fruit juices (30);

(d) fortification, the addition of nutrients to foods from which they are usually absent, or present at low levels, usually to reduce apparent or potential micronutrient deficiencies in the population e.g. the fortification of flour in the UK with calcium (28, 31).

In relation to vitamin D specifically, fortified foods can provide a valuable source especially for population groups who obtain little vitamin D from the sun and have low intake from natural sources and supplements (32). Some countries have introduced programmes of mandatory vitamin D fortification to improve status and therefore prevent micronutrient deficiencies, for example milk fortification in Canada and Israel (see table 2). In the UK some manufacturers voluntarily fortify foods with vitamin D (e.g. breakfast cereals, fat spreads, drinks, cheeses and dried milks) (see table 2). Infant formulae and foods intended for weight loss diets are also fortified with vitamin D by law, but are not foods consumed by the general population (33, 34).

Fortification has been recognised as a cost-effective long-term strategy for prevention of micronutrient deficiencies in middle and low income countries with an estimated expenditure of $66 to $70 per Disability Adjusted Life Year (DALY) averted for iron fortification programs (35). A review of nearly a 100 studies of the cost of micronutrient interventions however, identified that fortification strategies vary widely by country and nutrient, up to a factor of 15 dependent on the nutrient. One of the issues highlighted was a lack of information on food fortification coverage largely as a result of poor food consumption data in certain countries. The quality of the cost-estimation methods have also been found to vary (36).

A narrative review assessing the impact of mandatory fortification of cereal grains with folic acid in the US and Canada on serum folate status (37) included five studies (a cohort study (38); a cross-sectional study (39); a repeat cross-sectional study (40); a retrospective cross-sectional study (41) and a review of blood samples pre- and post- the time of fortification (42). The review concluded that mandatory fortification had been effective in improving folate status in population groups. This suggests that mandatory fortification programmes can be effective in improving micronutrient status.

In 2008, O'Donnell *et. al.* (43) published a systematic review of the efficacy of consuming foods or drinks fortified with vitamin D at improving vitamin D status. The review included nine RCTs, of which eight demonstrated significant improvements in serum 25(OH)D concentration after consumption of food or drink fortified with vitamin D. In 2012, Black *et. al.* (44) published an update to this review and carried out a meta-analysis of the results. Fourteen out of the 16 included studies demonstrated a significant increase in serum 25(OH)D concentration following consumption of a vitamin D fortified food or drink. They found serum 25(OH)D levels increased by 1.2nmol/l (85% CI:0.72, 1.68) per 1μg vitamin D consumed from fortified foods per day. This study assumed a linear relationship between vitamin D intake and serum 25(OH)D levels, which as discussed in section 3.4, is unrealistic. The O'Donnell *et. al.* and Black *et. al.* reviews therefore provide evidence that consumption of foods fortified with vitamin D improve vitamin D status. A systematic review with a wider scope of included studies (i.e. not restricted to RCTs) is presented in chapter 2, which looks specifically at whether fortification of foods with vitamin D improves status of groups at risk of deficiency and also reviews the efficacy of national vitamin D fortification schemes.

There is an on-going debate over the efficacy and toxicity of the different forms of vitamin D (D_2 and D_3) used in supplements and fortification (45, 46). IOM concluded from the available evidence that both forms generally have equal capacity to improve vitamin D status and there is no difference in their biological activity (1), however a recent meta-analysis found D_3 to be more effective than D_2 at raising serum 25(OH)D levels (47). This may have implications for the type of vitamin D used in any fortification scheme. This is discussed further in chapter 6.

Table 2: Examples of worldwide vitamin D fortification practices. The counties selected were identified from the literature as having mandatory and voluntary fortification schemes. Other countries not mentioned here may also have similar schemes.

Country	Fortification position	Food	Fortification level	Reference
UK	Mandatory	Margarine	7.05-8.82µg/100g	Statutory instrument 3116 (29)
		Infant formula	1-2.5µg per 200kcal	Statutory instrument 77 (33)
		Diet foods	≥1.5µg per meal	Statutory instrument 2182 (34)
	Voluntary*	Most fat spreads	5-9µg/100g	Search of websites in 2011 (see section 3.1)
		Some breakfast cereals	3.2-8.3µg/100g (dry weight)	
		Some dried milk powders	1.4-1.6µg/100g (dry weight)	
		Some powdered malt drinks	3.2-4µg/100g (dry weight)	
		Some soya milks	0.3-0.9µg/100ml	
		Some cereal based infant foods	5-11.6µg/100g (dry weight)	
Finland	Voluntary	Milk	0.5µg/100ml	Laaksi *et. al.* (48)
		Margarine	10µg/100g	
Canada	Mandatory	Milk	0.9-1.2 µg/100ml	Health Canada (49)
		Margarine	13.25µg/100g	
United States	Voluntary	Milk	0.96µg/100ml	IOM (1)
Australia	Mandatory	Margarine and edible oil spreads (fat spreads)	No less than 5.5µg/100g	Food Standards Australia New Zealand (50)
Israel	Mandatory	Milk (1% milk only)	0.7-0.8µg/100ml	Personal communication (51)

* In the UK, manufacturers voluntarily fortify brand specific products with vitamin D. Other types of vitamin D fortified brand specific foods include yogurts, milks, milk shakes, fruit juices, soft drinks, processed cheeses, cereal bars and bread.

1.2.5 Deficiency

Vitamin D deficiency leads to poor bone mineralization (1). Prolonged deficiency during infancy can cause rickets, resulting in growth deformities in the form of bow legs and thickened wrists and ankles (1, 4). In adults, chronic deficiency leads to osteomalacia, a syndrome of abnormalities resulting in pain, psychological changes and increased risk of fractures (1, 4). IOM concluded, largely from the AHRQ systematic evidence-based review published in 2007, that vitamin D deficiency plays a key role in poor bone health, although the extent to which calcium inadequacy is implicated in this risk remains uncertain (8). The second AHRQ report published in 2009 identified some observational studies that suggested vitamin D status may play a role in the risk of developing other chronic diseases such as cancer, cardiovascular disease, autoimmune disorders, tuberculosis, multiple sclerosis and type 1 diabetes however these studies were not supported by RCTs (9). The IOM considered the role of vitamin D in these diseases as '*hypotheses of emerging interest*' (1). Other than bone health, the committee concluded there was no convincing or adequate evidence of cause or effect for vitamin D playing a role in disease risk (1).

In the UK, poor vitamin D status is defined by a serum 25(OH)D concentration below 25nmol/l (4). This is based on observed serum 25(OH)D concentrations up to 20nmol/l in cases of vitamin D deficiency diseases (4, 52). In the US and Canada, the threshold defining vitamin D deficiency is set at 30nmol/l (1). There are concerns regarding whether assays measuring serum 25(OH)D levels can be accurately compared across laboratories. Evidence from the Vitamin D External Quality Assurance Scheme (DEQAS) performance reports has indicated between laboratory variability of up to 15% to 20% (1, 53). This has implications in defining deficiency as a sample could be defined as vitamin D deficient by analysis in one laboratory, but not another, resulting either in untreated deficiency or unnecessary supplementation. The difference of 5nmol/l between UK (25nmol/l) and US/Canadian (30nmol/l) minimum status thresholds is therefore likely to be within this range of variability. DEQAS serves to minimise such variability by monitoring the performance of analysts and serum 25(OH)D analytical methods of over 700 laboratories worldwide (54).

1.2.6 Toxicity and excess vitamin D

Vitamin D toxicity is caused by excessive consumption of vitamin D. There have been no reports of vitamin D toxicity from excessive consumption of foods containing naturally occurring vitamin D (55) or from excessive sunlight exposure, as endogenous vitamin D production is tightly regulated and serum 25(OH)D levels plateau after about 30 minutes of UV exposure (56, 57). There have however been a number of reports of vitamin D toxicity where either foods were fortified with vitamin D at high levels intentionally (55) or accidentally (58-60), cases of high supplementation (61), errors in supplement manufacturing and labelling (62), and accidental consumption of large doses (63). Although there are no defined levels of intake for vitamin D determining symptoms of toxicity (1), IOM concluded that daily intakes above 250μg may be associated with toxicity (1).

Vitamin D toxicity causes hypervitaminosis D, leading to excessive calcium absorption and demineralisation of bone causing hypercalcaemia and hypercalciuria which leads to deposition of calcium in soft tissues (64), and can cause renal and cardiovascular damage (65). Other symptoms observed include anorexia, weight loss, weakness, fatigue, disorientation, vomiting, dehydration, polyuria and constipation (58).

In food safety assessments, Tolerable Upper Intake Levels (UL) are used to define the highest average daily intakes of a substance likely to pose no risk of adverse effects to almost all individuals in the general population (1). ULs are set well below levels likely to cause toxicity. In 2002, the European Scientific Committee on Food (SCF) set daily ULs for the whole diet at 25µg for children aged 10 years and below and 50µg for children and adults aged over 10 years (66). In 2003 the UK Food Standards Agency's Expert Group on Vitamins and Minerals (EVM) advised as a guide that 25µg of vitamin D per day would be safe for all as a supplement, but considered there was not enough evidence to provide a UL suitable for the whole diet (64). Following the publication of ULs by the IOM (1), the European Food Safety Authority (EFSA) re-evaluated the ULs set for use in Europe (67) in July 2012. Table 3 outlines the ULs for vitamin D set by these various committees. The health impact of consuming vitamin D at levels exceeding the ULs, but below the levels at which toxicity has been observed, is not known.

Table 3: Tolerable Upper Intake Levels for vitamin D

	Tolerable Upper Intake Level (UL) and age at which it is set (µg/d)						
Source	**<25**	**25**	**38**	**50**	**63**	**75**	**100**
EFSA (67)	0-12mths			1-10yrs			≥11yrs
IOM US/Canada (1)		0-6mths	6-12mths		1-3yrs	4-8yrs	≥9yrs
EVM (64)	For all: safe as a supplement						
European SCF (66)		≤10yrs		>10yrs			

Serum 25(OH)D concentrations observed in cases of toxicity range from 140nmol/l to 1740nmol/l (58, 61, 68). There remains uncertainty over the health effects of prolonged raised serum 25(OH)D concentrations below the levels likely cause toxicity, however adverse outcomes have been observed across different health indicators at levels ranging from 75nmol/l to 125nmol/l (including for all-cause mortality (9); some cancers (69); cardiovascular disease (70-73), and fractures and falls (74, 75). Although it seems IOM may have misinterpreted the conclusions of the study by Melamed *et.al.* in defining the lower threshold at 75nmol/l, and serum 25(OH)D levels above a threshold of 125nmol/l may be more likely to cause risk of excess (70). IOM stated that to avoid being *'unnecessarily restrictive given the uncertainties...for the purpose of the UL, concern would be for levels above 125nmol/l to 150nmol/l'* (1).

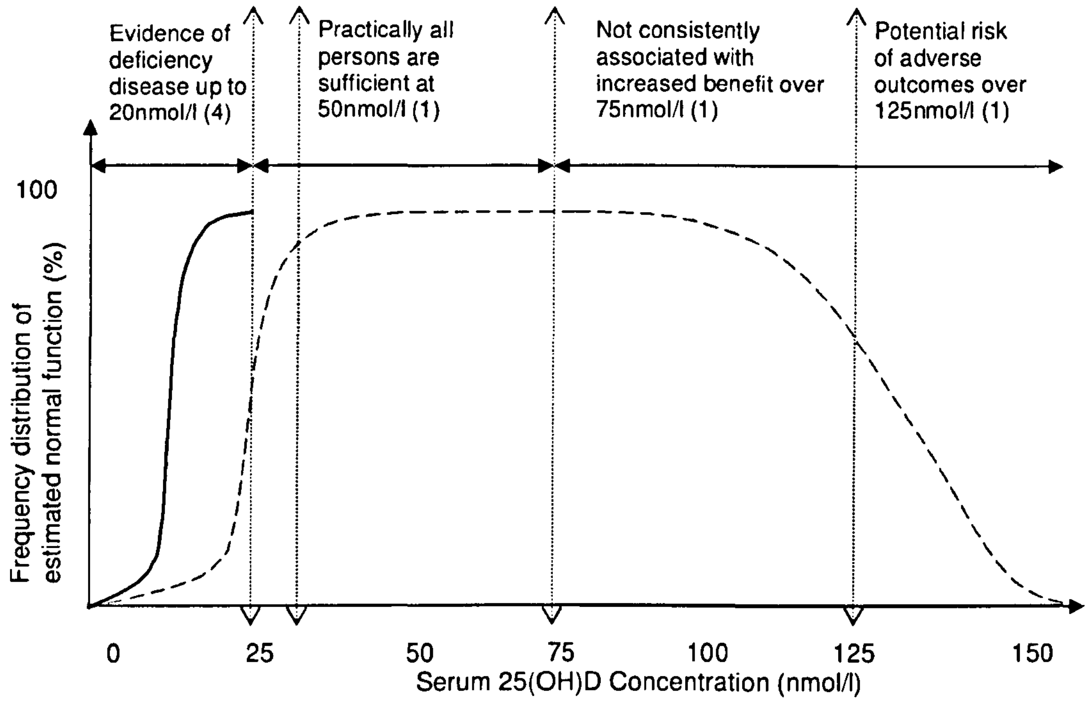
The UK Committee on Toxicity (COT) is due to review the toxicological effects of vitamin D to feed into SACN's risk assessment, as there is currently no maximum level at which vitamin D intakes are considered to cause adverse effects in the UK.

1.2.7 Summary of vitamin D status-deficiency and toxicity

Figure 3 estimates the proportion of the population assumed to have serum 25(OH)D levels suitable for normal function at each of the various serum 25(OH)D concentration thresholds considered to cause deficiency and excess in the UK (represented by the solid line (4, 5)) and in the US/Canada (represented by the dashed line (1)). It should be noted that no maximum status thresholds have been set as an indication of toxicity/adverse effects in the UK and there is only reliable evidence of cases of vitamin D deficiency disease at serum 25(OH)D concentrations below 20nmol/l, evidence of adequacy or inadequacy at the other thresholds is inconclusive.

There is an international debate regarding serum 25(OH)D concentrations associated with optimum health. As discussed, in the UK the threshold of serum 25(OH)D used to define poor status (25nmol/l) differs to the threshold used in the US (30nmol/l). However there are some academics who consider serum 25(OH)D levels below 75nmol/l to be inadequate (76-78). In addition, supporting documentation for a laboratory frequently referenced in the literature for testing serum 25(OH)D concentrations (79-82), quotes levels of vitamin D inadequacy at below 75nmol/l and deficiency below 50nmol/l (83). Any clinicians using this laboratory to analyze serum samples for vitamin D, unless otherwise informed, will likely use a threshold of 75nmol/l to determine vitamin D inadequacy. As levels above 75nmol/l to 125nmol/l may result in adverse outcomes from excess vitamin D (see section 1.2.6) this misclassification of vitamin D inadequacy is likely to result in unnecessary supplementation and increased toxicity risk.

Figure 3: Diagram of estimated sufficiency thresholds for serum 25(OH)D levels agreed by SACN for the UK represented by the solid curved line and set by IOM for the US/Canada represented by the dashed curved line (Figure adapted from (56)).



UK minimum threshold of adequacy 25nmol/l (4)
US minimum threshold of adequacy 30nmol/l (1)
US threshold above which is not associated with increased benefit 75nmol/l (1)
US threshold above which increases risk of potential adverse outcomes 125nmol/l (1)

1.3 Current situation in the UK with regards to vitamin D deficiency

Table 4 summarises vitamin D intake for the UK population sub-groups known to be at risk of poor vitamin D status. It should be noted that women of childbearing age are used as a proxy group for pregnant and breast-feeding women in this analysis, due to the lack of data on this population sub-group, see section 3.2.1. Data for the general population have been extracted from the National Diet and Nutrition Survey (NDNS) report published in 2011 (84). The NDNS is a survey of the diets of the general population living in the UK in which respondents are required to take part in a face-to-face interview, provide a detailed record of food consumption over four consecutive days to assess food consumption, and if willing, take part in physical measurements and provide a blood sample. These data have not been updated with more recent NDNS data published in July 2012, as vitamin D intakes are only presented as a proportion of the RNI and are therefore not presented for population groups for whom an RNI is not set. The most recent national data available on the diets of ethnic minorities have been extracted from a survey of the low income population, the Low Income Diet and Nutrition Survey (LIDNS) (26), which aimed to collect information on the dietary habits of the 15% most materially deprived population in the UK. As well as a face-to-face interview, physical measurements and a blood sample, this survey required respondents to complete a 24 hour recall of all food and drink consumed on four non-consecutive days. Caution should be taken when interpreting the LIDNS data as the LIDNS ethnic minority population does not represent the general ethnic minority population.

Table 4 illustrates that between 2008 and 2010 young children (aged 1.5 to 3 years) consumed a daily average of 1.9µg vitamin D from food sources, less than a third of the RNI for this age group (84). Women aged 11 to 18 years and 19 to 64 years consumed an average daily vitamin D intake from food sources of 1.9µg and 2.6µg respectively (84). Older adults (aged 65 years and over) had mean intakes of 3.3µg vitamin D from food sources only, a third of the RNI for this age group (84). Black and Asian men from low-income families had mean daily vitamin D intakes of 2.4µg compared to 3.4µg for White men from low income families. Asian women from low-income families had mean daily vitamin D intakes of 3.4µg compared to 2.5µg for White women and 2.7µg for Black women (26). It should be noted that all these intake data exclude the contribution from dietary supplements, however as discussed in section 1.2.3, supplement intake is poor in groups at risk of deficiency.

Table 5 illustrates the proportion of the UK population reported to have poor vitamin D status as found in a number of national dietary surveys. The NDNS report published in 2012 provides vitamin D status data for the population aged 11 to 64 years (21). It indicates that between 2008 and 2011, 17% to 20% of this age group had serum 25(OH)D levels below 25nmol/l (21). Although there are currently no national data on vitamin D status in ethnic minorities, regional data are available. For example, a one year prospective cohort study of 35 South Asian women in Surrey found about 80% to have serum 25(OH)D levels below 25nmol/l in winter and autumn (85). These data highlight that poor vitamin D status is an issue for many groups of the UK population including, but not exclusive to, those traditionally thought to be at a particular risk of deficiency. Hyppönen and Power (86) also reached this conclusion by studying national UK cohort data, and suggested action to improve vitamin D status should be taken at a population level. UK Chief Medical Officers wrote to health practitioners to reinforce current advice to prescribe vitamin D supplements to groups at risk of deficiency (87), following a case of child mortality attributed to vitamin D deficiency disease. There however remain no recommendations for dietary supplementation in the general population.

Table 4: Vitamin D intake from <u>food sources only</u> (µg/d) for 'at risk' groups (3). The percentage below the RNI is not available.

	Population subgroup									
	Young children	Women of childbearing age*		Older adults	Ethnic minorities					
					Asian		Black		White (for comparison only)	
	All 1.5-3yrs	11-18yrs	19-64yrs	All 65+ yrs	Male	Female	Male	Female	Male	Female
					19+ yrs					
Data source	NDNS (84)				LIDNS (26)					
RNI	7	10		10	10					
Mean (median)	1.9 (1.4)	1.9 (1.6)	2.6 (2.1)	3.3 (2.6)	2.4 (2.0)	3.4 (1.3)	[2.4] [(2.1)]	2.7 (2.2)	3.4 (2.9)	2.5 (2.1)
Mean as % of RNI	27%	19%*	26%*	33%	13%	14%	24%	18%	35%	27%

*Women of childbearing age are used to represent pregnant and breast-feeding women see section 3.2.1.[ ] Fewer than 30 samples

Table 5: Proportion (%) of the population with poor vitamin D status from various national dietary surveys.

Data source		Proportion (%) of the population with serum 25(OH)D levels less than 25nmol/l							
	Population group	1.5-4.5yrs	4-10yrs	11-18yrs	19-24yrs	25-34yrs	35-49yrs	50-64yrs	65+yrs
NDNS 2008/11 (21)	Males			19	17				
	Females			20	19				
LIDNS 2003/05 (26)	Males		[0] (8-10yrs)	8	18		24	25	14
	Females		[16] (8-10yrs)	23	19		14	24	14
NDNS 1994/5 (88)	Males								6
	Females								10
NDNS 2000/1 (89)	Males				24	16	12	9	
	Females				28	13	15	11	
NDNS 1997 (90)	All		8						
NDNS 1992/3 (91)	All	1							

[ ] Fewer than 30 samples

Poor bone health can be caused by a wide range of factors including genetics, poor physical activity, hormonal influences, smoking, drinking alcohol and dietary factors including poor vitamin D status (4). Due to the role of these many factors, measurement of the prevalence of poor bone health resulting from vitamin D deficiency alone is not straightforward. Poor bone mineral density (BMD) is not a health outcome routinely reported by hospitals or General Practitioners (GPs). It is however probable that poor BMD resulting from vitamin D deficiency plays a role in the risk of fracture (1).

Hospital episode statistics data can be useful for providing information on hospital inpatients treated for a specific medical condition. These data are however limited in their use, as they not only exclude patients treated in GP surgeries as well as hospital outpatients, but the accuracy of the diagnoses recorded is likely to vary between hospitals. Figures for the number of episodes treated for a given condition are less useful than figures for the number of patients treated, as they include individuals treated more than once for the same condition. There were 343,536 hospital episodes for fractures reported in England between 2009 and 2010 (92). As the IOM concluded however, evidence of a link between vitamin D alone and fracture risk is inconsistent and vitamin D deficiency may only play a role in increasing fracture risk when accompanied by poor calcium status (1). It is therefore not possible to interpret the proportion of fractures caused by poor vitamin D status alone. There has also previously been a concern that fractures caused by vitamin D deficiency such as vertebrae fractures in older people may not be diagnosed (4), although it is not known if this is still an issue. Table 6 presents cases of vitamin D deficiency disease reported between 2010 and 2011 in English hospitals. It indicates that 395 people were treated for active rickets in English hospitals between 2010 and 2011 (93). Over this same year 7,742 people were reported to be treated for undefined vitamin D deficiency (93), although this may be an over representation of the true estimate if thresholds above 25nmol/l were used to define vitamin D deficiency. Many cases of vitamin D deficiency disease are likely to be reported at GP surgeries or may be treated as hospital outpatients, and a number are likely to remain undiagnosed, and would not therefore have been captured in these figures. Although data on national prevalence are limited, local cases of rickets have also been reported, largely in children of Asian or Afro-Caribbean origin (5). In Birmingham, an area recognised for its ethnic diversity, 65 cases of rickets and hypocalcaemic fits were reported between 2001 and 2003 in children aged under five years (94).

Table 6: Number of patients presenting with vitamin D deficiency disease in hospitals in England between 2010 to 2011 (93).

Number of patients presenting with vitamin D deficiency disease in hospitals in England 2010 to 2011.	
Disease	**Number of patients**
Adult osteomalacia	8
Active rickets	395
Unspecified vitamin D deficiency*	7742

*This estimation of unspecified vitamin D deficiency may be an over representation if thresholds above 25nmol/l are used to define vitamin D deficiency in different hospitals.

1.4 Global vitamin D deficiency

Poor vitamin D status is a global health problem. As discussed, some other countries have introduced schemes to improve vitamin D intakes through national fortification either due to the similar issue experienced in the UK of reduced sun exposure resulting from the country's high latitude (e.g. Finland) (48), or through the covering of skin for religious reasons (e.g. Israel) (51). A survey of the published literature identified a number of factors associated with poor vitamin D status globally including: '*Older age, female sex, higher latitude, winter season, darker skin pigmentation, less sunlight exposure, dietary habits, and absence of vitamin D fortification'* (95). Out of the six areas investigated in this survey (Asia, Europe, Middle East and Africa, Latin America, North America, and Oceania[1]) serum 25(OH)D levels below 25nmol/L were most common in regions such as South Asia and the Middle East. It is interesting that sunshine is abundant in these areas and there is therefore the potential to achieve adequate vitamin D status through exposure of the skin to UV light. However these are also areas where it is common practice to cover up the skin for cultural reasons, which likely explains the high prevalence of poor vitamin D status.

1.5 Variations in individual response to vitamin D exposure

There are a number of factors which may influence an individual's response to exposure of vitamin D in terms of a change in serum 25(OH)D concentration or effect on bone mass. There are likely to be a number of genetic variations (gene polymorphisms) within components of the human vitamin D metabolism pathway that may influence the relationship between vitamin D intake and serum 25(OH)D

[1] A definition of 'Oceania' is not provided in the paper, but is assumed to encompass Australia, New Zealand and neighbouring islands.

levels (96) in individuals. For example, polymorphisms have been discovered in the vitamin D binding protein, which plays a significant role in vitamin D transport, as well as in the VDR, which plays a key role in calcium absorption. A cross-sectional study found premenopausal women to have varying levels of circulating serum 25(OH)D levels dependent on their gene variation for the vitamin D binding protein (97). A 12 month vitamin D supplementation RCT in adolescent girls demonstrated that polymorphisms in the VDR gene influenced the bone mass response to vitamin D supplementation (98). If specific population subgroups have a predisposition to certain genotypes they may be at a greater risk of vitamin D deficiency and/or poor bone health.

Body composition may also affect an individual's serum 25(OH)D response to a change in vitamin D intake. A higher body mass index (BMI) of individuals has been seen to result in a smaller change in serum 25(OH)D concentration following consumption of vitamin D compared to those with lower BMIs (99, 100). As discussed, pigmentation of the skin (23, 24) and older age (22) are likely to reduce an individual's ability to synthesise vitamin D on exposure to sunlight. Despite the impact these variables may have on an individual's response to vitamin D exposure, it is not within the scope of this project to look at their impact on the relationship between vitamin D intake/exposure and vitamin D status of the UK population.

1.6 Examples of modelling the impact of fortification

Various types of modelling and data simulation have been conducted worldwide to assess the potential impact of micronutrient fortification (101-104), and de-fortification of foods (105), as well as the effect of reduced consumption of fortified foods (106) on micronutrient intake. In specific relevance to vitamin D, simulation calculations for different fortification scenarios including fortification of milk, bread, spread and cheese products carried out in Finland, were influential in determining the fortification vehicle for use in Finland (107). The Federal Office of Public Health in Switzerland also commissioned an analysis to look at the impact of increasing vitamin D intakes through manipulating dietary intake data. The simulation involved four scenarios: 1) substitution of foods for those of equivalent energy value naturally rich in vitamin D; 2) substitution of foods for comparable fortified foods found on the Swiss market; 3) scenario 2 repeated with the level of fortification increased to above the legal maximum level; 4) scenarios 1 to 3 repeated including the addition of a supplement. For the food fortification scenarios the authors concluded that increasing the current level at which foods are legally required to be fortified with vitamin D was '*the most effective and promising scenario*' for improving vitamin D intakes (108).

Renwick *et. al.* (109) presented a risk-benefit analysis approach that enabled risk of micronutrient deficiency to be weighed more fairly against the risk of excess as opposed to simply comparing point estimates such as RNIs and ULs, to aid the policy makers' decision-making process. The current method of establishing an adequate level of intake for a nutrient in the UK involves a risk benefit analysis, or perhaps better described as a 'risk risk' analysis (109), of the levels of intake at which there is minimum risk of deficiency and minimum risk of excess of a nutrient. Policy makers usually have at their disposal when making such decisions, a level below which intakes are thought to be a cause for concern, such as the RNI, EAR or LRNI, and a level above which intakes are thought not to present appreciable risk from excess, such as the UL. Determining an optimum level of intake somewhere within this range remains a challenge for policy makers, especially as the risks of ill health at either end of the intake range are unlikely to be equivalent. Renwick's *et. al.* model therefore further developed the standard approach discussed above, by using intake related risk data to establish a range of 'acceptable' levels of intake, providing a combined risk benefit analysis as opposed to the standard separate analysis of risks from excess and risks from deficiency. Such an analysis requires evidence of intake related incidence of risk, however, which is often lacking for nutrients such as vitamin D.

A step further than looking at the impact of fortification on population nutrient intakes would be to assess the potential impact of the strategy on health outcomes. In 2006, SACN published a risk assessment of folate and disease prevention including a data analysis that assessed the potential impact of folic acid[2] fortification of flour on UK population folate intakes, as well as the likely reduction in neural tube defect-affected pregnancies observed (110). In order to estimate the reduction in risk of neural tube defect-affected pregnancies at increasing levels of folic acid fortification, published relationships between maternal red blood cell (111, 112) and serum (111, 113) folate concentrations in response to increasing levels of folate intake were used. As a result, the committee concluded that mandatory fortification of flour with folic acid would improve folate status of women most at risk of neural tube defect-affect pregnancies, however the committee recommended that fortification should

[2] Folic acid is the synthetic form of folate used in fortified foods and supplements.

only be introduced in the UK if accompanied by restrictions to voluntary folic acid fortification to prevent the risk of consuming excess folic acid (110).
Stein *et. al.* (114) demonstrated a further example of assessing the potential impact of fortification on health. Biofortification of crops has become a useful way of improving micronutrient intakes of populations in developing countries through improving the nutrient content of staple crops (115). Stein *et. al.* described a model investigating the impact of biofortification of crops in India on iron intakes, including an assessment of the long-term health impact in terms of DALYs avoided through improved iron status (114). An analysis of DALYs avoided following implementation of a fortification strategy requires dose-response data between the nutrient and relevant health outcome, which is again often lacking for nutrients such as vitamin D.

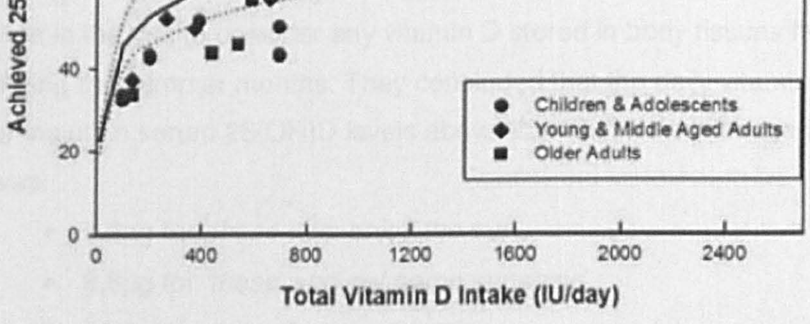
1.7 Published models identifying a relationship between vitamin D intake and serum 25(OH)D concentrations

To assess the impact on the UK population of introducing further vitamin D fortification, it is possible to look at the impact on vitamin D intakes, including an assessment of the proportion of the population at risk of deficiency and excess. It would be useful to translate this into the potential impact on serum 25(OH)D levels and then the potential impact on health, however there is currently no defined dose-response relationship between vitamin D intake, or serum 25(OH)D levels, and bone health (1). In addition, the extent to which serum 25(OH)D levels serve as a biomarker of the effect on health outcomes is not clearly established (1). Sophisticated modelling options involving a risk analysis similar to that proposed by Renwick *et. al.* (109), or an assessment of the impact of fortification on long-term health outcomes similar to that described by Stein *et. al.*, (114) are therefore restricted by a lack of data regarding the relative risks associated with vitamin D deficiency or excess and health outcomes.

Although levels of serum 25(OH)D are established as a reliable biomarker of total vitamin D exposure from both sunlight and the diet, the relationship between dietary vitamin D intake and serum 25(OH)D levels is difficult to define due to the contribution of vitamin D obtained from the sun. Many studies have measured a change in serum 25(OH)D levels following an increase in vitamin D intake (see chapter 2) and a number have set out specifically to determine a dose-response relationship between vitamin D intake and serum 25(OH)D levels (1, 99, 116-119).

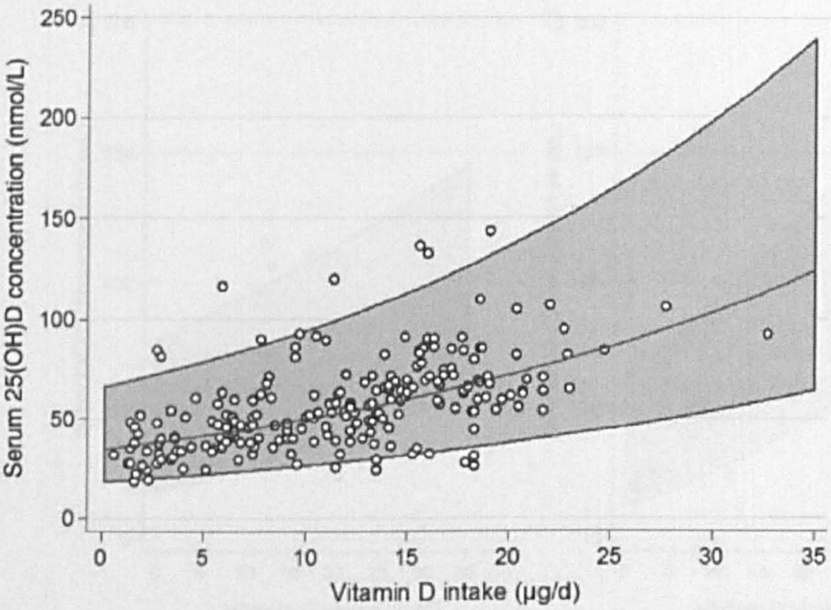
In an exercise to determine dietary references values for the US and Canada, the IOM used data available in the literature to establish a range of adequate daily intakes based on the serum 25(OH)D levels seen to be adequate, or inadequate in maintaining bone health (1). The committee included studies carried out in Northern Europe (above 49.5ºN) and Antarctica (78ºS) only, which were assumed to be carried out in conditions of minimal sun exposure thereby assuming only dietary vitamin D would have contributed to serum 25(OH)D levels (1). For comparison, the UK is at a latitude of 50ºN to 60ºN. Figure 4 illustrates that the relationship between vitamin D intake and serum 25(OH)D proposed by IOM is non-linear (1). The figure includes a fitted curve with serum 25(OH)D concentration as a function of log vitamin D intake, with vitamin D intake transformed back to the original scale to illustrate the goodness of fit of the model. The IOM intake/status relationship was based on a target serum 25(OH)D level of 50nmol/l, a level the committee considered to be adequate for 97.5% of the population. There is no equivalent threshold in the UK, but this is higher than the UK 25nmol/l minimum threshold. The resulting DRIs (RDAs and EARs) were based on the assumption that individuals do not receive any vitamin D through exposure of the skin to the sun, but rely solely on dietary intake (1).

Figure 4: The relationship between serum 25(OH)D concentration and vitamin D intake proposed by IOM extracted from figure 5-4 of the IOM report (1). Data presented for all age groups in northern latitudes in winter in Europe and Antarctica. Each data point represents a different study. The mean response is illustrated by the solid line with confidence intervals presented by the dashed lines. It should be noted that 40 international units (IU) is equivalent to 1µg of vitamin D. Reproduced with permission (120).



Cashman *et. al.* (117, 118) carried out two randomised placebo controlled, double-blind trials in Ireland and Northern Ireland in order to establish a supplemental dose of vitamin D_3 required to maintain serum 25(OH)D concentrations above specific thresholds in young (117) and older (118) adults. In order to establish a relationship between vitamin D intake and serum 25(OH)D levels in adults aged 20 to 40 years, Cashman *et. al.* (117) fitted a linear regression model of the log-transformed serum 25(OH)D concentration as a function of vitamin D intake. Figure 5 illustrates the data alongside the fitted curve transformed back to the original scale to illustrate the goodness-of-fit of the model of total vitamin D intake against serum 25(OH)D concentration.

Figure 5: The log-linear relationship between serum 25(OH)D concentration and total vitamin D intake in adults aged 20 to 40 years in late winter 2007 proposed by Cashman *et. al.* (117). The mean response is presented alongside the 95% range (from the 2.5th to the 97.5th percentile) in the shaded area. Each data point represents one individual. Extracted from figure 2 of Cashman *et. al* (2008). (117). Reproduced with permission (121).



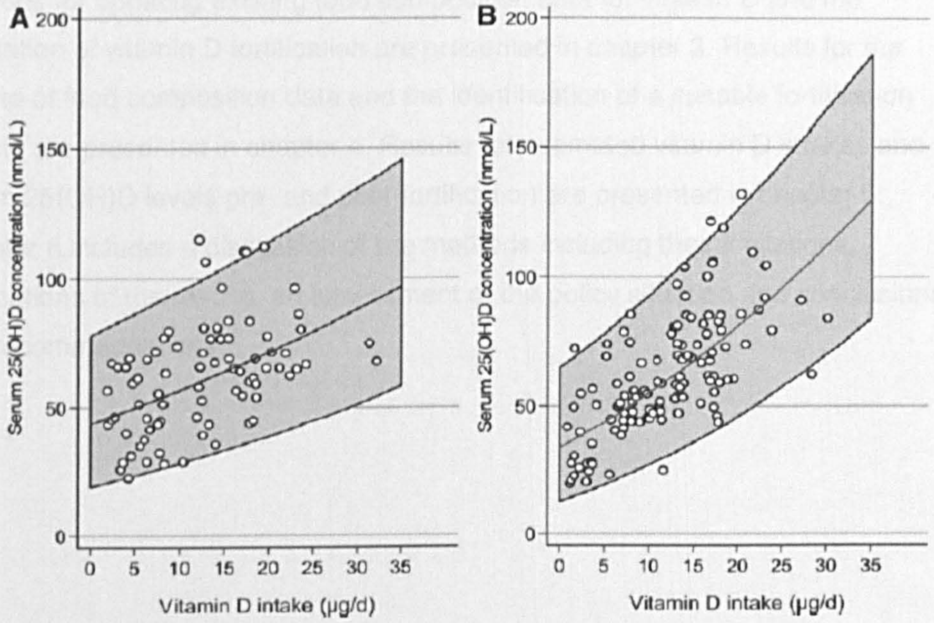
Individuals were sorted into three groups depending on whether or not they spent time in the sun to consider any vitamin D stored in body tissues from sun exposure during the summer months. They concluded that the daily vitamin D intake required to maintain serum 25(OH)D levels above 25nmol/l for adults aged 20 to 40 years was:

- 7.2µg for '*those who enjoy the sun*',
- 8.8µg for *'those who get some sunshine*'
- 12.3µg for '*sunshine avoiders*'

They found a daily intake of 8.7µg vitamin D was enough to ensure serum 25(OH)D levels exceeded 25nmol/l in 97.5% of the population (117).

This study was repeated for adults aged over 64 years (118). In this study, the authors fitted a linear regression of the square root-transformed serum 25(OH)D as a function of vitamin D intake. Figure 6 illustrates the data alongside the fitted curves transformed back to the original scale to illustrate the distribution of serum 25(OH)D concentration as a function of total vitamin D intake. They found a daily intake of 8.6µg vitamin D was enough to ensure serum 25(OH)D levels exceeded 25nmol/l in 97.5% in the population (118).

Figure 6: Square root-linear relationships between serum 25(OH)D concentration and total vitamin D intake in healthy men (A) and women (B) aged over 65 years in late winter 2008 proposed by Cashman *et. al* (2009). (118). The mean response with 95% range (from the 2.5th to the 97.5th percentile) are illustrated in the shaded area. Each data point represents one individual. Extracted from figure 2 Cashman *et. al.* (118). Reproduced with permission (121).



In 2011, Cashman *et. al.* published a systematic review and meta-regression analysis of studies investigating the vitamin D intake/status relationship to inform European recommendations (119). This is discussed further in chapter 3 in the identification of a suitable relationship for use as a framework for translating UK vitamin D intakes into serum 25(OH)D levels.

1.8 Aims and objectives

The primary aim of this study was to test, by using a computer-based data processing exercise, whether introducing vitamin D fortification of specific staple foods in the UK would reduce the proportion of 'at risk' groups failing to achieve minimum thresholds for vitamin D intake and status without causing other population groups to exceed maximum thresholds. The study also included the following secondary aims:

- To carry out a systematic review to identify whether fortification of foods with vitamin D is an effective way of improving population vitamin D status, particularly for groups at risk of deficiency;
- To update an existing food composition dataset to improve the quality of information on vitamin D fortification.

The methods and results of the systematic review are presented in chapter 2. The methods for updating existing food composition data for vitamin D and the simulation of vitamin D fortification are presented in chapter 3. Results for the update of food composition data and the identification of a suitable fortification vehicle are presented in chapter 4. Results for estimated vitamin D intakes and serum 25(OH)D levels pre- and post-fortification are presented in chapter 5. Chapter 6 includes a discussion of the methods including their limitations, implications of the results, an assessment of the policy situation and conclusions and recommendations.

CHAPTER 2: SYSTEMATIC REVIEW

Does fortification of foods with vitamin D improve serum 25(OH)D levels of groups at risk of vitamin D deficiency?

2.1 Abstract

A systematic review was carried out to identify whether fortifying foods with vitamin D improves vitamin D status, specifically among those known to be at risk from deficiency. In 2010 Medline, Embase, Global Health, the Web of Science and Cochrane library electronic databases were searched for papers published in English describing studies of any design measuring vitamin D status, in any healthy population group, following consumption of foods or drinks fortified with vitamin D. The review concludes that consumption of foods fortified with vitamin D improves vitamin D status and that national fortification schemes can increase status in some, but not all groups of the population. Consideration of the vehicle and level of fortification is essential to ensure all groups at risk of deficiency acquire the benefit of fortification without increasing the risk of excess in other groups of the population.

2.2 Introduction

Vitamin D is essential for maintaining adequate bone health. The main source for the majority of the UK population is sunlight (4), however when inadequate vitamin D is synthesised in the skin, dietary supply is critical (5). There are certain sub-groups of the UK population (young children, older people, pregnant and breast-feeding women and ethnic minorities) at risk of deficiency for whom dietary supplements are recommended (16). However, as evidence suggests supplement uptake is poor (5, 21, 25, 26), intake of vitamin D from food sources is essential to prevent deficiency. As there are few natural dietary sources, a number of countries (US, Finland, Canada and Israel) fortify milk with vitamin D (1, 48, 49, 51). Since 1940 vitamin D has been added to all margarines in the UK (29), and a range of other foods (including reduced fat spreads and some breakfast cereals) are now voluntarily fortified by manufacturers. As vitamin D status remains poor (21, 26), it is likely that the UK population could benefit from controlled fortification of further types/number of foods with vitamin D. Prior to considering widespread fortification, it is necessary to assess the efficacy of fortified foods at improving vitamin D status. The purpose of this review was therefore to systematically review the evidence to identify whether fortifying foods with vitamin D improves status, specifically among those known to be at risk from deficiency.

2.3 Methods

2.3.1 Search Strategy

During November 2010, the published literature was searched for studies of any design measuring vitamin D status, in any healthy population group, following consumption of foods or drinks fortified with vitamin D. Medline, Embase, Global Health, the Web of Science and Cochrane library electronic databases were searched for papers published in English, studying human subjects with no date restrictions, using terms outlined in table 7. Auto alerts were checked up until February 2011. Bibliographies of all included studies were checked for additional citations.

Table 7: Databases and search terms used within literature search.

Databases searched	**Search terms to be used – each synonym combined by the Boolean operator "OR", each group of terms combined by "AND"**	**Medical Subject Headings (Mesh) terms used**		
		Medline	**Embase**	**Global health**
		Includes all subheadings		
Medline (Ovid) (search for keywords) Embase (Ovid) (search for keywords) Global health (Ovid) (search for keywords) Web of science (search topic) All of the Cochrane library (search for words in abstract)	'vitamin D*', '25OHD*', '25-OH-D*', '25hydroxyvitaminD*', 25-hydroxyvitamin-D*', 'D2', 'D3', 'ergocalciferol*', 'cholecalciferol*'.	'Vitamin D' exploded.	'Vitamin D exploded.	'Vitamin D' exploded.
	'fortif*', 'enrich*', 'food supple*'	'Food, fortified', not exploded.	'Diet supplementation' exploded.	'Fortification' exploded

2.3.2 Quality assessment and data extraction

Studies were critically assessed on their overall study design (122). As studies varied in their design, not all criteria were applicable to all studies. Additional data (sample size, calculation of study power, length of intervention, response rate, accounting for confounding) provided further assessment of study quality.

Key data were extracted and tabulated from each included study in relation to design, key findings and data quality. All relevant data were extracted whether statistically significant or not in order to minimise reporting bias. For consistency, any levels of vitamin D fortification stated in international units (IU) were converted to micrograms (µg) using the conversion factor of 40IU equivalent to 1µg and where appropriate vitamin D status was converted from nanograms per millilitre (ng/ml) to nanomoles per litre (nmol/l) using the conversion factor of 1ng/ml equivalent to 2.5nmol/l. Once completed, the process was repeated to ensure all data were correctly transcribed.

Studies were ordered by hierarchy of study design, then ordered by reference number at each level. As the studies were heterogeneous in design, a quantitative synthesis of the findings was not considered to be appropriate, so a non-quantitative, narrative assessment of the design, quality and findings was carried out. Excluded studies, for which there was uncertainty over their inclusion, were summarized and reasons for exclusion discussed.

2.4 Results

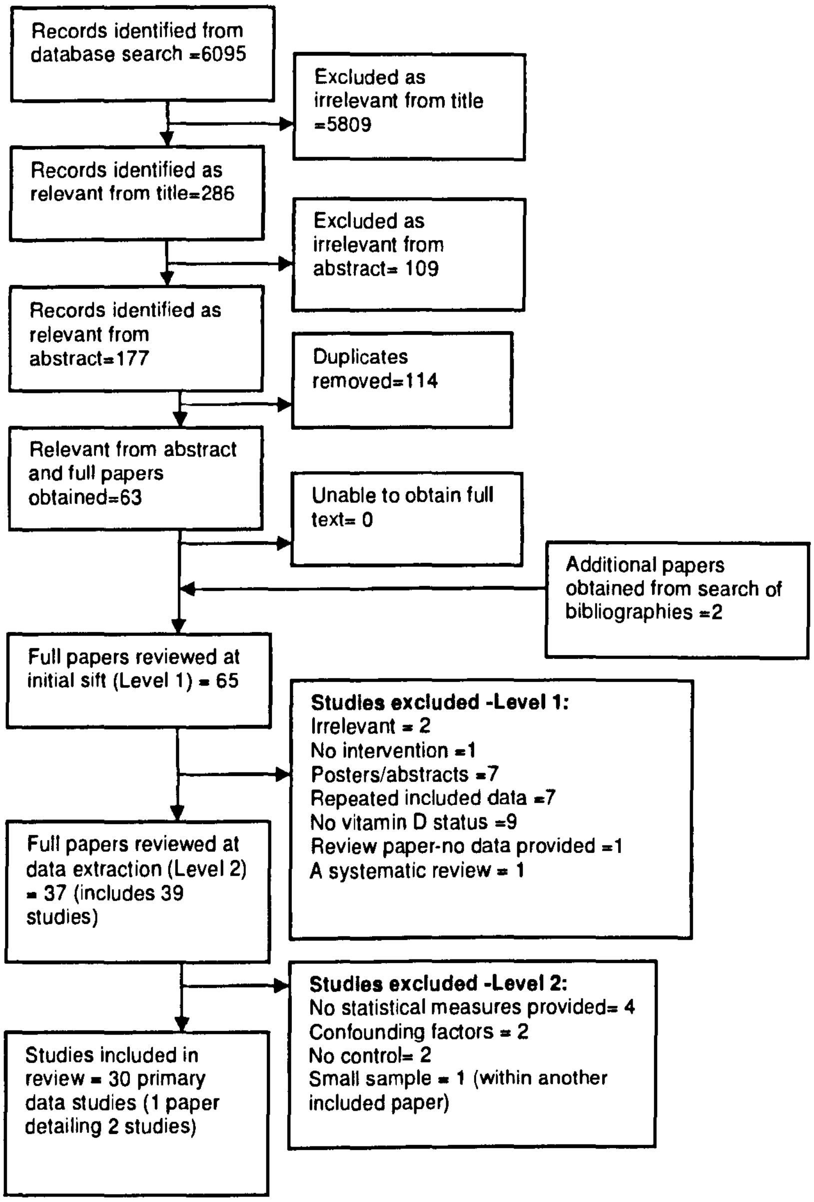
Studies meeting the inclusion criteria listed in table 8 were included within the review.

As figure 7 illustrates, 37 full papers were selected for data extraction, consisting of 39 studies. Four studies were excluded due to lack of statistical analysis (48, 58, 123, 124), two were excluded due to confounding factors of the study design (125, 126), two were excluded due to lack of a control measure of vitamin D status (59, 60) and one (127) was excluded due to a small sample. The review therefore included 30 primary data studies.

Table 8: Inclusion and exclusion criteria applied in systematic review

Aspect	Inclusion criteria	Exclusion criteria
Level 1-Initial sift		
Papers	Published in English	Not published in English
Types of studies:	All, including case-control/single arm studies/population interventions	
Type of setting:	All, including low, middle and high income countries	
Type of participants:	Healthy general population, term infants, pregnant and breast-feeding women, older people including those in institutions, ethnic minorities, including individuals with inadequate vitamin D and overweight individuals	Intervention for the unwell/injured, preterm infants, recovering from hip fracture, treatment of chronic pain etc.
Type of intervention:	Food fortification, supplementation in food/drink	Supplementation in tablet/capsule form (i.e. not in food/drink form), fortification of infant or follow on formula milk
Type of outcome measures:	Vitamin D status (serum 25(OH)D concentration)	All others
Level 2-Data extraction		
Statistical analysis:	Presentation of a statistical analysis of the change in vitamin D status as a result of the intervention	Lack of presentation of statistical analysis of change in vitamin D status
Control/baseline data:	Control or baseline data pre-intervention presented for comparison	Lack of control or baseline data pre intervention for comparison
Confounding of intervention effect	Clear association of the effect from consumption of the fortified food i.e. lack of confounding factors (excluding general sun and day to day dietary factors)	Lack of detail on level of fortification for fortified food available for consumption. Intervention including the fortified food as only one among many intervention strategies that may affect vitamin D status, in each arm.
Number of participants	≥10 in each study arm	<10 in each study arm

Figure 7: Flow diagram illustrating results of literature search and exclusion process



2.4.1 Characteristics of included studies

Table 9 outlines the characteristics of the studies included within this review: randomised controlled trials (RCTs) (128-142); cluster RCTs (cRCTs) (143-147); including a matched pair cRCT (146) and a matched pair cRCT cross-sectional follow up (147); a double arm trial (DA) (148) and single arm trials (SA) (149-154). The remaining studies assessed the effects of a population-wide intervention in Finland, including longitudinal studies (LS) (155, 156) and a repeat cross-sectional (rCS) study (157). The design of one study (146) was published in a separate paper (158). As one paper detailed two studies, each study has its own reference (142, 154).

The geographical coverage of the studies included: the US (128, 137, 142, 153, 154); Canada (133, 149); New Zealand (129, 147); Australia (131, 135, 152); Netherlands (132, 136); Ireland (138, 140, 145)·; Finland (141, 155-157); Spain (148); France (150); Romania (151); India (146); China (139, 143); Indonesia and the Philippines (130); Sri Lanka (144) and Malaysia (134).

Vehicles of fortification were milk (130, 131, 135, 138-140, 143, 145, 147, 148, 152, 154-157); milk based drinks (129, 132, 134, 146, 153); margarine (155-157); cheese (133, 137, 150); orange juice (128, 142); bread (141, 151); other cereal products (144); oil (154); pureed vegetables and pureed meat (149); and fruit and dairy based products (136).

The population groups investigated were children (ages ranging from 3 to 16 years) (143, 144, 146, 147, 157); teenage girls (155); young men (aged 18 to 21 years) (156); women of childbearing age (129, 141); adults (128, 133, 140, 142, 154); post-menopausal women (130, 134, 139, 148); older men (ages ranging from 50 to 79 years) (131, 135); institutional (132, 145, 149-152) and non-institutional (136-138, 153) older people.

The daily dose of vitamin D ranged from 0.9µg to 125µg. Two studies did not provide a daily estimate (155, 157). One study measured the effect of a single 625µg dose (154).

2.4.2 Quality of included studies

Table 10 summarises the quality of studies included within this review.

The double blind RCTs (128, 129, 132, 133, 137, 138, 140, 142) followed by the single blind (141) then non-double blind RCTs (130, 131, 134-136, 139) were the strongest of the trials in terms of design, as randomisation minimises allocation bias and blinding reduces treatment bias. The cRCTs (143-147) were the next strongest, as cluster randomisation minimises the risk of confounding and is the most effective method of measuring the effect of a community intervention. The DA (148) and SAs (149-154) were the weakest design of the trials as there were no control groups for comparison, only baseline measurements. The three studies measuring the effect of the population intervention (155-157) were weakest in design of all the studies as they risk confounding from environmental effects. The two LSs (155, 156) were the strongest out of the three as they followed the same cohort of individuals through the intervention, while any differences observed in the rCS study (157) may have resulted from differences between the two population groups.

A number of studies measured follow up exactly one (131, 151); two (134, 135, 139, 143, 147, 157); three (156); and four (155) years following the start of the intervention, and therefore were not only reliable due to length of follow up, but also accounted for confounding by the seasonal effect of sun exposure on vitamin D status, by carrying out the follow up measurements at the same time of year. Other studies lasted 14 months (146); six to nine months (132, 144, 145, 148, 152) and less than six months (128-130, 133, 136-138, 140-142, 149, 150, 153, 154). Sample sizes were generally small (less than 50 in each arm (128-133, 136-138, 141, 142, 144, 145, 148-151, 154, 157)) although some were larger (50 to 100 (134, 135, 139, 140, 147, 153, 156); and 100 to 200 (146, 152, 155) in each arm); and greater than 200 (143) increasing the validity of the findings.

Response rate was not reported in some studies (128, 136-138, 140, 142-145, 149-151, 153, 155, 157). A number of studies were opt in (129, 133, 135, 139, 141, 144), some reported 100% response (130, 146, 158) and others ranged from 25% to 99% response. A number of studies reported concealment of allocation by blinding respondents (128, 129, 132, 133, 137, 138, 140-143, 146, 148, 158) or randomisation by cluster (144-147, 158). For the remaining studies concealment of allocation was either not reported (130, 131, 134-136, 139) or not required due to the study design (149-157). The method of randomisation was described in some studies (128, 134, 139, 142).

Six of 18 studies for which follow up was applicable, did not achieve results for ≥80% of the sample at follow up (132, 136, 144-146, 156, 158). Blind assessment of the outcome was measured in 11 studies (128, 129, 132, 133, 137, 138, 140, 142, 143, 146, 148, 158). All studies provided baseline measurements as this was an inclusion criterion. Protection against contamination was only achieved for those studies randomising by cluster (143-147, 158). Many studies did not consider the effect of confounding of vitamin D exposure from the diet or sun (128-130, 141, 144, 145, 147, 148, 153, 154); some considered both (131, 133, 135, 138, 139, 142, 143, 149, 155, 156) and the remainder only accounted for either diet or sun exposure (132, 134, 136, 137, 140, 146, 150-152, 157, 158).

As all studies measured serum 25-hydroxyvitamin D (25(OH)D) concentration, which is widely accepted as an indicator of vitamin D status (5) and well known current methods are generally considered to provide valid results (159), although their comparability may be limited, all studies were considered to have used a reliable measure of vitamin D status. Most used radio immunoassay (RIA) from the same supplier (DiaSorin) (129, 131-133, 135, 137, 141, 147, 148, 150-152, 155-157); with some using alternative suppliers (130, 134, 140, 144, 153). Other studies used high-pressure liquid chromatography (HPLC) (156), liquid chromatography mass spectrometry (128, 149) and protein binding assay (136, 138, 139, 142, 143, 145, 146, 154, 158). All used the same method for baseline, control and intervention arms.

2.4.3 Study Findings

Due to varying statistical presentation of the included studies, treatment effects are not summarised in the text for every study design. Details of the post-intervention treatment effects for all studies are described in table 9.

-Randomised controlled trials

All but three of the RCTs, including the cRCTs and cross-sectional follow up found significant increases in serum 25(OH)D concentration from baseline following an intervention of consumption of a food/drink fortified with vitamin D compared to the control group (128, 130-136, 138, 139, 141-147).

Three RCTs (129, 137, 140) observed significant decreases in serum 25(OH)D from baseline post-intervention, in both the intervention and control groups. For two of these studies (129, 140) serum 25(OH)D concentrations were however significantly higher in the intervention groups compared to the control following the interventions. For the other RCT (137) there was no difference in post-intervention 25(OH)D concentrations between the intervention and control groups.

An RCT focusing on the difference between two types of vitamin D (D_2, ergocalciferol and D_3, cholecalciferol) found serum 25(OH)D concentration increased following consumption of orange juice fortified with vitamin D_2 significantly more compared to the control ($p<0.0001$) (128), but found the difference after consuming orange juice fortified with vitamin D_3 was not significant compared to control ($p>0.05$).

-Double arm study

In the DA (148) study the group receiving milk fortified with vitamin D and calcium only did not observe a significant increase in vitamin D status (from 110.6nmol/l (SD:56.8) to 111.3nmol/l (SD:49.3)), whereas the group receiving milk fortified with other vitamins and minerals in addition to vitamin D and calcium, did observe a significant increase (109.9nmol/l (SD:49.9) to 123.9nmol/l (SD:42.5)) following a six month intervention.

-Single arm studies

Five out of the six SA trials observed significant differences in serum 25(OH)D compared to baseline following intervention (149-152, 154). One SA trial observed a non-significant ($p=0.208$) increase in serum 25(OH)D concentration from baseline following a four week intervention (25.27nmol/ to 25.9nmol) (153).

-Longitudinal studies

One longitudinal study observed a significant ($p=0.0015$) increase in serum 25(OH)D concentrations three years after the introduction of a population wide fortification programme of milk and margarine fortification in Finland among a sample of young men (24nmol/l (range 13-48) to 27nmol/l (range 10-59)) (156). However another longitudinal study (155) observed no difference for teenage girls after a four year follow up (48.3nmol/l (SD:19.6) to 48.1nmol/l (SD:17.1)).

-Repeat Cross-sectional

The rCS study observed a significant increase ($p=0.002$) in serum 25(OH)D concentration among children aged four years following the introduction of Finland's fortification programme (54.7nmol/l (95%CI: 51, 58.4) to 64.9nmol/l (95%CI:59.7, 70.1) (157).

All different types of foods and drinks used as vehicles for fortification (including milk, bread, other cereals, orange juice, cheese, fruit and dairy based products, margarine and oil, pureed vegetables and meat) were shown to significantly improve serum 25(OH)D concentration following the intervention in at least one study.

It should be noted that the study groups varied considerably in their baseline vitamin D status, which is likely to be mainly due to the range of age groups, time of year and latitudes of the countries included. However, it also raises the issue of the reliability of the measures of vitamin D status, and whether the samples are in fact comparable. As the same methods were used for measuring status at baseline and follow up for all studies, and the outcome of interest in this review is whether vitamin D status changed following the intervention, rather than any baseline differences observed between studies, the variation in baseline status values is unlikely to affect the conclusions of this review.

2.5 Discussion

There are a large number of published trials investigating the efficacy of the consumption of vitamin D fortified foods and drinks on vitamin D status. Most observed a significant increase in serum 25(OH)D concentration following the intervention. Studies where an increase in status was observed in certain arms of the trial and not others (128, 148) may be explained by varying compliance between the arms. The four short (one to five months) studies (three RCTs (129, 137, 140) and one SA (153)) that did not see a significant increase in status following interventions are likely to be explained by a seasonal decline in serum 25(OH)D levels caused by decreased sun exposure in the winter months. Therefore the non-significant increase/decline observed may have been an improvement compared to a control (as seen in two RCTs (129, 140)). Where serum 25(OH)D concentrations declined in the intervention group, but were not significantly different at the end of the study between the intervention and control groups (137), this may be explained by higher baseline serum 25(OH)D concentrations in the intervention arm (137).

The longitudinal study (155) investigating the effects of the national vitamin D fortification programme of milk in Finland on teenage girls may not have observed a statistically significant difference in serum 25(OH)D concentration after four years, as this group may not have consumed enough milk to have affected vitamin D status. Therefore, a different vehicle of fortification might be more suitable for this population sub-group.

Vitamin D is a fat-soluble vitamin, and therefore requires fat in the diet to be absorbed. It could therefore be assumed that only foods and drinks containing a certain level of fat would be suitable vehicles for vitamin D fortification. Use of a dry vitamin D powder, which is cold water soluble in low fat foods and drinks, has however been shown to be effective at improving vitamin D status (128, 129, 141, 142) and all foods and drinks assessed were shown to significantly improve vitamin D status in at least one study, suggesting that milk, bread, other cereals, orange juice, cheese, fruit and dairy based products, margarine and oil, pureed vegetables and meat would all be suitable vehicles for improving vitamin D status if consumed by groups at risk of deficiency.

The doses of vitamin D assessed in the included studies ranged from 0.9µg to 125µg per day, which further emphasises the heterogeneity of the survey designs. It is interesting to note that the daily doses of the three RCTs that did not observe increases in serum 25(OH)D concentration from baseline when compared to the control were at the lower end of this range (3µg to 15µg per day) (129, 137, 140).

2.5.1 Fortification trials verses real life programmes

This review shows that many foods can be effective vehicles for improving vitamin D status through fortification, ranging from staple foods such as milk and bread, to cheese, orange juice and other cereals. Three studies found that fortified cheese (133), orange juice (128) and bread (141) were as effective as supplements at improving vitamin D status. It should be noted however, that controlled trials may provide a false impression of the effectiveness of national/local fortification programmes as they ensure optimum compliance by monitoring consumption. One study (145) observed a greater improvement in serum 25(OH)D levels when consumption was enforced compared to when fortified milk replaced usual milk in the diet. Trials often offer the fortified food/drink in addition to the usual diet, so vitamin D status levels are likely to increase above usual seasonal levels. The population interventions (155-157) carried out in Finland following national fortification of milk in 2003, may be weaker in study design, but they reflect more accurately whether national fortification strategies effectively improve status, particularly among populations most at risk. From these studies it seems that milk fortification in Finland is sufficient to increase vitamin D status in young men (156) and young children (157), but not teenage girls (155), which as mentioned above, this is likely to relate to the volume of milk consumed by teenage girls.

2.5.2 'At risk' groups

As discussed previously, young children, pregnant and breast-feeding women, older people and ethnic minorities are traditionally considered at risk of deficiency. This review provides limited evidence for the effect of vitamin D fortification in these groups. A national programme of milk fortification in Finland was shown to improve vitamin D status in young children (157). One study showed that fortified milk could reduce the severity of the seasonal decline in women of childbearing age (representing pregnant and breast-feeding women), but could not prevent it all together (129); and a number of trials showed fortification of a range of foods to be effective at improving status in older people (132, 136-138, 145, 149-152); however one (152) identified that although status increased, fortification levels required for adequate status were not reached. There were no studies identified in ethnic minorities, although one study (123) excluded from the review due to the lack of statistical measurement investigated the effect of fortifying chapatti flour with vitamin D and found that vitamin D status improved in an Asian community and fortification led to a more even distribution of vitamin D compared to supplement intake (123).

Although none of the included studies was carried out in UK, a wide range of developed countries including many European countries were represented. It was therefore considered that these findings are applicable to the UK population. A number of studies excluded from the review (58-60), reported the effects of excess vitamin D resulting from over fortification. Any fortification programme should therefore carefully monitor fortification levels to prevent risk of excess consumption. As discussed, a number of foods are already fortified with vitamin D in the UK, however as vitamin D status remains poor in certain groups, further fortification of foods or drinks should be considered to improve the health of the UK population, with careful consideration given to the vehicle and level of fortification.

This review has several limitations. The included studies are heterogeneous in study design and so the potential for accurate comparison is limited. Only one person carried out the literature search and data extraction, which increases the risk of human error. A number of studies may have been excluded due to publication in a different language. This review identified a need for further research to investigate the impact of vitamin D fortification on ethnic minorities and pregnant and breast-feeding women, as well as a need for further research into the effect of population interventions on vitamin D status in terms of achieving adequate status as well as looking at signs of excess.

In conclusion, this review provides evidence that consumption of foods fortified with vitamin D can improve vitamin D status, in some, but not all groups of the population. Consideration of the vehicle and level of fortification is critical to ensure all groups at risk of deficiency acquire the benefit of fortification without increasing the risk of excess in other groups of the population.

Table 9: Characteristics of studies included in the systematic review

Study-country	Date	Population group	Vehicle	Relevant intervention/outcome	Daily intake from fortified food (or eq.)	Relevant treatment effect	Primary outcome of interest
Randomised control trial							
US (128)	2007	Adults (18-79yrs)	Orange juice (OJ)	Effect on serum 25(OH)D of daily consumption of 236.6ml orange juice fortified with 25µg either D2 or D3 (and calcium) (D2OJ or D3OJ) accompanied by placebo supplement (PS), compared to control unfortified orange juice (COJ) accompanied by either D2 or D3 supplement (D2S or D3S) compared with COJ accompanied by PS.	25µg	Significant difference in area under curve (AUC) for 25(OH)D2 between D2OJ juice group and COJ PS control (p<0.0001). Although there was no significant difference (p>0.05) between the AUC for serum 25(OH)D3 for D3OJ group and COJ PS control group. Mean serum 25(OH)D increased from 17.9nmol/l (SD:+/-11.1) to 30.7nmol/l (SD:+/-8.5) in D3OJ group. Mean serum 25(OH)D increased from 15.8nmol/l (SD:+/-10.0) to 26.4nmol/l (SD:+/-7.4) in D2OJ group. Mean serum 25(OH)D decreased from 19.8nmol/l (SD:+/-9.6) to 18.1nmol/l (SD:+/-6.4) in COJ PS group.	Vitamin D status
New Zealand (129)	Published 2010*	Women (18-45yrs) (taken from paper as differs to abstract)	Milk powder	Effect on serum 25(OH)D of daily consumption of 2x 37.5g of fortified milk powder containing 2.5µg of vitamin with 200ml water, compared to control unfortified milk.	5µg	Mean serum 25(OH)D decreased significantly (p<0.01) in the fortified milk group from 76nmol/l (95%CI:66,87) at baseline to 65nmol/l (95%CI:57,73) following 12 weeks intervention. Mean serum 25(OH)D decreased in the control group from 74nmol/l (95%CI:65,85) to 53nmol/l (95%CI:46,62). However serum 25(OH)D levels at 12 weeks were significantly different (p<0.001) between the two groups adjusting for baseline values.	Vitamin D status and parathyroid hormone
Indonesia and Philippines (130)	2007/ 2008*	Post-menopausal women (<55yrs)	Milk	Effect on serum 25(OH)D of daily consumption of 2x 60g of milk each carton fortified with 4.86µg of vitamin D, also containing 600mg calcium, 48mg magnesium and 1.2mg zinc compared to control of unfortified rice drink.	9.6µg	Mean serum 25(OH)D increased significantly in both countries following intervention compared to control in Indonesia (p<0.001) and the Philippines (p<0.01). Increasing 45nmol/l (95%CI:41-49) to 58nmol/l (95%CI:53-62) in Indonesia and from 62nmol/l (95%CI: 56-68) at baseline to 86nmol/l (95%CI: 80-92) at 16 wks in the Philippines. €	Vitamin D status and markers of bone turnover

Study-country	Date	Population group	Vehicle	Relevant intervention/outcome	Daily intake from fortified food (or eq.)	Relevant treatment effect	Primary outcome of interest
Australia (131)	Published 2008*	Caucasian men (50-79yrs)	Milk	Effect on serum 25(OH)D of daily consumption of 2 x200ml cartons milk fortified with 10µg D3, with 500mg calcium, compared to fortified milk plus exercise and controls of exercise only and no intervention.	20µg	Mean serum 25(OH)D increased from baseline by 11.4% in the fortified milk groups compared to a decrease of 11.6% in the non-supplemented control groups after 12 months intervention. This resulted in a significant ($p<0.001$) increase of 23% (95% CI: 13.1,32.8) in the fortified milk groups compared to the non-supplemented controls.	Bone mineral density
Netherlands (132)	2000-2003	Institutional older people (≥60yrs)	Fruit flavoured dairy drink	Effect on serum 25(OH)D of daily consumption of 2x 125ml fortified drink containing 7.5µg vitamin D compared to control unfortified drink.	13µg	Median serum 25(OH)D increased by 28.7nmol/l (P_{10}-P_{90}:11.7-50.4) following intervention for fortified drink group from 21.5nmol/l (P_{10}-P_{90}:13.1-34.5) at baseline to 49.2nmol/l(P_{10}-P_{90}:28.7-73.4) at week 24 which is significantly different ($p<0.001$) to the control group which decreased by 2.5nmol/l (P_{10}-P_{90}:-6.4-22.8) from 20.3nmol/l (P_{10}-P_{90}:8.6-93.7) to 18.1nmol/l (P_{10}-P_{90}:10.4-112.5).	Dietary intake and nutritional status
Canada (133)	2007	Healthy adults (18-60yrs)	Cheese	Effect on serum 25(OH)D of a **weekly** consumption of cheddar cheese (DC) (33.6g) or low fat (DLF) cheese (41.4g) fortified with 700µg vitamin D. Compared to a vitamin D liquid supplement taken with (DS+) or without food (DS-), a placebo supplement (PS) and unfortified cheese (PC) controls.	100µg	Mean serum 25(OH)D increased significantly ($p<0.005$) from baseline to 8 wk follow up by 65.3nmol/l (SD:+/-24.1) and 69.4nmol/l (SD: +/-21.7) following the intervention for the fortified cheddar and low fat cheese groups respectively. Status in the placebo groups significantly ($p=0.046$) declined from 55.0nmol/l (SD:+/-25.3) to 50.7nmol/l (SD:+/-24.2) over the 8 week period. ∏	Vitamin D status
Malaysia (134)	Published 2003*	Chinese Post-menopausal women (55-65yrs)	Milk powder	Effect on serum 25(OH)D of 50g skimmed milk powder fortified with calcium, phosphorus, magnesium and 10µg D3 per 50g daily serving, reconstituted with 400ml water. Compared to control group with normal diet.	10µg	In the milk group, mean serum 25(OH)D increased significantly ($p<0.01$) from 69.1nmol/l (+/-16.1) at baseline to 86.4 (+/-22) nmol/l at 24 months post-intervention. In the control group, mean serum 25(OH)D increased not significantly from 68.4nmol/l (+/- 15.7) at baseline to 71.2nmol/l (+/-21.7) at 24 months post- intervention.	Bone loss
Australia (135)	Published 2006*	Men >50years Caucasian	Milk	Effect on serum 25(OH)D of daily consumption of 400ml milk 20µg D3 and 100mg Ca for 2 years. Compared to control group consuming no extra milk.	20µg	In the milk group mean serum 25(OH)D increased significantly ($P<0.05$) from 77.2nmol/l (+/-22.6) by 7.4nmol/l at 24 months. In the control group mean serum 25(OH)D decreased significantly $P<0.001$) from baseline 76.1nmol/l (+/-23.5) by 19.9nmol/l at 24 months.	Bone loss

Study-country	Date	Population group	Vehicle	Relevant intervention/outcome	Daily intake from fortified food (or eq.)	Relevant treatment effect	Primary outcome of interest
Netherlands (136)	1997	Free living frail older people (mean 78 +/- 5.7yrs)	Fruit based and Dairy products	Effect on serum 25(OH)D of daily consumption of 2 servings of either fortified fruit or dairy products (total 7.5µg/d) compared to group (2) with exercise program only, and group (3) with nutrient dense products plus exercise and control group (4) with regular unfortified products and a social program.	7.5µg (Dutch RDA for vitamin D)	In the fortified group mean serum 25(OH)D increased by 35nmol/l (+/-18) from 37nmol/l (+/- 20) at baseline. In the fortified food plus exercise group mean serum 25(OH)D increased by 31nmol/l (+/-18) from 39nmol/l (+/-16) at baseline. These changes were statistically different (p<0.001) to the change observed in the control group (4) 5nmol/l (+/-9).	Biochemical and hematologic markers of nutritional and health status
US (137)	Published 2005*	Adults aged 60yrs and over	Cheese	Effect on serum 25(OH)D of 85g daily portion of cheese fortified with vitamin D3 (15µg/d) for 2 months, compared to unfortified cheese group and no cheese group.	15µg	There were significant differences in baseline 25(OH)D concentrations (P=0.04) between groups. At 2 months mean 25(OH)D was significantly **<u>lower</u>** (a decrease of 6nmol/l (+/-2) P<0.001)) compared to 57.5nmol/l (+/-3.5) at baseline. The fortified cheese group had a greater decrease than both other groups, but there were no differences between serum 25(OH)D levels at study completion.	Vitamin D status, PTH and osteocalcin concentration
Ireland (138)	1993-4	Community based older people subjects (65-92yrs)	Milk	Effect on serum 25(OH)D of daily consumption of 500ml fortified milk containing 5µg vitamin D compared to control group with unfortified milk (0.1µg vitamin D).	5µg	In the milk group mean serum 25(OH)D increased significantly (p<0.001) from baseline 24nmol/l (13.75-31.75) to 46.25nmol/l (24-66.75) after one year. This was significantly (p<0.001) different to the control group 31.75nmol/l (10-60.25) after 1 year. There was no significant difference between the two groups at baseline.	Vitamin D and calcium status
China (139)	Published 2001*	Chinese post-menopausal women (55-59yrs)	Milk	Effect on serum 25(OH)D of daily consumption of 50g fortified milk containing 6µg of vitamin D compared to a control group.	6µg	In the milk group mean serum 25(OH)D increased significantly (p<0.05) from 66nmol/l (SD17) to 89.2nmol/l (SD=22) after one year. There were no data provided in text as to how this compared to the control. The abstract states serum 25(OH)D concentrations were higher in the milk group compared to the control at 12 months (p<0.05).	Bone loss

Study-country	Date	Population group	Vehicle	Relevant intervention/outcome	Daily intake from fortified food (or eq.)	Relevant treatment effect	Primary outcome of interest
Ireland(140)*	1993-1994	Adults	Milk	Effect on serum 25(OH)D of daily consumption of 2 litres of fortified milk containing 12µg/l of vitamin D3 per week compared to a control group consuming unfortified milk (0.3µg/l).	Additional 3.3µg	In the milk group serum 25(OH)D decreased by 15nmol/l from 77nmol/l (+/-35) to 62nmol/l (+/-26) (p<0.001). In the control group serum 25(OH)D decreased by 31nmol/l from 85nmol/l (+/-39) to 54nmol/l (+/-25). The decline in the milk group was significantly less than the decline in the control group (p<0.001) and at the end of the study the serum 25(OH)D of the control group was significantly lower (p=0.05) than the milk group.	Vitamin D status
Finland (141)	Published 2006	Healthy women 25-45 yrs	Bread	Effect on serum 25(OH)D of 85g daily portion of wheat and rye bread fortified with a mean dose of 12µg/100g vitamin D3 for 3 weeks. Compared with unfortified bread and supplement control groups.	10µg	The mean increase in serum 25(OH)D was not significantly different to the supplement group (19.5nmol/l +/-10.1) for fortified wheat (16.3nmol/l +/-6.6) (p=0.571) and fortified rye group (14.9nmol/l +/-6.2) (p=0.442). The control group had a significantly lower change (-0.3nmol/l +/-4) than all other groups (p=0.005).	Vitamin D status
US (142)	Published 2003	Adults aged 22-60 yrs	Orange juice (OJ)	Effect on serum 25(OH)D of daily 240ml portion of orange juice fortified with 25µg D3 for 12 weeks. Compared to a control group of unfortified orange juice.	25µg	The mean increase in serum 25(OH)D seen after 12 weeks in the fortified group from 37.0nmol/l (+/-8.0) to 94.0nmol/l (+/-20) was significantly greater (p<0.001) than the increase seen in control group from 50.0nmol/l (+/-10) to 73.0nmol/l (+/-8.0).	Vitamin D status
Cluster randomisation matched pair control trial							
India (146, 158)	1999/ 2000	Middle income students (6-16 yrs) from 2 schools	Milk based 'health' drink	Effect on serum 25(OH)D of **twice** daily consumption of 1x 27g fortified drink sachet in 150ml milk containing 2.5µg vitamin D and other nutrients compared to a matched control consuming unfortified drink	5µg	Mean serum 25(OH)D increased from 75nmol/l (SD:+/-10) to 90nmol/l (SD:+/-15) after 14 months in the fortified drink group compared to a decrease from 88nmol/l (SD:+/-12) to 63nmol/l (SD:+/-18) in the control group. The 25(OH)D levels for the two groups were significantly different (p<0.001) from each other at baseline and at 14 months. €	Nutritional status
Cluster randomisation matched pair control trial-Cross-sectional follow up							
New Zealand (147)	2007	Children (aged 7-8 yrs)	Milk	Effect on serum 25(OH)D of daily consumption of 330ml of milk fortified with 1.5µg vitamin D compared to control group receiving no milk.	1.5µg	The mean serum 25(OH)D levels were statistically different (p=0.01) with mean of 49.6nmol/l (SD:15.7) for fortified milk group and 43.8nmol/l (SD:14.8) for control group.	Vitamin D status

Study-country	Date	Population group	Vehicle	Relevant intervention/outcome	Daily intake from fortified food (or eq.)	Relevant treatment effect	Primary outcome of interest
Cluster randomised control trial							
China (143)	1999-2001	Girls (10 yrs) from 9 primary schools	Milk	Effect on serum 25(OH)D of daily (school days) consumption of a 330ml carton of milk fortified with 5µg or 8µg vitamin D and 370mg calcium. Compared to milk fortified with calcium only and a control of no supplementary milk.	3.33µg (mean consumption 144ml)	At 24 months the mean serum 25(OH)D for the group consuming vitamin D fortified milk was significantly higher ($p<0.0005$) (more than double) compared to the group consuming milk not fortified with vitamin D and those in control arm: (47.6nmol/l (SD:23.4); 17.9nmol/l (SD:9.0) and 19.4nmol/l (SD:10.2) respectively). Means at baseline were 20.6nmol/l (SD:8.8); 17.7nmol/l (SD:8.7) and 19.1nmol/l (SD:7.4) respectively.	Growth and mineral accretion
Sri Lanka (144)	Published 2010*	Preschool children (3-5yrs)	Cereal-Thriposha	Effect on serum 25(OH)D of daily consumption of 50g of cereal fortified with 2.5µg vitamin D, compared to control group consuming unfortified cereal.	2.5µg	Mean serum 25(OH)D increased by 24.3nmol/l(SD:6.5) from 71.95nmol/l (SD:32.3) at baseline to 96.28nmol/l (SD:27.5) after 9 months. This increase was significantly different ($p<0.05$) to a decrease of 7.1nmol/l (SD:7.3) observed in the control group from 103.44nmol (SD:26.4) at baseline to 96.3nmol/l (SD:36.9) after 9 months.	Total spine bone mineral density
Ireland (145)	Published 1992*	Institutionalised (long term) older people (mean age 84yrs)	Milk	Effect on serum 25(OH)D of daily consumption of 500ml fortified milk containing 5µg for 3 months (phase 1) followed by consuming the milk as part of normal diet for 6 months (phase 2), compared to control of unfortified milk.	4µg phase 1 (mean consumption 359ml) <2µg phase 2 (mean consumption 140ml)	Mean serum 25(OH)D increased significantly ($p<0.001$) from 4.9nmol/l (95%CI:4-8) at baseline to 37nmol/l (95%CI:29.8-44.3) at the end of 3 months (phase 1), and remained significantly higher than baseline ($p<0.001$) at 25.5nmol/l (95%CI 23-28) after a further 6 months (phase 2). This is compared to the control group in which 25(OH)D increased significantly ($p<0.001$) from 7.8nmol/l (95%CI:5.3-10.3) at baseline to 17.8nmol/l(95%CI:14.3-21.3) at the end of 3 months (phase 1), and fell to 7.5nmol/l (95%CI:5.5-9.5) after a further 6 months (phase 2).	Manage-ment of hypo-vitaminosis
Double arm trial							
Spain (148)*	Published 2005*	Post-menopausal women (49-71yrs)	Milk	Effect on serum 25(OH)D of daily consumption of 3x 250ml/d of skimmed milk fortified with 1.9µg vitamin D in place of usual milk. In group A each carton of milk also contained 400mg calcium, 315mg phosphorus and lactose. Group B only fortified with additional calcium 300/250ml, compared to baseline measurements.	5.7µg	In group A mean serum 25(OH)D increased significantly ($p<0.001$) from 109.9nmol/l (SD:49.9) to 123.9nmol/l (SD:42.5) following 6 month intervention. In group B mean serum 25(OH)D did not change significantly from 110.6nmol/l (SD:56.8) to 111.3nmol/l (SD:49.3) following 6 month intervention Ω∫	Biomarkers of bone turnover.

Study-country	Date	Population group	Vehicle	Relevant intervention/outcome	Daily intake from fortified food (or eq.)	Relevant treatment effect	Primary outcome of interest
Single arm trial							
Canada (149)	2007	Institutional (long term) older people (<50yrs)	Pureed vegetables and meat	Effect on serum 25(OH)D of daily consumption of two portions of vegetable puree and two portions of meat puree with added fortification powder containing vitamin D and other nutrients (4x 4µg vitamin D per 100g serving) in place of unfortified purees compared to baseline measurements.	16µg	Mean serum 25(OH)D increased significantly (p=0.003) from 41nmol/l (SD:+/- 21) to 66 nmol/l (SD:+/- 11).	Nutrient intake and status
France (150)	2007	Institutional older women (>65yrs)	Soft cheese	Effect on serum 25(OH)D of daily consumption of two 100g servings of soft plain cheese fortified with vitamin D at 1.25µg, also fortified with calcium compared to baseline measurements.	2.5µg	Mean serum 25(OH)D increased significantly (p=0.0051) by 14.5% from 13.8nmol/l (SD:4.4) at baseline to 15.8nmol/l (SD:4.3).	Bone resorption
Romania (151)	2003-04	Institutional older people (58-89yrs)	Bread	Effect on serum 25(OH)D of daily consumption of a 100g bun fortified with 125µg D3 (also fortified with 329mg calcium), compared to baseline measurements.	125µg	Mean serum 25(OH)D increased significantly (P<0.001) from baseline from 28.8nmol/l (SD:+/9.9) to 126.4nmol/l (SD:+/-37.3) at 12 months with a mean increase of 98.9nmol/l. ¥	Long term safety/ efficacy of higher doses of vitamin D
Australia (152)	Published 2009*	Institutional older people (mean 80yrs)	Milk	Effect on serum 25(OH)D of daily consumption of full cream fortified with 5µg/100ml vitamin D, as well as 190mg/100ml calcium, and 75µg/100ml folate in place of usual milk, compared to baseline measurements.	7.1µg – median daily intake of milk 160ml (range 0-898ml)	Mean serum 25(OH)D increased significantly (p<0.001) from baseline by 23nmol/l (SE+/-2) (83%) following the 6 month intervention.	Nutritional status, bone quality, bone turnover, muscle strength and mobility
US (153)	1994	Older people (56-94yrs) participating in congregate dining program	Carnation Instant Breakfast (CIB) fortified powder added to milk	Effect on serum 25(OH)D of daily consumption of CIB powder containing 2.5µg *vitamin D with 1/2 pint whole milk, in addition to their usual diet, for 4 weeks, compared to baseline measurements.	2.5µg *	Mean serum 25(OH)D increased not significantly (p=0.208) by 0.65nmol/l from 25.27nmol/l* at baseline to 25.9nmol/l after 4 weeks. (Units*)	Nutritional status

Study-country	Date	Population group	Vehicle	Relevant intervention/outcome	Daily intake from fortified food (or eq.)	Relevant treatment effect	Primary outcome of interest
US (154)	Published 2003	Adults aged 19-68 yrs	Milk, corn oil	Effect on serum 25(OH)D of a dose of 625µg vit D2 in three different vehicles: 240ml whole or skimmed milk or 0.1l corn oil on toast. All three consumed by each individual on different occasions.	625µg one off dose	The mean increase in serum 25(OH)D was not significantly different between different vehicles (p=0.62), but the change from baseline was significantly different for all vehicles p<0.05).	Vitamin D status
Population intervention							
-Longitudinal							
Finland (155)	2000/04	Adolescent females (12-18yrs)	Milk and margarine	Effect on serum 25(OH)D of national policy to fortify milk with vitamin D at 0.5µg/dl and margarine at 10µg/100g (48), compared to baseline measurements.	Unknown*	Mean serum 25(OH)D did not change significantly from baseline 48.3nmol/l (SD:19.6) compared to follow up 48.1nmol/l (SD:17.1)	Vitamin D intake and status
Finland (156)	2001/04	Young men (18-21yrs)	Milk (and margarine)	Effect on serum 25(OH)D of national policy to fortify milk with vitamin D at 0.5µg/dl (and margarine at 10µg/100g) (48), compared to baseline measurements.	≤0.9µg =≤ 1glass 1.8µg= 2glasses 2.7µg=3glasses ≥3.6µg ≥4glasses	Median serum 25(OH)D increased significantly (p=0.0015) from 24nmol/l (Range:13-48) to 27nmol/l (Range:10-59). The higher the milk consumption between 2001-2004 the higher the difference in 25(OH)D P=0.0025).	Prevalence of hypo-vitaminosis
-Repeat cross-sectional							
Finland (157)	2001/2 2003/4	Children (4 yrs)	Milk and margarine	Effect on serum 25(OH)D of national policy to fortify milk with vitamin D at 0.5µg/dl and margarine at 10µg/100g (48), compared to a control group measured pre fortification.	Unknown*	Mean serum 25(OH)D increased significantly (p=0.002) from 54.7nmol/l (95%CI: 51-58.4) to 64.9 mol/l (95%CI: 59.7-70.1).	Impact on intake Vitamin D status

* Not directly stated in the paper, but where possible inferred from other information provided
∏ Status data at baseline and follow up were graphically presented, and were unable to estimate for extraction
€ Status figures are extracted from graphs presented in paper and are therefore not precise
Ω Figures extracted from table data, as they do not match figures presented in the text
∫ It is assumed the units presented in the table (mg/dl) are incorrect, and those stated in the text (ng/ml) are used.
¥ Figures extracted from paper, as they differ slightly to abstract

Table 10: Assessment of bias for studies included in the systematic review

Study-author	Inter-vention length	Sample size-productive individuals	Power calcul-ations	Response rate	Concealment of allocation	Follow up of participants	Blind assessment of outcome	Baseline measure-ment	Reliable outcome measure £	Protection against contamination	Accounted for confounding	
											Diet	Sun
Randomised control trial												
Biancuzzo *et. al.* (128)	11 wks	D3OJ+PS: 18 D2OJ +PS : 17 D3S + COJ:20 D2S + COJ:16 COJ and PCS :15	X	X	✔ √Σ	✔ €Ω	✔ √	✔	✔	X	X	
Green *et. al.*(129)	12 wks	Fortified milk: 32 Control: 34	X	Opt in	✔ √	✔ €	✔ √	✔	✔	X	X	
Kruger *et. al.* (130)	16 wks	116 (30, 30 Philippines; 29, 27 Indonesia) Ω	✔	100%	X	✔ €Ω	X	✔	✔	X	X	
Kukuijan *et. al.*(131)	12mths	Milk+Exercise: 44 Milk alone: 44 Exercise alone: 45 Control group: 42	X	99%	X	✔ €	X	✔	✔	X	✔	✔ ©
Manders *et. al.*(132)	24 wks	Fortified: 30 Placebo: 13	X	25%	✔ √	X ¥	✔ √	✔	✔	X	✔	X
Wagner *et. al.*(133)	8 wks	DC: 20; DLF: 10; DS+: 20; DS-: 10 PC: 10; PS: 10	X	Opt in	✔ √	✔ €	✔ √	✔	✔	X	✔	
Chee *et. al.*(134)	2 yrs	Milk group:91 Control group: 82	X	84%	X Σ	✔ €	X	✔	✔	X	X	✔ ©
Daly *et. al.* *(135)*	2 yrs	Milk group:76 Control group: 73	X	Opt in	X	✔ €	X	✔	✔	X	✔	✔ ©
De Jong *et. al* (136)	17 wks	1:Nutrient dense products: 37 2: Exercise: 34 3: 1&2: 38 4: Control: 34	X	X	X	X ¥	X	✔	✔	X	✔	X
Johnson *et. al.* (137)	2 mths	D3 cheese:33 Unfortified cheese: 34 Control no cheese:33	X	X	✔ Δℓ	✔ €	✔	✔	✔	X	✔	X

Study-author	Inter-vention length	Sample size-productive individuals	Power calcul-ations	Response rate	Concealment of allocation	Follow up of participants	Blind assessment of outcome	Baseline measure-ment	Reliable outcome measure £	Protection against contamination	Accounted for confounding	
											Diet	Sun
Keane *et. al.* (138)	18 mths	Fortified milk: 24 Control :18	X	X	✔	✔ €	✔	✔	✔	X	✔	✔ ©
Lau *et. al.(139)*	24 mths	Fortified milk: 95 Control:90	X	Opt in	X	✔ €	X	✔	✔	X	✔	✔ ©
McKenna *et. al.(140)*	5 mths	Fortified mlk:52 Control: 50	X	X	✔	✔ €	✔	✔	✔	X	X	✔
Natri *et. al.*(141)	3wks	D3 wheat:11 D3 rye:10 Control:9 D3 supp :11	X	Opt in	✔ ◊	✔ €	X◊	✔	✔	X	X	
Tangpricha *et. al* (A) (142)	12 wks	OJ:14 Control 12	X	X	✔	✔ €	✔	✔	✔	X	✔	
Cluster randomisation match control trial												
Sivakumar *et. al.*(146, 158)	14 mths	Biochem eval: Fortified:110 Placebo:133	X	100%	✔ √ ≠	X¥	✔ √	✔	✔	✔ ≠	✔	X
Cluster randomisation matched pair control trial-Cross- sectional follow up												
Graham *et. al.*(147)	2 yr follow up	Fortified milk: 89 Control: 83	X	82% schools; 77% pupils	✔ ≠	-	X	-	✔	✔ ≠	X	
Cluster randomised control trial												
Du *et. al(143)*	2yrs	D3 and Ca milk: 242 Ca milk only: 209 Control no milk: 247	X	X	✔ ∆	✔ €	✔ √	✔	✔	✔ ≠	✔	
Hettiarachchi *et. al.* (144)	9mths	Fortified cereal: 30 Control: 30	X	Opt in	✔ ≠	X	X	✔	✔	✔ ≠	X	
Keane *et. al.* (145)	9mths (3&6 mths)	Phase 1: 78; Phase 2: 62.	X	X	✔ ≠ ◊	X¥ (Phase 1 & 2)	X◊	✔	✔	✔ ≠	X	
Randomised double arm trial												
Palacios *et. al.* (148)	6mths	Grp A:34; Grp B:35	X	99%	✔ √	✔ €	✔ √	✔	✔	X	X	

Study	Inter-vention length	Sample size-productive individuals	Power calcul-ations	Response rate	Concealment of allocation	Follow up of participants	Blind assessment of outcome	Baseline measure-ment	Reliable outcome measure £	Protection against contamination	Accounted for confounding	
											Diet	Sun
Single arm trial												
Adolphe *et. al.* (149)	8wks	11	X	X	-	✔ €	-	✔	✔	-	✔	✔ Π
Bonjour *et. al.*(150)	1mths	35	X	X	-	✔ €	-	✔	✔	-	X	✔ Π
Mocanu *et. al.* (151)	1yr	40	X	X	-	✔ €	-	✔	✔	-	X	✔ ©
Grieger *et. al.* (152)	6mths	107	✔	44%	-	✔ €	-	✔	✔	-	✔	X
Scrader *et. al.* (153)	4wks	57	X	X	-	✔ €	-	✔	✔	-	X	
Tangpricha *et. al. (B) (154)*	6 wks	18	X	X	-	✔ €	-	✔	✔	-	X	
Population intervention												
-Longitudinal												
Lehtonen-Veromaa *et. al.* (155)	4 yr follow up	142	X	X	-	✔ €	-	✔	✔	-	✔	✔ ©
Valimaki *et. al.* (156)	3yrs	65	X	39% ®	-	X ¥ ®	-	✔	✔	-	✔	✔ ©
-Repeat cross-sectional												
Piirainen *et. al.* (157)	2yrs	Pre: 82; Post: 36	X	X	-	-	-	-	✔	-	✔	X

✔ Reported X Not reported
£ Scored as ✔ if 25(OH)D blood status was measured using recognised method (RIA, protein binding assay and HPLC)
√ Double or single blind trial –method of randomisation not explicitly described
Σ Method of randomisation provided
€ Outcome measures obtained for ≥80% of subjects entering trial
Ω Figures taken from table data as they do not match the text
© Follow up is at the same time each year to take into account seasonal changes in vitamin D
¥ Where follow up rate is stated, outcome measures obtained for <80% of subjects entering trial
Δ Except for control group
ℓ Any couples enrolled were randomised by the pair
◊ The paper states that the study was single blind, but is not explicit about whether the participants or assessors were blinded.
≠ Cluster randomisation, so minimal risk of contamination
- Not relevant to the study design
Π Assumes risk of vitamin D synthesis from sun exposure would be minimal as study participants were immobile.
® 167 participants partaking in original study in 2001 were invited to take part in 2004, 65 accepted. There was no evidence of follow up as to why other original participants did not accept, or response rate to original study.

CHAPTER 3: METHODS

This project aimed to fulfil three broad objectives in assessing the impact of fortifying more foods with vitamin D in the UK. The systematic review presented in chapter 2 concluded that consumption of foods fortified with vitamin D improves vitamin D status and that national fortification schemes have been seen to improve status in some, but not all groups of the population. It also highlighted the importance of the vehicle and level of fortification in the effectiveness of the strategy. This chapter describes the methods used to complete the remainder of the objectives. This includes (described in detail in the sections that follow):

3.1 Updating an existing food composition dataset to improve the quality of information on vitamin D fortification

3.2 Computer manipulation of updated UK dietary consumption data to simulate fortification of a range of foods with vitamin D

3.3 Estimation of the impact of fortification on vitamin D intakes

3.4 Identification of a published relationship between vitamin D intakes and status suitable to a UK setting to use in identifying the impact of fortification on vitamin D status

3.5 Estimation of the impact of fortification on vitamin D status

3.6 Determination of an optimum vehicle and level of fortification to improve vitamin D intakes and status of those most at risk of deficiency in the UK without increasing the risk of excess in the rest of the population.

This project used food consumption data and blood data from the first two years of the National Diet and Nutrition Survey (NDNS) Rolling Programme (2008/10) (from here on called the NDNS dataset), obtained from the Economic and Social Data Service (ESDS) data archive (160, 161). These data were published in 2011 and 2012 respectively and were the most recent NDNS data available at the time. Results from year three of the rolling programme (2010/11) were published in July 2012 (21), although the dataset was not available at the time this thesis was printed, and the results and data from years four and five (2012 to 2014) will be published in due course. The analysis was carried out using SPSS software (PASW statistics 18) at the Department of Health in London. The SPSS syntaxes detailing the various stages of this analysis are available on request. Approval from the London

School of Hygiene and Tropical Medicine ethics committee was obtained in October 2011 (Approval number: 6058).

3.1 Updating existing food composition data to improve the quality of information on vitamin D fortification

3.1.1 Background on food composition data used in the NDNS

The NDNS programme of dietary surveys is supported by the NDNS Nutrient Databank (from here on called the Nutrient Databank), which holds nutrient composition data for all foods, supplements and recipes consumed within recent and previous NDNS surveys. The Nutrient Databank is a standalone piece of software maintained by staff at the Department of Health. The Department funds a programme of analytical food composition projects, which are fed into the Nutrient Databank to update the nutrient composition of foods, however manufacturers reformulate the recipes of foods, especially fortified foods, so regularly that analytical projects rapidly become out of date. For example, the most recent nutrient analysis survey of breakfast cereals was carried out 10 years ago in 2002 (162). Since then manufacturers may have changed the recipe of certain products, including the number and quantity of fortified nutrients. Each year the Department of Health therefore uses label data to update the composition of foods and supplements within specific categories within the Nutrient Databank. Foods consumed by respondents during the NDNS survey period are compared with existing NDNS codes and new codes are created where necessary. The Nutrient Databank contains 1000s of food codes. As it is not possible to have a separate code for every brand of food and drink, most codes are generically described to incorporate commonly consumed brands. However, as the nutrient composition of fortified foods and supplements varies, brand-specific codes are often included.

The nutrient composition data held within the dataset from the first two years of the NDNS Rolling Programme (2008/10) used in this analysis represent a snapshot of the Nutrient Databank taken at the start of each year of fieldwork and only includes foods and supplements consumed by respondents during the survey period. The data therefore date back to the start of the first year of fieldwork in 2008. As vitamin D fortification practices may have since changed, it was necessary to update the vitamin D content of fortified foods and supplements consumed within the first two years of the survey in order to represent current vitamin D intakes. It was also important to be aware of any vitamin D fortified foods that were new to the market since 2008, not consumed in the survey, in order to consider any underestimation of current vitamin D intakes.

During the manufacture of a fortified food or supplement, an additional amount of the vitamin or mineral is added on top of the amount stated on the label to account for processing losses and degradation over time and to ensure the level stated on the label is achieved in any sample. This additional amount is called the 'overage'. Using label data to update the vitamin D values in the Nutrient Databank does not take into consideration any 'overage' remaining in the product at the time of consumption, so it was necessary to identify a suitable level of 'overage' to apply to all fortified foods and supplements in the analysis.

3.1.2 Identification of fortified foods and supplements

In order to update the vitamin D content of fortified foods and supplements within the NDNS dataset, it was necessary to identify which foods were fortified with vitamin D. As the NDNS dataset to be used in this analysis was not available until November 2011, an extract of the Nutrient Databank was taken in July 2010 to identify vitamin D fortified food and supplement codes. A list of all food codes were extracted into an Excel spreadsheet and sorted into descending levels of vitamin D content:

- Food codes with a vitamin D content of zero (2722 food codes) were removed.
- Food codes with a vitamin D content above 1µg vitamin D per 100g or ml known to be natural sources of vitamin D (i.e. either contained meat, fish and egg) were removed (265 food codes). A list of these codes are presented in appendix 1.
- The remaining 1925 food codes were searched and any homemade food recipe codes or composite foods containing other natural or fortified (where the level of fortification was known) sources of vitamin D (i.e. meat, fish, egg, butter or fat spreads) were excluded. Each code was individually assessed and compared against the types of foods that are known to be fortified with vitamin D (i.e. breakfast cereals, cereal bars, fat spreads, hot drinks, soft drinks, processed cheeses and infant foods). A decision was then made as to whether the vitamin D present within the food or drink was likely to be present naturally or added through fortification. It was concluded that the vitamin D within 1,636 of these codes was naturally present.
- Two hundred and eighty nine vitamin D fortified food and supplement codes were therefore identified. A list of these codes are presented in appendix 2.

3.1.3 Update of the vitamin D content of fortified foods and supplement via websites

In March and April 2011 websites were searched to update the vitamin D composition of the fortified food and supplement NDNS codes identified in section 3.1.2.

- The websites of the four leading retailers in the UK[3] were searched along with 41 manufacturer websites[4] with the aim of identifying the majority of brands and own branded products fortified with vitamin D on the UK market.
- All brand specific foods listed in appendix 2 were searched for as well as non-brand specific foods within all categories identified from the Nutrient Databank to include vitamin D fortified foods (i.e. breakfast cereals, cereals bars, fat spreads, hot drinks, soft drinks, processed cheeses and infant foods).
- The vitamin D content of all fortified foods and supplements identified were recorded, including any not included in the Nutrient Databank and any that were no longer fortified with vitamin D.
- To update generically named fortified food or supplement codes, a range of products within the relevant category were searched and a range of vitamin D values were recorded.

This was not designed to be an exhaustive search of all foods available on the UK market, but aimed to cover the fortified foods and supplements containing vitamin D identified in the Nutrient Databank, and establish an up-to-date picture of the types of other foods fortified with vitamin D in the UK. For vitamin D containing supplements, only the specific brands identified in appendix 2 were searched for and updated. Thousands of brands of supplements are available worldwide via the internet, so it was not feasible, as part of this project, to search for all vitamin D containing supplements and consider any that were new to the UK market since 2008.

3.1.4 Update of the vitamin D content of fortified foods and supplement via retailers and supermarkets

Not all brands of fortified foods or supplements were available via websites, so supplement retailers and supermarkets were visited:

- Three leading high street retailers selling nutritional supplements[5] and two supermarkets[6] were visited in order to establish the vitamin D content of

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[3] Sainsbury's, Tesco, Ocado (representing Waitrose) and Asda

[4] Actimel, Alpro, Boots, Benecol, Bertolli, Cereal Partners, Complan Foods, Cow & Gate, Dairylea, Enfamil, Ensure, Enviva, Flora, Healthspan, Heinz, Hipp, Holland and Barratt, Horlicks, Kelloggs, LifePlan, Milupa, Multipharmacy, MyProtein, Nestle, Nesquik, Nurishment, Nutricia, Oatly, Ovaltine, Pure, Rice Dream, Provamel, Seven Seas, Slimfast, SMA Nutrition, So Good, Vitalite, Vitamin Water, Weetabix, Vwater, Zipvit

specific own brand foods and supplements that were not available from respective websites.

- The label data of products were checked to obtain the vitamin D content for the remaining NDNS food codes and any additional vitamin D fortified foods within the above food categories.
- All products and their vitamin D content were recorded.

3.1.5 Confirmation from manufacturers and retailers

In May and June 2011, manufacturers were contacted in order to confirm that the vitamin D values of fortified foods and supplements collected from internet and in-store searches described in sections 3.1.3 and 3.1.4 were accurate and up-to-date. This was carried out to ensure that any recent changes made to the vitamin D content of foods or supplements by manufacturers, which may not have been reflected by online or in-store packaging were considered in the update:

- Three food[7] and three supplement[8] trade associations with whom all major UK food and supplement manufacturers are registered were contacted via email.
- Four individual manufacturers[9,10] were contacted directly, three of which were large providers of fortified foods[9] and the other[10] was not associated with a trade association, so it was considered appropriate to contact these companies directly. As the composition of infant formula is tightly regulated and the values found through website searches matched the values within the Nutrient Databank, manufacturers of infant formula were not contacted.
- Each organisation was emailed a spreadsheet listing all known vitamin D fortified foods or supplements relevant to the trade association or individual manufacturer, accompanied by the vitamin D content obtained from the internet and in-store searches (see appendix 3).
- The three supplement trade associations were sent information for all brands of supplements as it was not known which brands were represented by each trade association.

Organisations were asked to:

- Confirm the vitamin D values provided.

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[5] Holland and Barratt, Boots, Superdrug
[6] Morrisons and Waitrose
[7] The British Retail Consortium (BRC), The Food and Drink Federation (FDF); British Specialist Nutrition Association (BSNA) (UK infant food trade association)*.
[8] The Council for Responsible Nutrition (CRN), Proprietary Association of Great Britain (PAGB) and Health Food Manufacturers' Association (HFMA)
[9] Kellogg's; Nestle; Unilever
[10] Kallo Foods

- Provide vitamin D values for products where an up-to-date value was not available via internet or retail searches.
- Provide details of any other vitamin D fortified foods or supplements not included on the list.
- Provide feedback on the rationale for fortifying these foods with vitamin D; the levels of fortification chosen; any technical issues involved in fortifying foods with vitamin D; the levels of 'overage' applied; and the reason for the form of vitamin D used (i.e. D_2 or D_3).

3.1.6 Collation of data on up-to-date vitamin D levels and 'overage'

Data received from trade associations and directly from manufacturers were collated and any updated vitamin D values were recorded. In order to obtain further information on typical 'overages' applied to fortified foods, a nutrient analysis survey of breakfast cereals (162, 163) providing both label and analytical data for the vitamin D content of breakfast cereals was consulted.

Based on all the information available and from advice provided by an expert in micronutrient 'overages' (164) a suitable level of 'overage' was determined for application to all vitamin D fortified food and supplement codes. Further details of how the 'overage' was determined are outlined in section 4.1.3. All assumptions made to the vitamin D content of generic food groups, 'overages' and any fortified foods identified that were not consumed during the survey were recorded, see appendix 4.

There were limitations of using an extract from the Nutrient Databank taken in July 2010 to determine which vitamin D fortified food and supplement codes required updating within the 2008-10 NDNS dataset. The vitamin D content of food codes within the Nutrient Databank may have been updated between 2008 and 2010, so the vitamin D content of a food could have appeared up-to-date in the 2010 extract, but would have been out of date within the 2008-10 NDNS dataset. To check for this post-analysis, the vitamin D content of all food and supplement codes within the 2008-10 NDNS dataset were compared to the updated 2010 Nutrient Databank extract, to ensure there were no discrepancies between the vitamin D content of any food and supplement codes not already updated.

The up-to-date vitamin D label values and level of 'overage' were applied to the NDNS dataset as described in section 3.2.5. The up-to-date vitamin D label values were also included in the Department of Health's 2011 annual update of the Nutrient Databank.

Figure 8 summarises the approach used to update the vitamin D content of fortified foods and supplements reported to have been consumed in the NDNS dataset.

Figure 8: Flow chart illustrating steps involved in update of vitamin D fortified foods and supplements

The vitamin D content of all foods and supplement codes were obtained from an extract of the NDNS Nutrient Databank 2010.

↓

- Food codes containing no vitamin D were deleted.
- Food codes known to be naturally rich in vitamin D were deleted.
- Vitamin D containing supplements and fortified food codes were identified.

↓

- Websites were searched for up-to-date vitamin D values for brand specific food and supplement codes and a range of values were obtained for generic food codes.
- The vitamin D values of all fortified foods and supplements including those not currently present in the databank were recorded

↓

- High street retailers and supermarkets were visited to obtain the vitamin D content of any remaining codes.

↓

- Trade associations and manufacturers were contacted to confirm vitamin D values were up-to-date.
- They were asked to provide details of other vitamin D fortified foods and supplements and levels of overage.

↓

- A nutrient analysis survey of breakfast cereals was consulted.
- A suitable general level of overage was identified and applied to all fortified foods and supplements.

↓

Up-to-date vitamin D content for all fortified food and supplement codes were recorded for use in the analysis to update the dataset from the first two years of the NDNS Rolling Programme (2008-10).

↓

Post analysis all fortified food and supplement codes within the NDNS dataset (2008-2010) were checked against the 2010 Nutrient Databank extract to ensure all values were up-to-date.

3.2 Computer manipulation of the updated UK dietary consumption data to simulate fortification of a range of foods with vitamin D

3.2.1 Definition of 'at risk' groups

In order to determine the impact of fortification on vitamin D intakes and serum 25(OH)D concentration of population groups considered most at risk of vitamin D deficiency, it is important to clarify which population groups it has been possible to assess in this analysis. Population groups considered most at risk of vitamin D deficiency in the UK are young children, pregnant and breast-feeding women, older people and ethnic minorities (3). The following section describes how these groups were assessed in this study.

Young children: As there were no recent dietary data available for infants aged under 18 months,[11] the focus of this assessment was the impact of fortification on children aged 18 months to three years, in line with Reference Nutrient Intakes (RNIs). It is acknowledged that the Department of Health recommends supplements up to five years of age, however this assessment compared vitamin D intakes to the RNI for young children, which only relates to children up to three years. The RNIs were 'reiterated' by SACN in 2007 (5).

Pregnant and breast-feeding women: There were no national intake data available for pregnant and breast-feeding women as these groups are excluded from the national surveys. A large regional longitudinal study of pregnant women found that their diets compared very closely to the diets of women aged 16-64 years, although vitamin D specifically was not mentioned in the report (165). Dietary advice for pregnant and breast-feeding women is generally the same as for the general population, with the exception of supplemental vitamin D and folic acid, exclusion of specific foods for food safety reasons and a recommended limit of no more than two portions of oily fish per week (166). As supplement uptake and oily fish consumption are known to be low in women of childbearing age (21), it was assumed for the purposes of this analysis, that consumption patterns and dietary vitamin D intake of pregnant and breast-feeding women were equivalent to all women of childbearing age (aged 15-49 years).

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[11] In 2013, the Diet and Nutrition Survey of Infants and Young Children (DNSIYC) is due to be published which will provide detailed diet and nutrition data for children aged 4 to 18 months of age.

Older people: For the purposes of the discussion 'older people' were classified as adults aged 65 years and over. As the RNIs are set for all adults aged over 50 years however, the assessment of the proportion of 'at risk' groups with intakes below the RNIs included adults aged over 50 years.

Ethnic minorities: There were limited national data available for the diets of ethnic minority groups. The Low Income Diet and Nutrition Survey (LIDNS) provided a separate analysis for the Black and Asian population, however the number of subjects in each category were small and represent the low income population rather than the general UK ethnic minority population (26). In addition, using regional dietary data within the assessment would not have been representative of the UK. Ethnic minorities were therefore not included as a population sub-group in this analysis.

Other 'at risk' groups: Other individuals at risk of vitamin D deficiency, due to poor sun exposure, living in institutions, covering their skin for cultural reasons, excessive use of sunscreen, taking certain medication or with specific medical conditions that result in poor vitamin D status, were not included in this analysis as there were no consumption data available for these specific groups within the UK (5).

A summary of all assumptions made within the methods are presented in appendix 4.

3.2.2 Identification of suitable vehicles for vitamin D fortification

Before simulating vitamin D fortification it was necessary to identify suitable vehicles for fortification. To be a suitable fortification vehicle, a food should be consumed in sufficient quantity by a large proportion of the population at risk of deficiency. The systematic review concluded that consumption of a number of different fortified foods and drinks can be effective at improving vitamin D status. Vitamin D is a fat-soluble vitamin, requiring dietary fat for absorption, however it is not just foods with a high fat content that would be suitable vehicles for vitamin D fortification. Use of a cold-water soluble dry vitamin D powder in low fat foods and drinks has been shown to be effective at improving serum 25(OH)D concentration (128, 141). Vitamin D has also been demonstrated to be heat stable and endure processing in a range of foods including milk and yogurt (167), cheese (133) and bread (141).

An assessment was carried out in April 2011 of the foods most commonly consumed by 'at risk' groups, using published food consumption data from the first year of the NDNS Rolling Programme (168) and LIDNS (26). UK food purchase data were used for ethnic minority groups (169).

3.2.3 Identification of composite foods containing the chosen fortification vehicles

In order to assess the full effect of fortifying a food (fortification vehicle) with vitamin D (fortificant) it was necessary to estimate vitamin D intake from not only the food acting as a vehicle, but also from composite foods containing the vehicle as an ingredient. For example, bread typically contains about 60% flour (110), so if flour was used as a fortification vehicle for vitamin D, bread would also be fortified at a level about 60% of the level at which flour was fortified. It was therefore necessary to identify a typical level of the fortification vehicle present within composite foods. Literature sources and recipes of composite foods within the Nutrient Databank were assessed to obtain a suitable proportional content (i.e. a percentage) of each fortification vehicle in range of composite foods. These percentages were used to determine the vitamin D content of broad categories of composite foods for each fortification scenario.

3.2.4 Establishment of a range of suitable levels of fortification

In order to simulate fortification it was necessary to establish a range of fortification levels that would likely provide suitable vitamin D intakes. Published dietary vitamin D intakes (168) and RNIs (3) were therefore considered for each population group at risk of poor vitamin D status alongside data on the proportion of the fortified food within composite foods, determined above.

3.2.5 Simulation of fortification

To ease data manipulation key variables required for analysis were extracted from the Food Level Dietary Data SPSS dataset and the Individual Data dataset from the first two years of the NDNS Rolling Programme (2008 to 2010). The extracted variables included: individual serial number; day number; main food group name and number; subgroup name and number; food name and number; vitamin D consumed; weight of food consumed per day; sex; age; adult and child interview weighting factor and socio-economic group (National Statistics Socio-Economic Classification (NS-SEC) 8 group). Using the food level dataset the vitamin D content per 100g of each food code was estimated, based on the amount of each food code consumed per day and vitamin D consumed per day from each food. The vitamin D content of codes identified in section 3.1.6 was then updated to reflect current levels of vitamin D within fortified foods and supplements. The standard level of 'overage' identified in section 3.1.6 was applied to the vitamin D content of all vitamin D fortified food and supplement codes, to represent a realistic level of vitamin D consumed. An up-to-date vitamin D content per 100g foods was calculated.

The vitamin D levels in this updated NDNS dataset were then manipulated to simulate fortification. The vitamin D content per 100g of all foods containing the food chosen as a suitable vehicle of fortification in section 3.2.2, and composite foods containing this food identified in 3.2.3, were changed to reflect fortification at the levels identified in section 3.2.4.

3.3 Estimation of the impact of fortification on vitamin D intakes

In order to estimate the impact of fortification on vitamin D intakes it was necessary to establish a baseline of vitamin D intakes. However as the NDNS food composition data were up to 3 years old, it was necessary to establish vitamin D intakes both prior to and following the update of vitamin D fortified foods and supplements
(as described in section 3.1), thus correcting for the effect of using out-of-date composition data.

Vitamin D intakes were calculated for the following scenarios:

- **Pre-update:** Prior to the update of vitamin D fortified foods and supplements. These vitamin D intakes therefore correspond to the figures published in the 2008-10 NDNS report (84), but are presented in different population groups.
- **Post-update:** After the update of the vitamin D content of fortified foods and supplements and application of 'overage'.
- **Fortification:** For each vehicle and level of fortification.

3.3.1 Population intakes

The following was therefore determined in SPSS and Excel for each scenario of vitamin D intake:

- Vitamin D intake per individual per day.
- The frequency distributions of vitamin D intakes for adults and children
- Population mean, median and standard deviation of vitamin D intake

Population weighting factors provided in the NDNS dataset were applied so that the NDNS population was representative of the UK population.

3.3.2 The proportion of the population above and below maximum and minimum thresholds for vitamin D intakes.

- The proportion of population groups with vitamin D intakes below the RNI (3) (for whom an RNI is set) and the percentage of the whole population with intakes above the Tolerable Upper Levels (UL) as set by the European Scientific Committee on Food (66). It was not possible to use the UL set by the UK Expert Group on Vitamins and Minerals (EVM) as this was only set for supplemental vitamin D and excludes vitamin D consumed from fortified foods (64).

- Data were calculated by sex for six age categories (1.5 to 3 years; 4 to 8 years; 9 to 14 years; 15 to 49 years; 50 to 64 years 65 years and above).
- Data were then collated into seven policy relevant groups determined by age/sex-specific dietary intake thresholds, three of which were of key interest in relation to vitamin D (i.e. young children aged 1.5 to 3 years, women of childbearing age aged 15 to 49 years (representing pregnant and breast-feeding women) and older people aged 65 years and over). The remaining four groups were organised by age and sex (children aged 4 to 8 years, girls aged 9 to 14 years, males aged 9 to 49 years and adults aged 50 to 64 years).

3.3.3 Assessment of the impact of fortification by socio-economic group

An assessment of vitamin D intake by socio-economic group was also carried out. The eight group NS-SEC categorisation provided in the NDNS dataset was reorganised into a three group NS-SEC categorisation (Managerial and professional occupations; Intermediate occupations; Routine and manual occupations) (170) for ease of comparison between the groups. The following was carried out:

- The frequency distributions of vitamin D intakes were obtained for adults and children by NS-SEC group before and after fortification.
- The mean, median and standard deviation of vitamin D intake were estimated by NS-SEC group.
- A statistical comparison of whether fortification had an effect by socio-economic group. Due to its skewed nature it was necessary to normalise the data in order to carry out parametric statistical tests. This was done by taking the square root of vitamin D intake. The difference between the normalised vitamin D intakes before and after fortification was calculated. A one-way analysis of variance (ANOVA) was performed on the differences by NS-SEC group.
- The contribution of foods to vitamin D intake over the four day diary period was also estimated by NS-SEC group.

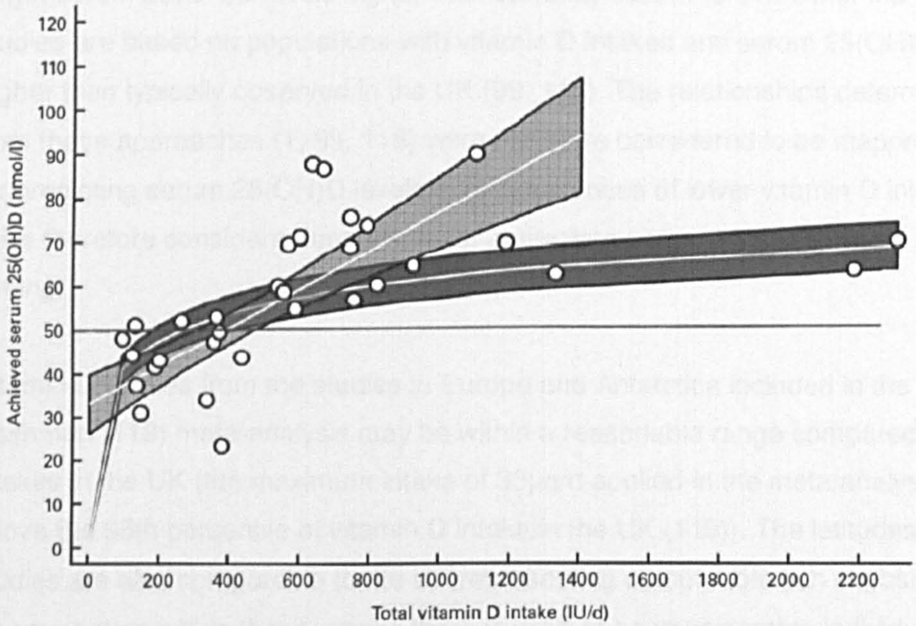
3.4 Identification of a published relationship between vitamin D intakes and status suitable to a UK setting for use in identifying the impact of fortification on vitamin D status

As discussed in chapter 1, serum 25(OH)D concentration is widely accepted as the best marker of vitamin D status. In order to estimate the theoretical impact of vitamin D fortification on serum 25(OH)D levels in the UK, it was necessary to identify a relationship between vitamin D intake and serum 25(OH)D levels published within the literature that was suitable to a UK setting.

3.4.1 Published relationships between vitamin D intake and serum 25(OH)D levels

Various attempts to establish a relationship between the distribution of vitamin D intakes and serum 25(OH)D concentrations are reviewed in chapter 1. There is a current debate as to whether the vitamin D intake/status relationship follows a linear or non-linear pattern. A non-linear relationship between transformed intake and status as proposed by IOM seems more biologically plausible than a linear relationship between intake and transformed status as proposed by Cashman *et. al.* (117, 118), because serum 25(OH)D levels are likely to plateau at high levels of vitamin D intake. In a systematic review and meta-regression analysis, Cashman *et. al.* (119) considered the two earlier Cashman studies (117, 118) in the context of other relevant published studies carried out at latitudes above 49.5ºN in Europe and a single study in 78ºS Antarctica. All included studies used vitamin D_3 supplements. They modelled the vitamin D intake/status relationship both in a linear and a non-linear model, see figure 9. As with the IOM approach illustrated in figure 4, Cashman's (119) non-linear model, illustrated in dark grey in figure 9, is forced to intercept with the y-axis at zero. This suggests that a daily intake of 0µg vitamin D results in a serum 25(OH)D concentration of 0nmol/l in conditions of minimal sun exposure i.e. in the winter. This is considered improbable due to the likely utilisation of vitamin D from stores within the body during the winter contributing to circulating serum 25(OH)D levels, even in the absence of dietary intake (121). In contrast, a linear relationship, as illustrated in light grey in figure 9, and as proposed by the Cashman studies (117, 118), illustrated in figures 5 and 6, is biologically implausible as it does not consider a likely reduction in the slope of the relationship at high vitamin D intakes (119).

Figure 9: Relationship between serum 25(OH)D concentration and total vitamin D intake in Northern latitudes in Europe and Antarctica during winter proposed by Cashman *et. al.* (2011). The mean responses and 95% confidence intervals are presented using a weighted linear meta-regression model following a natural logarithmic transformation of vitamin D intake (dark grey-curvilinear model) and no transformation (pale grey, linear model). Maximum vitamin D intake was capped at 35µg per day. Each data point represents a different study mean. Extracted from figure 2 of Cashman *et. al.* (119), reproduced with permission (121). It should be noted that 40 international units (IU) are equivalent to 1µg of vitamin D.



Based on a randomised placebo controlled double blind vitamin D supplementation trial over six months in the context of other literature, Aloia *et. al.* (171) suggested the gradient of the line is likely to fall at intakes of 35µg vitamin D per day. Cashman *et. al.* (119) therefore excluded vitamin D intakes above 35µg/d in their linear model on this basis (see figure 9). However, IOM proposed that the flattened response is likely to be seen at doses above 25µg vitamin D per day (1). It is likely therefore that in reality, the apex of the relationship between vitamin D intake and serum 25(OH)D concentration occurs somewhere between 25µg and 35µg of vitamin D intake per day (121). It is therefore likely that the true relationship between vitamin D intakes and serum 25(OH)D levels follows a linear pattern according to the pale grey line illustrated by Cashman *et. al.* (119) in figure 9, until an intake level of about 25µg where the gradient of the line begins to plateau.

3.4.2 Which model to use in this study?

Cashman *et. al.* (119) concluded that the model chosen to reflect the vitamin D intake/status relationship in a given setting needs careful consideration depending on the population in question and typical levels of observed vitamin D intake and serum 25(OH)D concentration. It may therefore be more appropriate to use models from individual randomised controlled trials (RCTs) relevant to the population in question rather than grouping together studies from varying geographical locations to identify a universal relationship.

The IOM (1) approach is based on intake thresholds in the US and Canada and target serum 25(OH)D levels higher than currently set in the UK. Other individual studies are based on populations with vitamin D intakes and serum 25(OH)D levels higher than typically observed in the UK (99, 116). The relationships determined from these approaches (1, 99, 116) were therefore considered to be inappropriate for predicting serum 25(OH)D levels in circumstances of lower vitamin D intake, and were therefore considered unsuitable for estimating serum 25(OH)D levels in a UK setting.

Vitamin D intakes from the studies in Europe and Antarctica included in the Cashman (119) meta-analysis may be within a reasonable range compared to intakes in the UK (the maximum intake of 35µg/d applied in the meta analysis is above the 95th percentile of vitamin D intake in the UK (119)). The latitudes of the studies are also comparable to the UK representing comparable sun exposure. However even within these ranges there is likely to be considerable individual variation in dietary vitamin D intake and sun exposure across these counties. An intake/status relationship generated from data across a mix of countries may not be as suitable for use in estimating serum 25(OH)D levels based on UK vitamin D intakes as using data from individual studies carried out in a setting representative of the UK.

The vitamin D intake/status relationships produced by the individual RCTs for adults aged 20 to 40 years (117) and adults aged 65 years and over (118) were therefore selected as the most suitable data available for use in translating dietary vitamin D intakes into serum 25(OH)D levels in a UK setting in this analysis, up to population mean intakes of 25µg vitamin D per day. It should be noted that estimates of serum 25(OH)D concentration data produced using these relationships are an estimate of winter serum 25(OH)D levels. On average, an increase in serum 25(OH)D levels of 25nmol/l (or a third) is observed in summer months compared to winter months (1).

3.4.3 Cashman equations

The equations for the relationship between vitamin D and serum 25(OH)D levels as identified by Cashman *et. al.* in young adults (117) and older adults (118) are presented in table 11, obtained on request from the author (121). Variance terms from the regression equation and standard deviations were used to determine equations for the mean and 95% confidence interval lines (as presented in figures 5 and 6), as well as the 2.5^{th} and 97.5^{th} percentiles of vitamin D intake at a given level of serum 25(OH)D concentration (121). The equations have been rearranged so as to determine the serum 25(OH)D concentration at a given level of vitamin D intake. Each transformed equation represents a straight line and the form of the equation depends on the approach used by Cashman *et. al.* (117, 118) to transform the data i.e. for adults aged 20 to 40 years Cashman *et. al.* (117) fitted a linear regression model of the log-transformed serum 25(OH)D as a linear function of dietary vitamin D intake, whereas for adults aged 65 years and above Cashman *et. al.* (118) fitted a linear regression model of the square root-transformed serum 25(OH)D as a linear function of dietary vitamin D intake. As Cashman *et. al. (118)* identified separate relationships for males and females aged 65 years and over, there are separate equations for determining serum 25(OH)D concentrations for men and women of this age.

3.4.4 Vitamin D intake/status relationship for children

There is currently no separate relationship identified specifically for children. IOM's approach (1) and Cashman's regression analysis (119) included studies in children, but IOM concluded there was no effect of age on the response of serum 25(OH)D to total vitamin D intake, concluding that individuals of all ages under minimal sun exposure with similar vitamin D intakes have similar serum 25(OH)D levels (1). The Cashman *et. al.* (117) equation (table 11) derived from the study carried out in adults aged 20 to 40 years was therefore assumed to be suitable for use for children and all adults aged under 65 years. The likely accuracy of this assumption is discussed in chapter 6.

Table 11: Relationships between total vitamin D intake (supplemental plus dietary) and serum 25(OH)D concentration identified by the RCTs carried out by Cashman *et. al.* (117, 118). Equations obtained from the author (121).

Adults aged 20 to 40 years:	
Mean	25(OH)D = Exponential (3.538545 + (0.0365897 * total vitamin D intake))
Lower 95%CI	25(OH)D = Exponential (3.443629 + (0.0293848 * total vitamin D intake))
Upper 95%CI	25(OH)D = Exponential (3.633461 + (0.0437945 * total vitamin D intake))
Lower 2.5^{th} percentile	25(OH)D = Exponential (3.538545 + (0.0365897 * total vitamin D intake) - 0.637009)
Upper 97.5^{th} percentile	25(OH)D = Exponential (3.538545 + (0.0365897 * total vitamin D intake) + 0.637009)
Men aged 65 years and above:	
Mean	25(OH)D = (6.603145 + (0.0926014 * total vitamin D intake))^2
Lower 95%CI	25(OH)D = (6.051161 + (0.0543739 * total vitamin D intake))^2
Upper 95%CI	25(OH)D = (7.15513 + (0.1308468 * total vitamin D intake))^2
Lower 2.5^{th} percentile	25(OH)D =(6.603145 + (0.0926104 * total vitamin D intake) - 2.23046)^2
Upper 97.5^{th} percentile	25(OH)D = ((6.603145 + (0.0926104 * total vitamin D intake) + 2.23046)^2
Women aged 65 years and above:	
Mean	25(OH)D = (5.813712 + (0.1594576 * total vitamin D intake))^2
Lower 95%CI	25(OH)D = (5.397616 + (0.1288859 * total vitamin D intake))^2
Upper 95%CI	25(OH)D = (6.229808 + (0.1900293 * total vitamin D intake))^2
Lower 2.5^{th} percentile	25(OH)D = (5.813712 + (0.1594576 * total vitamin D intake) - 2.23046)^2
Upper 97.5^{th} percentile	25(OH)D = (5.813712 + (0.1594576 * total vitamin D intake) + 2.23046)^2

3.4.5 Summary of approach

For this analysis the following approach was adopted:

- Winter serum 25(OH)D levels were estimated for a given level of population vitamin D intake using the Cashman *et. al.* equations outlined in table 11.
- In the absence of alternative relationships, the relationship for adults aged 20 to 40 years (117) was used for determining serum 25(OH)D levels in children and adults aged under 65 years.
- As these relationships assume a linear relationship between vitamin D intake and log/square root transformed serum 25(OH)D, which is unrealistic at high vitamin D intakes, they were not used for determining population serum 25(OH)D concentrations at vitamin D intake levels above 25µg per day (the level at which the intake/status relationship is likely to plateau).
- These relationships were not suitable for predicting individual serum 25(OH)D levels or the distribution of serum 25(OH)D across the population. It was

therefore not possible to estimate the proportion of the population failing to achieve or exceeding specific serum 25(OH)D concentration thresholds.

- The shift in the population mean, 2.5thand 97.5th percentile serum 25(OH)D levels were therefore determined using population mean vitamin D intakes.

The individual data points from figures 5 and 6 (117, 118) were not available to allow the variability to be studied in order to estimate the level of uncertainty associated within the vitamin D intake/status relationship curves.

3.5 Estimation of the impact of fortification on serum 25(OH)D levels

As with vitamin D intake, in order to estimate the impact of fortification on serum 25(OH)D levels it was necessary to establish a baseline of serum 25(OH)D levels for the UK population.

3.5.1. Population serum 25(OH)D levels estimated using NDNS blood data

The NDNS collects blood samples from a sub-group of participants, which are analysed for vitamin D status. Serum 25(OH)D levels of the population were therefore determined from NDNS data to represent pre-fortification baseline serum 25(OH)D levels. Using the NDNS Individual Data SPSS dataset serum 25(OH)D data were extracted for children aged 11 years up to adults aged up to 64 years, along with other variables including blood population weighting factors, age and sex for all individuals. Serum 25(OH)D data for all other age groups were not available at the time of analysis. Population weighting factors, provided in the NDNS dataset, were applied to the serum 25(OH)D data so that the NDNS population were representative of the UK population.

The following were therefore calculated:

- The frequency distributions of serum 25(OH)D levels for adults and children.
- The mean, standard deviation, median, 2.5th and 97.5th percentiles of serum 25(OH)D. These serum 25(OH)D values therefore corresponded to the figures published in the 2008-10 NDNS report (172), but were presented in different population groups.
- The percentage of groups with serum 25(OH)D levels below the lower thresholds of 25nmol/l (3) and 30nmol/l (1) and above the upper thresholds of 75nmol and 125nmol/l (1).
- Data were calculated by sex for four age groups (11 to 14 years, 15 to 18 years, 19 to 49 years and 50 to 64 years). Data were not available for young children and older adults.
- The data were then collated into four policy relevant groups: women of childbearing age (15 to 49 years), which were of particular relevance to vitamin D policy, and males aged 9 to 49 years, females aged 9 to 14 years and adults aged 50 to 64 years.

3.5.2 Serum 25(OH)D levels estimated using intake/status relationships.

Using baseline vitamin D intakes, baseline serum 25(OH)D levels were also estimated using the relationships identified in section 3.4.3 provided by Cashman *et. al.* (table 11). In order to assess the impact of fortification on serum 25(OH)D levels the intake/status relationships were therefore used for the following scenarios of vitamin D intake:

- **Pre-update:** Prior to the update of the vitamin D content of fortified foods and supplements in the NDNS dataset.
- **Post-update:** After the update of the vitamin D content of fortified foods and supplements and application of 'overage'.
- **Fortification:** For each vehicle and level of fortification.

The following was therefore determined in SPSS and Excel for each scenario of vitamin D intake:

- Population serum 25(OH)D levels were estimated using the 15 Cashman *et. al.* vitamin D intake/status equations (table 11)
- The equations for the population mean, 95% confidence intervals of the mean and 2.5th percentile and 97.5th percentile were applied to the population mean vitamin D intake values.
- Population serum 25(OH)D levels were calculated by sex and the previously defined six age categories and collated into the seven policy relevant groups.

The serum 25(OH)D data collected from blood samples in the NDNS estimated in section 3.5.1 were compared to the results using the Cashman *et. al.* equations (table 11) both pre- and post- the update of the vitamin D content of fortified foods and supplements in order to assess the reliability of the Cashman *et. al.* equations in estimating serum 25(OH)D levels based on vitamin D intake data and assess the potential impact fortification would have on actual serum 25(OH)D levels.

3.6. Determination of an optimum vehicle and level of fortification to improve vitamin D intakes and status, particularly for those at risk of deficiency, without increasing the risk of excess in the population.

3.6.1 A sensitivity analysis was carried out using a variety of international thresholds for vitamin D intake.

In order to determine which vehicle and level of fortification would be optimum in terms of reducing vitamin D deficiency and preventing population groups from exceeding maximum intakes, it was important to consider the varying international reference thresholds. The analyses described in section 3.3.2 used UK reference thresholds for vitamin D intake, which are illustrated in option 1 below and in table 12. Due to uncertainty within the literature regarding reference thresholds for vitamin D intake, a sensitivity analysis was carried out by employing the methods in section 3.3.2 for each fortification scenario using different thresholds for minimum and maximum vitamin D intakes. The different thresholds used, outlined in options 1 to 5 below and in table 12, represent all dietary reference thresholds for vitamin D currently set in the UK and the US/Canada for the population aged over 18 months, with an additional hypothetical threshold for the UK (Option 2). The different threshold options assessed were as follows:

- Option 1 used UK thresholds for vitamin D intake as described in section 3.3.2 (i.e. the RNI (3) and UL as set by the SCF (66)).
- Option 2 assumed an 'RNI equivalent' for all children and adults aged 4 to 50 years of 10μg vitamin D per day in addition to the RNIs set for the rest of the population.
- Option 3 used the Estimated Average Requirement (EAR) as the minimum intake threshold. The EAR is the amount considered to meet the needs of 50% of the population. As EARs have not been set for vitamin D in the UK (3), EAR values proposed by IOM (1) were used. These values are however the same as the UK RNI values, with the exception of young children.
- Option 4 used the Recommended Dietary Allowance (RDA), which is set for the whole population, and UL as proposed by IOM (1) for use in the US and Canada.
- Option 5 involved a simulation using a range of hypothetical thresholds from the UK up to the US/Canadian thresholds (assuming a uniform distribution between the lower and upper estimates) to give a sense of the uncertainty of the results. This was done by assigning all integers between the lowest and highest threshold relevant to each of the population groups as reference

thresholds and identifying the proportion of the population with vitamin D intakes below or above (for minimum and maximum reference thresholds respectively) each integer.

In order to test the association between international reference thresholds for minimum vitamin D intake and serum 25(OH)D concentrations, the Cashman *et. al.* equations, outlined in table 11, were applied to reference population vitamin D intakes.

All results were assessed in the context of the international thresholds, with specific relevance to a UK setting.

Table 12: Options included in the sensitivity analysis using different international reference thresholds for vitamin D intake. The policy relevant age ranges proposed were determined based on those defined for the age-specific thresholds.

Option 1-UK reference thresholds		
Sex/Age (years)	**Minimum intake threshold (RNI (3)) (µg/d)**	**Maximum intake threshold (UL (66)) (µg/d)**
1.5 to 3	7	25
4 to 8*	-	25
9 to 49 Males	-	50
9 to 14 Females	-	50
15 to 49 Females**	10	50
50 to 64	10	50
65+***	10	50
Option 2-UK reference thresholds and 'RNI equivalent'		
Sex/Age (years)	**Minimum intake threshold (RNI equivalent) (µg/d)**	**Maximum intake threshold (UL (66)) (µg/d)**
1.5 to 3	7	25
4 to 8*	10*	25
9 to 49 Males*	10*	50
9 to 14 Females*	10*	50
15 to 49 Females**	10	50
50 to 64	10	50
65+***	10	50
Option 3-Estimated Average Requirement (EAR)		
As for option 2 with the exception of children aged 1.5 to 3 years. Minimum intake threshold at 10µg/d for whole population (1).		
Option 4- US/Canadian reference thresholds		
Sex/Age (years)	**Minimum intake threshold (RDA (1)) (µg/d)**	**Maximum intake threshold (UL (1)) (µg/d)**
1.5 to 3	15	62.5
4 to 8	15	75
9 to 49 Males	15	100
9 to 14 Females	15	100
15 to 49 Females**	15	100
50 to 64	15	100
65+***	20	100
Option 5 - Simulation ranging from minimum to maximum thresholds		
Sex/Age (years)	**Hypothetical range of minimum intake thresholds** (µg/d)	**Hypothetical range of maximum intake thresholds** (µg/d)
1.5 to 3	7-15	25-62.5
4 to 8	10-15*	25-75
9 to 49 Males	10-15*	50-100
9 to 14 Females	10-15*	50-100
15 to 49 Females**	10-15	50-100
50 to 64	10-15	50-100
65+***	10-20	50-100

*In the UK there are no RNIs for vitamin D for these age groups, however for the RNI equivalent an RNI of 10µg/d was assigned for these groups.
** Women of childbearing age (15 to 49yrs) represent the diets of pregnant and breast-feeding women.
*** The IOM thresholds start at age 70 years and over for older people age group, however for the purposes of this analysis these thresholds shall be used for adults aged 65 years and over.

CHAPTER 4: RESULTS: Update of the vitamin D content of fortified foods and supplements and identification of suitable vehicles for fortification

This and the following chapter summarise the results of the methods described in chapter 3. This chapter describes the results of the data processing exercise to update the vitamin D content of fortified foods and supplements as outlined in section 3.1 and the process of identifying suitable fortification vehicles and levels of fortification as described in section 3.2.

4.1 Update of the vitamin D content of fortified foods and supplements

4.1.1 Obtaining up-to-date vitamin D values

- Assessment of the 2010 Nutrient Databank extract identified 289 fortified food and supplement codes.
- The internet and retail searches identified 117 vitamin D fortified products, or groups of products with the same level of vitamin D fortification, and 86 types of vitamin D containing supplements. See appendix 3 for the spreadsheets listing the vitamin D content of fortified foods and supplements identified, which were sent to each company.
- Following the initial email request and a reminder email, feedback was received from all of the 11 companies contacted, with the exception of one food manufacturer. One food trade association asked members to respond directly.
- The entire data updating exercise resulted in obtaining up-to-date vitamin D values for 257 (89%) of the 289 fortified food and supplement codes present within the Nutrient Databank.
- Up-to-date values were not available for 32 (11%) of the 289 codes, 16 vitamin D fortified food codes and 16 vitamin D containing supplements. These products may have been discontinued since being entered into the Nutrient Databank, or may have been purchased from outside of the UK. Existing vitamin D values within the Nutrient Databank were therefore used for these codes.
- The vitamin D content of 31 (11%) of the 289 fortified food and supplement codes required updating, 19 (7%) of which had reduced and the remaining 12 (4%) had increased compared to their previous vitamin D content. The mean of the change in vitamin D content was 3.5µg per 100g/ml ranging from 0.1µg to 10µg per 100g/ml. Examples of the revised food codes and vitamin D

values are provided in table 13. Appendix 5a provides a full list of updated codes and their previous and revised vitamin D content.

Table 13: Examples of vitamin D values, pre- and post- update and after an application of 'overage'.

	Vitamin D content (µg/100g or ml)		
NDNS Food code name	**Previous Nutrient Databank value (no 'overage')**	**Updated label value 2011**	**Including addition of 12.5% 'overage'**
Bertolli light fat spread	4.9	7.5	8.4
Slimfast drink dry weight	10.3	11.5	12.9
Horlicks low fat instant dry weight	3.1	3.2	3.6
Actimel probiotic drinking yogurt	0.1	0.8	0.8
Kellogg's Special K Sustain cereal	4.2	0.0	0.0
Kellogg's Cornflakes	0.0	4.2	4.7
Sainsbury's Fruit and Yogurt Balance bar	0.0	3.7	4.2
Petit Filous fromage frais	1.5	1.5	1.7
Kellogg's Branflakes	4.2	4.2	4.7

- A further eight food codes previously unfortified in the 2010 Nutrient Databank extract were identified as fortified with vitamin D. The mean fortification level was 3.3µg per 100g/ml ranging between 2.5µg to 8µg per 100g/ml (see appendix 5a).
- All 39 codes requiring an update were brand-specific, with the exception of baby rusks. For these codes the out-of-date vitamin D values were simply substituted for the up-to-date values. For the non-brand specific, generic baby rusk code, three brands were identified via the internet, two of which were not fortified with vitamin D. The other brand was fortified at 10µg vitamin D per 100g. Rather than take an average vitamin D value across all three brands, the fortified brand was given double the weighting of the two unfortified brands as it was the brand leader (173). The level of fortification for baby rusks was therefore assumed to be half the label value of the fortified brand (i.e. 5µg vitamin D per 100g). The Nutrient Databank has since been updated and now holds separate codes for vitamin D fortified and unfortified baby rusks.
- A number of vitamin D fortified products were identified that were not represented in the Nutrient Databank. These comprised of: one brand of vitamin D fortified bread; one retail own brand range including vitamin D fortified fruit juice, milk and yogurt; one branded range of vitamin D fortified processed cheese-based snacks and a number of retail own brand vitamin D fortified cereal bars. These products may have been introduced onto the

market since the survey fieldwork was carried out, or these products may have been available, but not consumed by any participants and therefore not captured within the Nutrient Databank. Alternatively these products may have been available and been consumed during the survey period, but the researchers may not have identified that they were fortified with vitamin D and these foods may have been coded as generic unfortified products. These vitamin D fortified foods were not considered within this analysis as it was not known in what quantity, frequency or by which individuals, these foods would have been consumed.

- Vitamin D fortified foods such as margarine and fat spreads are used in the recipes of composite foods such as cakes and biscuits, so these foods contribute to vitamin D intake. The Nutrient Databank is updated as and when new data become available from analytical projects, however the nutrient composition of ingredients used within these foods may have changed since they were last analysed. There are now very few brands of margarine on the UK market, as they are being replaced with fat spreads, which are not subject to mandatory vitamin D fortification (although most manufacturers choose to fortify fat spreads with vitamin D), so some foods previously containing margarine may now contain unfortified fat spreads. In summary, the proportion of vitamin D within some composite food products may have changed since they were included in the Nutrient Databank, but this was not considered within the analysis.

4.1.2 Responses to additional questions

Responses to the additional questions regarding vitamin D fortification practices were received for seven individual food companies. Three were received directly from the company itself and four were received through two of the food trade associations. This represented 35% of the total food companies contacted (seven out of a total of 20; 19 were contacted either directly or through a trade association plus one trade association provided a response for a fortified brand not previously identified). Two of the three supplement trade associations provided collated responses to the additional questions regarding vitamin D fortification, it is not known how many companies these answers represent. No responses to the additional questions were received from the food or supplement manufacturers represented by the remaining two trade associations. The answers to these questions are summarised in table 14, company names are not mentioned in order to preserve confidentiality.

The answers presented include:

- the reason for fortifying that food with vitamin D;
- the type of vitamin D used in fortification and reason;
- the reason for the level of fortification;
- level of 'overage';
- technical issues experienced with fortifying with vitamin D.

4.1.3 Application of 'overage'

Feedback received from manufacturers and trade associations indicated a range in 'overages' typically applied from 20% to 30% for fortified foods and from 20% to 40% for supplements. Table 14 summarises the responses received. Some fortified food manufacturers state they carry out rigorous testing to ensure the end label value is achieved; others use a standard guideline tolerance level of plus or minus 30% of the declared value. Based on the information provided in table 14 and following a consultation with an expert in micronutrient 'overages' (164), a typical standard 'overage' of 25% was assumed to be added to all fortified foods and supplements. This additional amount of vitamin D added by the manufacturer is likely to decrease by the time the product reaches the consumer due to processing losses and the effect of degradation over time. Based on advice (164), this reduction was assumed to be 50%. A standard 'overage' of 12.5% was therefore assumed to be present in all vitamin D fortified foods and vitamin D containing supplements at the time of consumption. This 'overage' was therefore applied to the vitamin D content of all 289 food and supplement codes known to contain added vitamin D in the Nutrient Databank (see appendices 5a and 5b for a list of the food codes and their previous and updated vitamin D values).

The nutrient analysis survey of breakfast cereals (162, 163), which was consulted during this process, was found to have generally analysed composite samples (i.e. a mixture of different brands of a specific cereal product, with each brand fortified at a different level, some of which were not fortified with vitamin D) rather than samples of individual brands of food. It was therefore not possible to make direct comparisons between the label and analytical vitamin D values. Out of the 40 samples analysed only one provided both an analytical and label value for a brand specific product. The analytical value was 32% greater than the label value, indicating an 'overage' of 32% at the time of analysis. However, it was not possible to make general conclusions regarding typical 'overage' levels to be applied to all fortified foods in this analysis, from this single product.

4.1.4 Comparison of vitamin D values in 2010 Nutrient Databank extract to the NDNS dataset (2008 to 2010) post-analysis

On checking the vitamin D values of fortified foods and supplements within the National Diet and Nutrition Survey (NDNS) dataset (2008 to 2010) against the vitamin D values of products within the 2010 Nutrient Databank extract post-analysis, all values matched with the exception of one supplement code (previous content of 5μg vitamin D per capsule updated content of 10μg per capsule). This code was only consumed by five out of the 2126 people in the survey and therefore not considering this update in the analysis would have had a minimal impact on the results.

Table 14: Responses from organisations regarding vitamin D fortification practices. Each line represents a different response.

D_2 or D_3?	Reason given	Level of fortification	'overage'	Reasons for fortification of certain foods	Technical issues of fortification
Foods					
D_3	Believed to be the most effective form of vitamin D	Aim for 25% RDA* per serving. Some < due to restrictions in other countries, others > as part of a calorie controlled diet	Test to ensure end product is compliant with label value.	**Breakfast cereals:** Acknowledge poor vitamin D status in the UK and aim to fortify where possible, particularly in products encouraged as part of a calorie controlled diet.	As a fat-soluble vitamin it requires use of a water-soluble form in fortification. Heat degradation is a concern.
D_3	Recommended and 'the more natural form'	>15% RNI	Test to ensure end product is compliant with label value.	**Infant cereals:** Key nutrient for infants, limited natural sources. Weaning directive states vitamin D fortification is only allowed in cereal based weaning foods.	Degradation during processing is a concern. Toxicity is a concern in excessive amounts.
D_3		15% RDA* per 10g serving of fat spread 30% of requirements per serving.		**Spreadable fats:** Legislation states fortification between 7.05 and 8.82μg/100g **Meal replacements:** Legislation states must provide at least 30% of recommended vitamin D in each serving.	
D_2	Suitable for Vegans	15% RDA* per 100ml	Guideline tolerance of +/- 30% declared value.	**Organic products not fortified:** It is illegal to fortify organic products.	
D_3		38% RDA*		**Bread:** One type of bread is fortified with D as it is high in calcium and it made sense to add vitamin D to aid calcium absorption.	
D_3		Sufficient to provide a source	Guideline tolerance of +/- 30% declared value.	**Milkshakes:** Vitamin D plays a role in calcium and phosphorus absorption and so makes a great partner for milk.	No major issues
D_3			20%	**Infant cereal:** Key nutrient for infants, cereal is an integral part of infants' diets.	Dry vitamin mix used-can create inhomogeneity.
Supplements					
D_3			Up to 30% (typically 20%)		
Mostly D_3			23 to 40%		

* European Recommended Daily Allowance (RDA) of 5μg per day vitamin D (2).

4.2 Identification of a suitable vehicle for fortification, estimation of the proportion of the fortification vehicle within composite foods & identification of levels of fortification to be simulated.

4.2.1 Identification of a suitable vehicle for fortification

The systematic review in chapter 2 identified a number of foods to be suitable vehicles for vitamin D fortification. Table 15 indicates the quantity of foods consumed (including those presented in the systematic review) by population sub-groups known to be at risk of vitamin D deficiency in the UK including young children, women of childbearing age (representing pregnant and breast-feeding women), older people and ethnic minorities. The quantity of food consumed is presented for consumers only (with the exception of the ethnic minority data) and the percentage of consumers is also reported as a range across the whole food category (i.e. white bread, brown bread etc.). Unfortunately, the percentage of consumers is not available by ethnicity.

For each population group the food categories consumed in the greatest quantity by consumers were milk (ranging from 195g to 560g per day), meat and meat products (ranging from 224g to 440g per day) and vegetables including potatoes (ranging from 135g to 469g per day). To be a good vehicle for fortification however, it is not just important that the food acting as the vehicle is consumed in a large quantity, it is essential that it should be consumed by a large proportion of individuals in the population group at risk from deficiency. The category of food with the highest proportion of consumers across all population groups was bread, with white bread consumed by 74% to 83% of all 'at risk' groups.

Bread consists of about 60% flour (SACN, 2006). As several nutrients are already added to flour in the UK (28), the practical implications of adding another nutrient would likely be relatively straightforward (this is discussed further in chapter 6). Although not consumed as widely as bread, milk would likely be a successful vehicle in reaching some groups of the population, particularly young children. As discussed, nationwide vitamin D fortification of milk has been implemented in other countries and therefore the UK could benefit from their experience in terms of the practicalities of milk fortification. Milk and flour were therefore both considered practical options for vehicles of vitamin D fortification in the UK.

Table 15: Daily consumption of foods (g/day) for population groups at risk of poor vitamin D status (the range of percentage consumers across the whole food category is presented in brackets).

	Young children	Women of childbearing age*		Older people			Ethnic minorities	
							Asian	Black
	All 1.5-3 yrs	Females 11-18 yrs	Females 19-64 yrs	Males 65+ yrs	Females 65+ yrs		All 19 yrs +	
Category of food consumed	NDNS 2008/09 (168)			LIDNS 2003-05 (26)		Category of food consumed	Family Food includes non-consumers (169)	
Amount of food consumed (g) (% consumers)								
Bread total	43 (25-74%)	147 (19-83%)	145 (18-77%)	202 (25-81%)	128 (32-82%)	Total cereals	239	201
Breakfast cereals	18 (43-64%)	45 (36-48%)	59 (25-46%)	108 (27-48%)	76 (32-52%)			
Other flour containing[1]	18 (44-73%)	48 (57-69%)	51 (46-67%)	92 (18-67%)	79 (14-72%)			
Other cereals[2]	50 (95%)	113 (83%)	94 (76%)	291 (3-23%)	177 (2-22%)			
Milk, total	270 (4-66%)	375 (4-64%)	302 (18-75%)	560 (6-55%)	522 (10-71%)	Milk/ cream	280	195
Other dairy[3]	59 (28-80%)	108 (24-68%)	109 (16-59%)	141 (16-50%)	129 (23-56%)	Cheese	7	6
Butter/ Spreads	5 (0-56%)	25 (2-63%)	30 (1-52%)	147 (1-33%)	84 (0-46%)	Fats/oils	40	25
Meat and products	224 (4-56%)	401 (15-66%)	440 (13-69%)	300 (4-78%)	389 (4-73%)	Meat and products	91	127
Fish and dishes	85 (10-39%)	109 (8-33%)	117 (31-35%)	183 (4-21%)	157 (6-26%)	Fish and dishes	18	26
Egg and dishes	26 (46%)	34 (38%)	36 (49%)	36 (56%)	26 (50%)	Eggs	12	13
Savoury snacks	9 (59%)	19 (72%)	13 (49%)	13 (21%)	12 (18%)	Savoury snacks[4]	-	-
Vegetables including potatoes	135 (42-87%)	229 (20-64%)	300 (65-91%)	469 (4-77%)	382 (5-77%)	Vegetables including potatoes	219	216
Fruit	115 (95%)	81 (71%)	111 (85%)	264 (18-41%)	231 (26-51%)	Fruit	163	198
Fruit juice	60 (47%)	128 (47%)	106 (39%)	128 (19%)	103 (25%)	Fruit juice[4]	-	-

* Women of childbearing age represented pregnant and breast-feeding women.
1. Includes other flour containing foods excluding pizza e.g. biscuits, buns, cakes, pastries and fruit pies
2. Includes pasta, rice and other miscellaneous cereals including pizza
3. Includes other types of milk, cream, cheese, yogurt, fromage frais and other dairy desserts and ice cream
4. The Family Food publication does not provide data on consumption of this food

In order to assess the impact of vitamin D fortification for a range of policy scenarios vitamin D fortification, as described in section 3.2.5, was simulated for both flour and milk in the following scenarios:

1. Wheat flour (including bread, and other sources of wheat flour)
2. Milk only (excluding cream and milk within cheese, yogurt or other dairy products).
3. Wheat flour and milk simultaneously

The natural level of vitamin D is 0μg per 100g wheat flour and less than 0.01μg per 100g milk (15).

Other dairy products were not included within the scenario of milk fortification as the approach to national fortification adopted in other countries had been to fortify liquid milk only (1, 48, 49). It was also considered the most likely policy option from a practical perspective in the UK as raw milk is divided into its different fates prior to pasteurisation. Fortification would likely need to occur at each of the different processing stages for each product to be fortified e.g. milk, yogurt, cheese, cream, which would increase costs to industry (174). This is in comparison to wheat flour, where flour fortification occurs in the mill so composite products would also contain the fortificant.

4.3 Estimation of the proportion of the fortification vehicle within composite foods

Table 16 illustrates the assumed proportion of flour within composite food codes within the Nutrient Databank. These proportions were used by SACN during the simulation of folic acid fortification of flour (110) and therefore were considered appropriate for use in this analysis. Using these food groups excluded some savoury flour containing products (pies, flans, quiches, breaded products) however the contribution of these products to total flour consumption was considered to be low (110).

Table 16: Flour content of food groups (110).

NDNS Food Group	Estimated % Flour
White bread	63
Wholemeal & brown bread	60
Other breads	55
Pizzas	25
Other cereals, dumplings, Yorkshire puddings etc.	25
Biscuits	50
Fruit pies	30
Buns, cakes & pastries	45
Sponge type puddings	30
Other cereal based puddings (crumbles, bread pudding, pancakes, cheesecake trifle etc.	10

Table 17 illustrates the assumed proportion of milk within composite food codes in the Nutrient Databank. Other foods containing milk consumed within the NDNS survey will not be captured here, however these were likely to contribute a minimal amount to total milk consumption and were therefore excluded from the analysis.

Table 17: Milk content of food groups assumed based on the milk content of milk-containing foods within the NDNS Nutrient Databank.

NDNS Food Group	Estimated % milk
Whole, semi-skimmed, skimmed milk	100
Milk based drinks (hot chocolate, milk shake etc.)	90
Cereal based milk puddings (rice puddings, blancmange, semolina etc.)[12]	62
Dairy desserts (crème caramel, egg custard etc.)[12]	60
Cream, yogurt, cheese*	0

*Assumed to contain no milk for the purposes of this analysis

4.4 Identification of the levels of fortification to be simulated

Pregnant and breast-feeding women and older people are recommended to consume 10µg and young children are recommended to consume 7µg of vitamin D per day (3). NDNS data (2008/09) suggest mean daily vitamin D intakes across these groups range from 2µg in young children to 4.1µg in older men (168). As a crude approximation, it was therefore assumed a daily average of 6µg of vitamin D is required by these groups in addition to their current vitamin D intake in order to meet these recommendations.

4.4.1 Level of vitamin D required per 100g flour for fortification

Daily consumption of bread ranges from 43g in young children to 202g in older men (table 15). As a crude approximation, it was assumed a daily average of 100g of bread is consumed by these 'at risk' groups. Bread was assumed to be 60% flour (table 16). As a suitable fortification vehicle, flour would need to deliver 6µg of vitamin D in 60g of flour, which equates to 10µg per 100g flour. Assuming a 12.5% 'overage' fortification at 8.9µg per 100g flour should result in consumption of 10µg vitamin D per 100g flour (this estimation did not consider vitamin D consumed from other flour containing foods.).

A range of levels were therefore chosen to simulate the impact of fortifying flour with vitamin D from an extreme low level to an extreme high level with the aim of identifying a level at which reference nutrient intakes would be achieved, minimising the risk of excess consumption. Levels were simulated at 5µg, 10µg, 20µg, 30µg vitamin D per 100g flour, (assuming a 12.5% 'overage' at the time of consumption, this was equivalent to manufacturers fortifying at levels of 4.4µg, 8.9µg, 17.8µg, 26.7µg per 100g flour.)

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[12] Many desserts included in these subgroups do not contain milk, but rather contain dairy products such as cream or fromage frais etc. which were not subject to fortification in this analysis. Individual milk containing codes were therefore identified within the NDNS nutrient databank and fortification was applied only to these milk containing codes, rather than applying fortification to the whole food group.

Upon further analysis of the results, it was considered appropriate to simulate a further fortification scenario of flour fortified at 15µg vitamin D per 100g flour to achieve results between those found at 10µg and 20µg per 100g flour. (Assuming a 12.5% 'overage' at the time of consumption, this was equivalent to manufacturers fortifying at levels of 13µg vitamin D per 100g flour.)

Appendix 6a lists all the food codes affected by fortification of flour and the levels of vitamin D added at each level of fortification.

4.4.2 Level of vitamin D required per 100ml milk for milk fortification

Daily consumption of milk ranges from 270ml in young children to 560ml in older men (table 15). As a crude approximation, it was assumed an average of 300ml milk is consumed per day by 'at risk' groups. Assuming fortification of milk only, excluding other dairy products, and assuming milk is consumed largely as milk, rather than as part of another food, as a suitable fortification vehicle milk would need to contain 6µg of vitamin D per 300ml in addition to usual intakes in order to meet the Reference Nutrient Intake (RNI). Fortification of 2µg per 100ml of milk would therefore be likely to reach the RNI. Assuming a 12.5% 'overage', 1.78µg/100ml milk would be required to deliver 2µg/100ml (this is at the higher end of levels currently added to milk in other countries (see table 2)). The levels chosen to simulate the fortification of milk (including any 'overage') were 0.5µg, 2µg, 5µg and 7µg per 100ml milk (assuming a 12.5% 'overage' at the time of consumption, this was equivalent to manufacturers fortifying at levels of 0.44µg, 1.78µg, 4.4µg, 6.2µg per 100ml milk).

On assessment of the results, a further fortification scenario was simulated for milk fortified at 1µg vitamin D per 100ml milk with the aim of achieving results between those found at 0.5µg and 2µg per 100ml milk. (Assuming a 12.5% 'overage' at the time of consumption, this was equivalent to manufacturers fortifying at levels of 0.9µg vitamin D per 100ml milk.)

Appendix 6b lists all the food codes affected by fortification of milk and the levels of vitamin D added at each level of fortification.

4.4.3 Level of vitamin D required per 100g flour and 100ml milk for simultaneous fortification of flour and milk

For the scenario of simultaneous fortification of milk and flour, the levels of fortification chosen were half of the levels chosen for the separate assessments of flour and milk fortification, outlined in table 18 below:

Table 18 Levels of vitamin D within flour and milk for the scenario of milk and flour fortification, including and excluding a 12.5% 'overage'.

Level of vitamin D per 100g flour (μg)	Level of vitamin D per 100ml milk (μg)	Level of vitamin D per 100g flour (μg)	Level of vitamin D per 100ml milk (μg)
Including 'overage'		Manufacturer level of fortification excluding a 12.5% 'overage'	
2.5	0.25	2.2	0.22
5	1	4.4	0.9
10	2.5	8.9	2.2
15	3.5	13	3.1

Appendix 6c lists all the food codes affected by fortification of milk and flour and the levels of vitamin D added at each level of fortification.

CHAPTER 5: RESULTS- Vitamin D intakes and status pre- and post-fortification

This chapter presents the results of the estimation of the impact of fortification on vitamin D intakes and serum 25(OH)D levels and determination of an optimum vehicle for fortification, as described in sections 3.3, 3.5 and 3.6.

5.1 Vitamin D intakes: pre-update –Table 19

As discussed in section 3.1.1 current composition data for fortified foods within the Nutrient Databank are based on label data and do not consider an 'overage' applied by manufacturers. Using current composition data i.e. prior to the update of the vitamin D content of fortified foods and supplements and application of an 'overage' (i.e. pre-update), population mean vitamin D intakes were 3.5µg a day (ranging from 2.3µg to 4.7µg across population groups). Of those for whom a Reference Nutrient Intake (RNI) is set, 93% had intakes below the RNI (ranging from 89% to 98%), this equates to nearly 36 million people in the UK (175). No individuals had vitamin D intakes above the Tolerable Upper Intake Level (UL) for vitamin D. Details of the RNI and the European UL referred to in this section can be found in tables 1 and 3 respectively.

Table 19: Vitamin D intakes for UK population sub-groups pre-update

NDNS data (2008-10)				
Years/sex	Vitamin D intakes (µg/day) Mean (s.d)	Median	Proportion (%) with intakes <RNI	Proportion (%) with intakes >UL
1.5 to 3 All	2.3 (2.4)	1.5	94%	0%
4 to 8 All	2.5 (2.0)	2.0	-	0%
9 to 49 Males	2.9 (2.2)	2.3	-	0%
9 to 14 Females	2.4 (1.9)	1.9	-	0%
15 to 49 Females	2.8 (2.4)	2.2	98%	0%
50 to 64 All	4.7 (3.6)	3.6	92%	0%
65+ All	4.7 (3.9)	3.4	89%	0%
Population	3.5 (2.8)	2.7	-	0%
Groups with RNI* only	-	-	93%*	-

*The RNI is only applicable to children between 1.5-3 years, women of childbearing (women aged 15-49 years) and adults over 50 years.

The bases of the analysis and population estimates are presented in appendix 7. Distributions of population vitamin D intake at all fortification scenarios are presented in appendix 8.

5.2 Serum 25(OH)D levels: pre-update –Table 20, Figure 10

Calculations from National Diet and Nutrition Survey (NDNS) blood data collected all year around for individuals aged 11 to 64 years indicated that 14% to 26% of population groups had serum 25(OH)D levels below the UK minimum threshold of 25nmol/l and were therefore considered to have poor vitamin D status. Population mean serum 25(OH)D levels ranged from 41nmol/l to 48nmol/l across these groups. The 2.5th percentile levels ranged from 9nmol/l to 12nmol/l and the 97.5th percentile levels ranged from 76nmol/l to 115nmol/l. Figure 10 illustrates the distribution of serum 25(OH)D for children and adults using NDNS blood data.

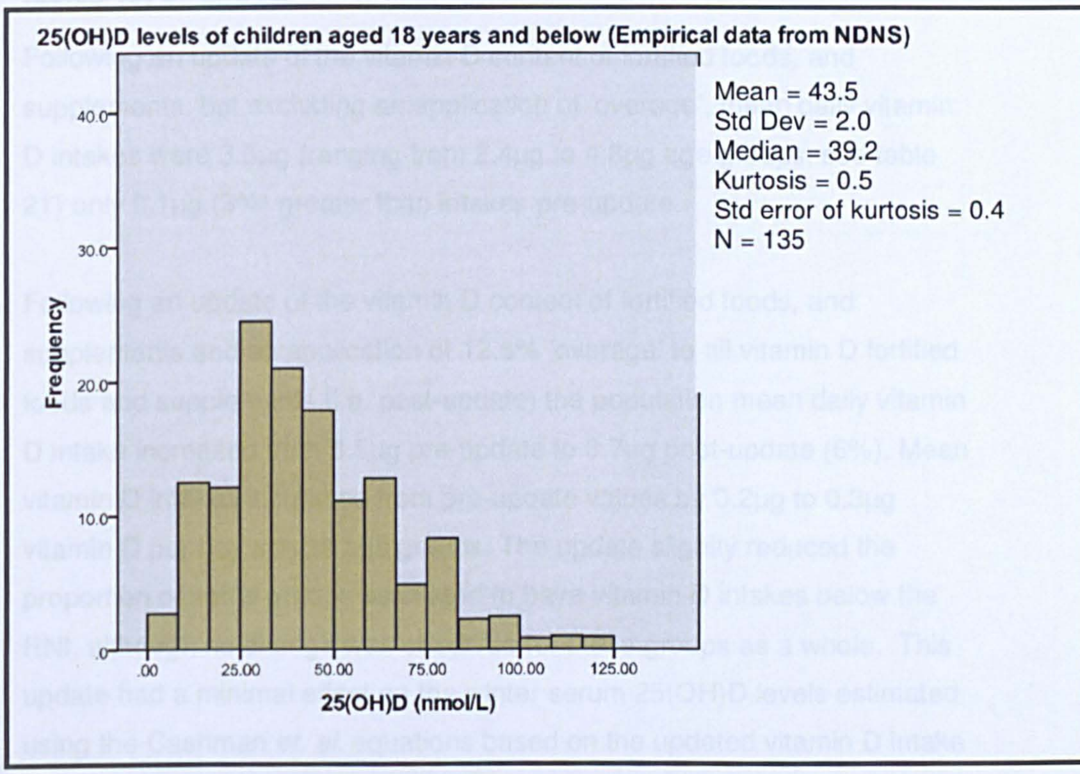
Mean winter serum 25(OH)D levels estimated by applying the Cashman *et. al.* equation for adults aged 20 to 40 years to population mean vitamin D intakes (pre-update), ranged from 38nmol/l to 41nmol/l across age groups for adults. The 2.5th percentile levels ranged from 20nmol/l to 21nmol/l and the 97.5th percentile levels ranged from 71nmol/l to 81nmol/l. Using the equation for adults aged 20 to 40 years therefore seemed to overestimate serum 25(OH)D levels at the 2.5th percentile (by 8nmol/l to 11nmol/l across population groups) and underestimate the 97.5 percentile (by 5nmol/l to 38nmol/l across population groups). Estimations of the impact of fortification on serum 25(OH)D levels using the Cashman *et. al.* equations in this analysis are likely to underestimate the proportion of individuals likely to be at risk of failing to reach minimum and exceeding maximum serum 25(OH)D thresholds at a given level of fortification. Potential reasons for the different serum 25(OH)D levels observed at the low and high end of the distribution using the Cashman *et. al.* equations are discussed in section 6.3.7.1.

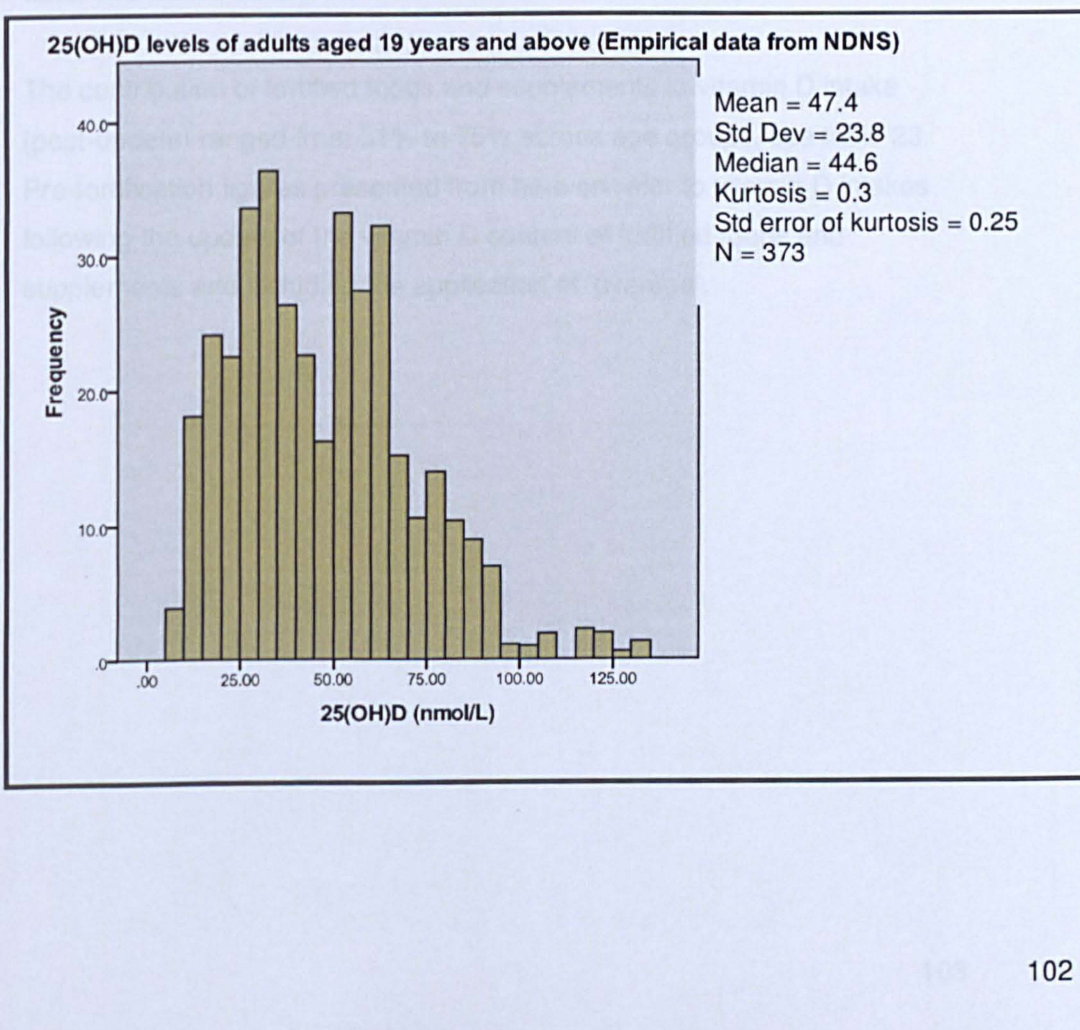
Serum 25(OH)D values determined from NDNS blood data are only presented to the nearest whole number due to the variability of assays for serum 25(OH)D. Data estimated using the Cashman *et. al.* equations (table 11) are also only presented to the nearest whole number due to the uncertainty of the relationship.

Table 20: Serum 25(OH)D levels for UK population sub-groups: NDNS blood data (only available for ages 11 to 64 years) (2008-2010) and using the Cashman *et. al.* equations applied to vitamin D intakes pre-update. Values in square brackets represent cell sizes below 50.

	Blood data from NDNS (2008-10)					Winter serum 25(OH)D concentration estimated using the Cashman *et. al.* equations (nmol/l) for intakes pre-update		
	25(OH)D status* (nmol/l)				Proportion (%) with 25(OH)D below <25nmol/l			
Years/sex	Mean (s.d.)	Median	2.5th%ile	97.5th%ile		Mean (95% CIs)	2.5th %ile	97.5th %ile
1.5 to 3 All	-	-	-	-	-	37 (34, 42)	20	71
4 to 8 All	-	-	-	-	-	38 (34, 42)	20	71
9 to 49 Males	45 (22)	42	12	91	19%	38 (34, 43)	20	72
9 to 14 Females	[41] (20)	[37]	14	76	[26%]	38 (34, 42)	20	71
15 to 49 Females	48 (26)	46	11	112	21%	38 (34, 43)	20	72
50 to 64 All	48 (24)	45	9	115	14%	41 (36, 47)	22	77
65+ All	-	-	-	-	-	46 (38, 55)	21	81

Figure 10: Population distribution of serum 25(OH)D levels in children and adults from NDNS blood data (2008-10)





5.3 Vitamin D intakes and winter serum 25(OH)D levels post-update-tables 19, 21 and 22

Following an update of the vitamin D content of fortified foods, and supplements, but excluding an application of 'overage', mean daily vitamin D intakes were 3.6μg (ranging from 2.4μg to 4.8μg age groups, see table 21) only 0.1μg (3%) greater than intakes pre-update.

Following an update of the vitamin D content of fortified foods, and supplements and an application of 12.5% 'overage' to all vitamin D fortified foods and supplements (i.e. post-update) the population mean daily vitamin D intake increased from 3.5μg pre-update to 3.7μg post-update (6%). Mean vitamin D intakes increased from pre-update values by 0.2μg to 0.3μg vitamin D per day across age groups. The update slightly reduced the proportion of some groups estimated to have vitamin D intakes below the RNI, although no change was observed for these groups as a whole. This update had a minimal effect on the winter serum 25(OH)D levels estimated using the Cashman *et. al.* equations based on the updated vitamin D intake data, see tables 19 and 22.

The contribution of fortified foods and supplements to vitamin D intake (post-update) ranged from 51% to 75% across age groups, see table 23. Pre-fortification figures presented from here on refer to vitamin D intakes following the update of the vitamin D content of fortified foods and supplements and including the application of 'overage'.

Table 21: Vitamin D intakes updated for fortified foods and supplements excluding application of 'overage'

Years/sex	Vitamin D intakes from fortified foods excluding application of 12.5% 'overage' (µg/day)	
	Mean (s.d.)	Median
1.5 to 3 All	2.4 (2.4)	1.6
4 to 8 All	2.6 (2.0)	2.1
9 to 49 Males	3.0 (2.3)	2.4
9 to 14 Females	2.5 (2.0)	1.9
15 to 49 Females	2.9 (2.6)	2.2
50 to 64 All	4.8 (3.6)	3.8
65+ All	4.8 (3.8)	3.6
Population	3.6 (2.9)	2.7

Table 22: Vitamin D intakes and predicted winter serum 25(OH)D levels for UK population sub-groups updated for fortified foods and supplements including the an application of 12.5% 'overage'.

Post-update, no fortification- intakes updated for fortified foods and supplements and 12.5% 'overage' applied							
	Vitamin D intakes (µg/day)		Proportion (%) with intakes below and above key thresholds		Winter serum 25(OH)D concentrations estimated using the Cashman *et. al.* equations (nmol/l) for intakes post-update		
Years/sex	Mean (s.d.)	Median	<RNI*	>UL	Mean (95% CIs)	2.5^{th} %ile	97.5^{th} %ile
1.5 to 3 All	2.5 (2.6)	1.7	93%	0 (0%)	38 (34,42)	20	71
4 to 8 All	2.7 (1.9)	2.1	-	0 (0%)	38 (34,43)	20	72
9 to 49 Males	3.1 (2.4)	2.5	-	0 (0%)	39 (34,43)	20	73
9 to 14 Females	2.6 (2.2)	2.0	-	0 (0%)	38 (34,42)	20	72
15 to 49 Females	3.0 (2.6)	2.2	97%	0 (0%)	39 (34,43)	20	73
50 to 64 All	5.0 (3.8)	3.9	90%	0 (0%)	41 (36,47)	22	78
65+ All	5.0 (4.1)	3.7	89%	0 (0%)	46 (38,56)	21	82
Population	3.7 (3.0)	2.8	-	0 (0%)	39 (35,45)	20	74
Groups with RNI* only	-	-	93%*	-	-	-	-

*The RNI only applies to children aged 1.5 to 3 yrs, pregnant and breast-feeding women (represented by females aged 15 to 49 yrs) and adults over 50 yrs.

Table 23: The contribution of fortified foods and supplements to vitamin D intake.

Years/sex	Vitamin D intake from fortified foods and supplements (including 'overage') (µg/day)		Proportion (%) of total vitamin D intake from fortified foods and supplements (including 'overage')*
	Mean (s.d.)	Median	
1.5 to 3 All	1.9 (2.3)	1.2	75%
4 to 8 All	1.7 (1.6)	1.3	64%
9 to 49 Males	1.6 (1.6)	1.5	52%
9 to 14 Females	1.6 (1.8)	1.3	62%
15 to 49 Females	1.7 (2.0)	1.4	57%
50 to 64 All	2.5 (2.5)	1.8	51%
65+ All	2.6 (2.8)	1.9	52%

*It should be noted that the contribution of composite foods containing vitamin D fortified ingredients is not included in the estimation of vitamin D from fortified foods and supplements

5.4 Impact of fortification

Appendix 8, tables 8a to 8g, presents the detailed results of the impact of fortification on vitamin D intakes and serum 25(OH)D levels, for each population sub-group and for the overall population.

5.4.1 Fortification of flour – Appendix 8, table 8d

Increasing levels of flour fortification progressively reduced the proportion of the population with intakes below the RNI. The proportion below the RNI ranged from between 67% and 90% across population groups at a fortification level of 5µg/100g flour, and was reduced to between 3% and 11% across population groups at 30µg/100g flour. Fortification at and above 15µg/100g flour increased vitamin D intakes of some groups above the UL.

The estimated mean winter serum 25(OH)D levels progressively increased with increasing levels of fortification. Levels at the 2.5th percentile increased above the minimum threshold of 25nmol/l in all age groups for fortification at and above 15µg/100g flour. With each 5µg/100g flour increment in fortification the population mean winter serum 25(OH)D level increased by a range of 6nmol/l to 7nmol/l across the population groups.

5.4.2 Fortification of milk - Appendix 8, table 8e

Increasing levels of milk fortification progressively reduced the proportion of the population with intakes below the RNI. The proportion below the RNI ranged from between 84% and 96% across population groups at a fortification level of

0.5µg/100ml milk, and was reduced to between 7% and 49% across population groups at 7µg/100ml milk. Fortification at and above 2µg/100ml milk increased some population groups over the UL.

The estimated mean winter serum 25(OH)D levels progressively increased with increasing levels of fortification. Levels at the 2.5th percentile increased above 25nmol/l in all groups for fortification at and above 5µg/100gml milk. With each 1µg/100ml milk increment in fortification population mean winter serum 25(OH)D level increased by a range of 2nmol/l to 4.5nmol/l across the groups.

5.4.3 Fortification of flour and milk - Appendix 8, table 8f

Increasing levels of simultaneous milk and flour fortification progressively reduced the proportion of population with intakes below the RNI. The proportion below the RNI ranged from between 76% to 94% across population groups at the lowest level of fortification, and was reduced to 2% to 12% at the highest level. Fortification at 10µg/100g flour and 2.5µg/100ml milk and above increased vitamin D intakes of some groups over the UL.

The estimated mean winter serum 25(OH)D levels progressively increased with increasing levels of fortification. Levels at the 2.5th percentile increased to above 25nmol/l in all groups at fortification levels at and above 10µg/100g flour and 2.5µg/100ml milk.

5.5 Summary-'Optimum' level and vehicle of fortification –Appendix 8

The 'optimum' level of fortification would be the level at which the lowest proportion of 'at risk' groups had intakes below the RNI without anyone exceeding the UL. Scenarios of flour and milk fortification, including simultaneous fortification, increased mean intakes and reduced the proportion with intakes below the RNI with increasing levels of fortification. However, the proportion of the population exceeding the UL also increased for many scenarios. At a population level, flour fortification at 10µg/100g flour was the most effective at reducing the proportion of the population with intakes below the RNI (from 93% to 50%) without increasing intakes of any groups above the UL. Fortification of flour at a lower level resulted in a higher proportion of the population with intakes below the RNI. Fortification at higher levels increased the risk of individuals exceeding the UL. Fortification of milk at 1µg/100ml milk or fortification of milk and flour simultaneously at 5µg/100g flour & 0.5µg/100g milk did not cause intakes to exceed the UL, but reduced the proportion of the population with intakes below the RNI to a lesser extent than observed at 10µg vitamin D per 100g flour. Fortification at higher levels of flour, milk and simultaneous fortification increased the risk of individuals exceeding the UL, especially in young children.

5.5.1 Fortification of flour with 10µg vitamin D per 100g flour - Table 24, Figure 11 and Appendix 8, tables 8d, 8g and figure 8a

Fortification of flour with 10µg vitamin D per 100g flour increased mean daily vitamin D intakes from levels of 3.7µg to 10.8µg, reducing the proportion of the population with intakes below the RNI from 93% to 50% without any individuals exceeding the UL. The estimated population mean winter serum 25(OH)D levels increased from pre-fortification estimates of 39nmol/l up to 51nmol/l post-fortification. The 2.5th percentile of winter serum 25(OH)D levels increased from a population pre-fortification level of 20nmol/l up to 27nmol/l post fortification, and all population groups except young children exceeded the UK minimum threshold for serum 25(OH)D of 25nmol/l. The 97.5th percentile of winter serum 25(OH)D levels increased from a population pre-fortification level of 74nmol/l up to 95nmol/l post fortification.

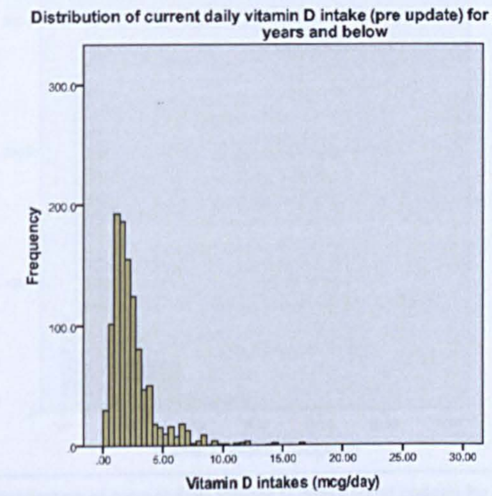
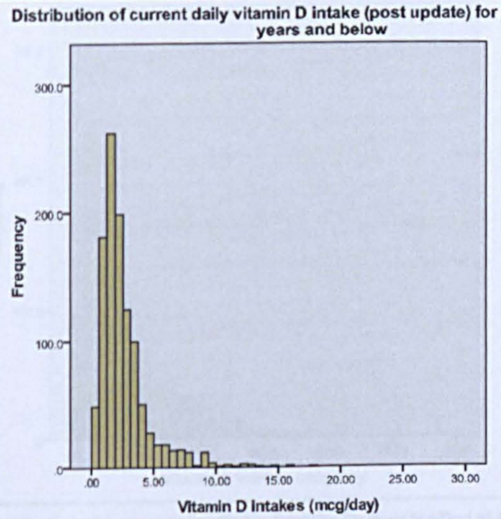
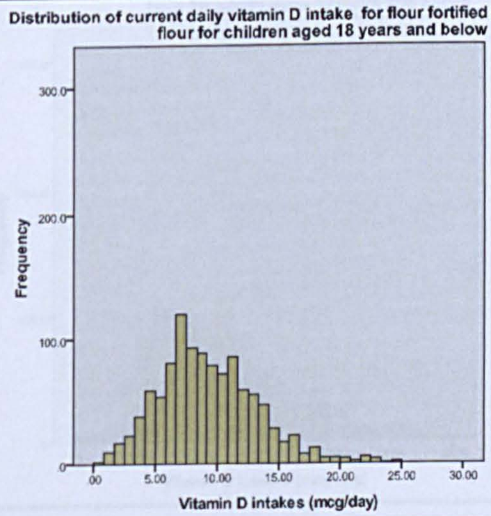
Figure 11 illustrates the shift in the distribution of vitamin D intake for children and adults at the intake pre-update for fortified foods and supplements, post-update and fortification at 10µg vitamin D per 100g flour. Distributions of population vitamin D intake at all other fortification scenarios are presented in appendix 8, figure 8a.

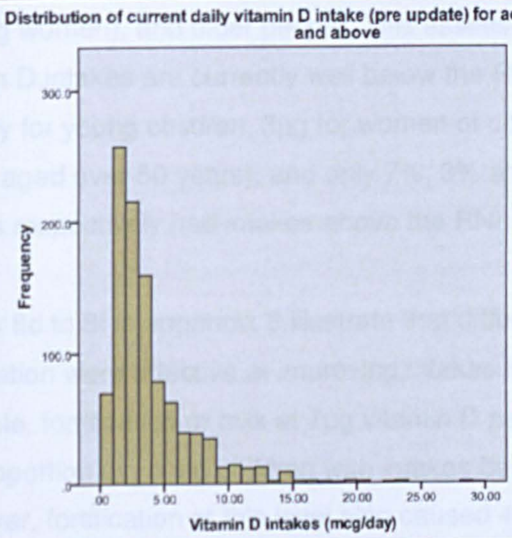
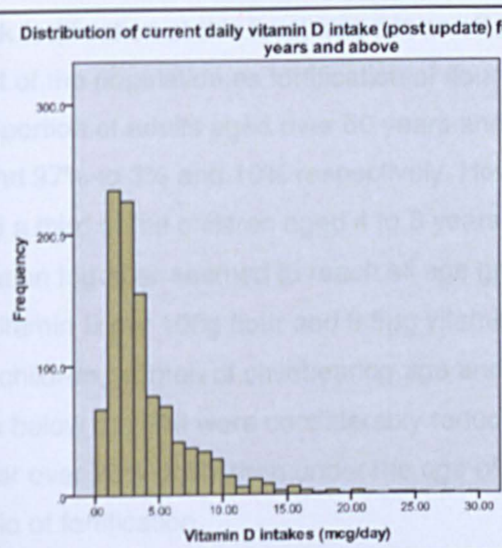
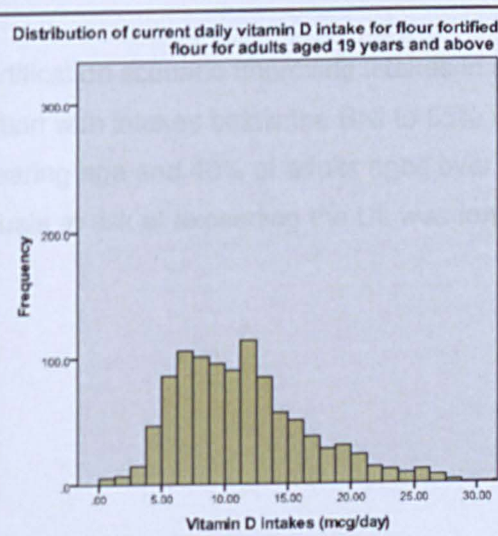
Table 24: Vitamin D intakes and serum 25(OH)D levels for UK population sub-groups assuming fortification of flour at 10μg vitamin D per 100g flour.

Fortification of flour at 10μg vitamin D per 100g flour							
Years/sex	**Vitamin D intakes (μg/day)**		**Proportion (%) with intakes below and above key thresholds**		**Serum 25(OH)D levels estimated using the Cashman *et. al.* equations (nmol/l)**		
	Mean (s.d.)	**Median**	**<RNI***	**>UL**	**Mean (95% CIs)**	**2.5th %ile**	**97.5th %ile**
1.5 to 3 All	6.3 (3.3)	5.6	65%	0%	43 (38,50)	23	82
4 to 8 All	9.1(3.3)	8.7	-	0%	48 (41,56)	25	91
9 to 49 Males	11.5 (4.8)	11.3	-	0%	52 (44,63)	28	99
9 to 14 Females	9.7 (3.9)	9.3	-	0%	49 (42,58)	26	93
15 to 49 Females	9.4 (4.3)	8.8	62%	0%	49 (41,57)	26	92
50 to 64 All	12.0 (5.5)	10.7	43%	0%	53 (45,64)	28	101
65+ All	12.2 (5.3)	10.9	40%	0%	59 (46,74)	30	99
Population	10.8 (4.7)	10.1	-	0%	51 (43,71)	27	95
Groups with RNI only*	-	-	50%*	-	-	-	-

*The RNI is only applicable to children between 1.5 to 3 years, pregnant and breast-feeding women (represented by females aged 15 to 49 yrs) and adults over 50 years.

Figure 11: Comparison of population distributions for adults and children for vitamin D intake: pre-update of fortified foods and supplements; post-update; and fortification of flour at 10µg per 100g flour. Distributions of population vitamin D intake at all other fortification scenarios are presented in appendix 8, figure 8a.

	Children
Vitamin D intake pre-update	 Mean = 2.4 Std Dev = 1.9 Median = 1.9 Kurtosis = 10.0 Std error of kurtosis = 0.15 N = 1095
Vitamin D intake post-update	 Mean = 2.6 Std Dev = 2.0 Median = 2.0 Kurtosis = 8.6 Std error of kurtosis = 0.15 N = 1095
Intake at 10µg vitamin D per 100g flour	 Mean = 9.3 Std Dev = 4.0 Median = 8.9 Kurtosis = 0.6 Std error of kurtosis = 0.15 N = 1095

	Adults
Vitamin D intake pre-update	 Mean = 3.9 Std Dev = 3.4 Median = 2.8 Kurtosis = 8.6 Std error of kurtosis = 0.15 N = 1031
Vitamin D intake post-update	 Mean = 4.1 Std Dev = 3.6 Median = 2.9 Kurtosis = 7.6 Std error of kurtosis = 0.15 N = 1031
Intake at 10µg vitamin D per 100g flour	 Mean = 11.5 Std Dev = 5.4 Median = 16.8 Kurtosis = 1.3 Std error of kurtosis = 0.15 N = 1031

5.6 'At risk' groups –Table 22 and Appendix 8

In this analysis, groups considered to be particularly at risk of poor vitamin D status were young children, women of childbearing age (representing pregnant and breast-feeding women), and older people. This assessment illustrates that mean updated vitamin D intakes are currently well below the RNIs set for each age group (2.5μg per day for young children, 3μg for women of childbearing age, and 5μg per day for adults aged over 50 years), and only 7%, 3% and 11% of individuals within these groups respectively had intakes above the RNI.

Tables 8d to 8f in appendix 8 illustrate that different vehicles and levels of fortification were effective at improving intakes in different population groups. For example, fortification of milk at 7μg vitamin D per 100ml resulted in a reduction in the proportion of young children with intakes below the RNI from 93% to 7%. However, fortification at this level also caused 40% of young children to exceed the UL. Milk fortification at this level was not as effective at raising vitamin D intakes in the rest of the population as fortification of flour at 30μg per 100g, which reduced the proportion of adults aged over 50 years and women of childbearing age from 89% and 97% to 3% and 10% respectively. However, fortification at this level caused a third of the children aged 4 to 8 years to exceed the UL. Milk and flour fortification together seemed to reach all age groups effectively. At fortification of 15μg vitamin D per 100g flour and 3.5μg vitamin D per 100ml milk the proportion of young children, women of childbearing age and adults aged over 50 years with intakes below the RNI were considerably reduced to 2%, 12% and 4% respectively, however over 20% of children under the age of 8 years exceeded the UL for this scenario of fortification.

The fortification scenario improving intakes in all 'at risk' groups reducing the proportion with intakes below the RNI to 65% in young children, 62% women of childbearing age and 40% of adults aged over 50 years, without putting any individuals at risk of exceeding the UL was fortification at 10μg vitamin D per 100g flour.

5.6.1 Socio-economic groups - Figures 12 and 13, Appendix 8 tables 8h and 8i.

An assessment of the proportion of the UK population with vitamin D intakes below the RNI by the NS-SEC 3 socio-economic group classification system is presented in figure 12. This figure suggests there is no trend in the current proportion of 'at risk' groups with vitamin D intakes below the RNI by NS-SEC group.

An assessment of the proportion of these 'at risk' population groups with vitamin D intakes below the RNI by socio-economic group for fortification at 10µg per 100g flour is presented in figure 13. This illustrates a marked reduction in the proportion with intakes below the RNI following flour fortification at this level. A one-way analysis of variance (ANOVA) identified that there was no difference in the effect of fortification on vitamin D intakes by socio-economic group ($F=1.107$; $p=0.354$) (see appendix 9 for details).

Mean vitamin D intakes post-update and for the scenario of flour fortified at 10µg vitamin D per 100g flour are presented by socio-economic group in tables 8h and 8i of appendix 8.

Figure 12: The proportion (%) of 'at risk' groups failing to achieve the RNI for current vitamin D intake, post-update, by socio-economic group (NS-SEC 3)[13](170). Approximate confidence intervals were estimated based on a normal distribution.

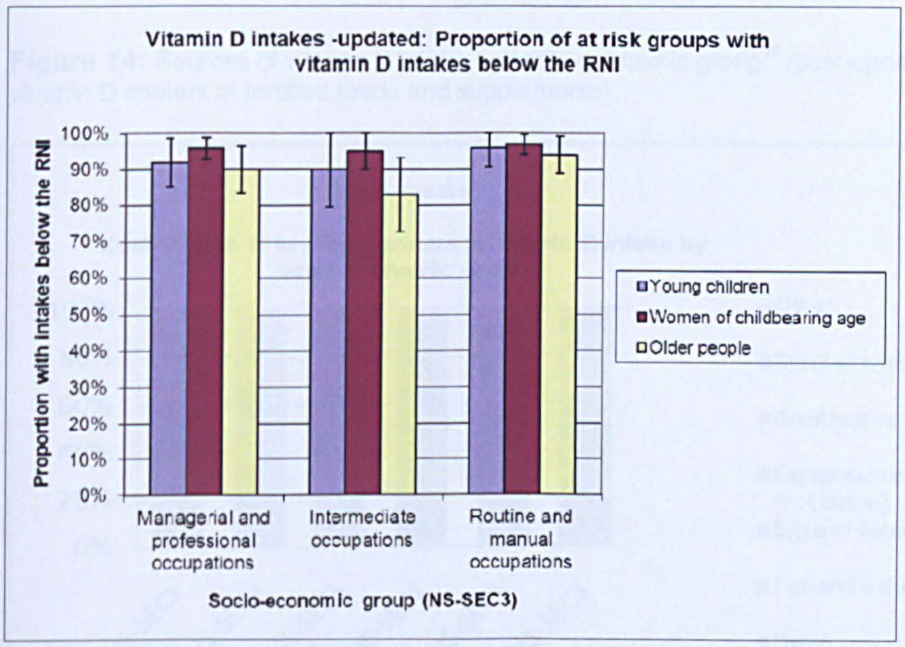
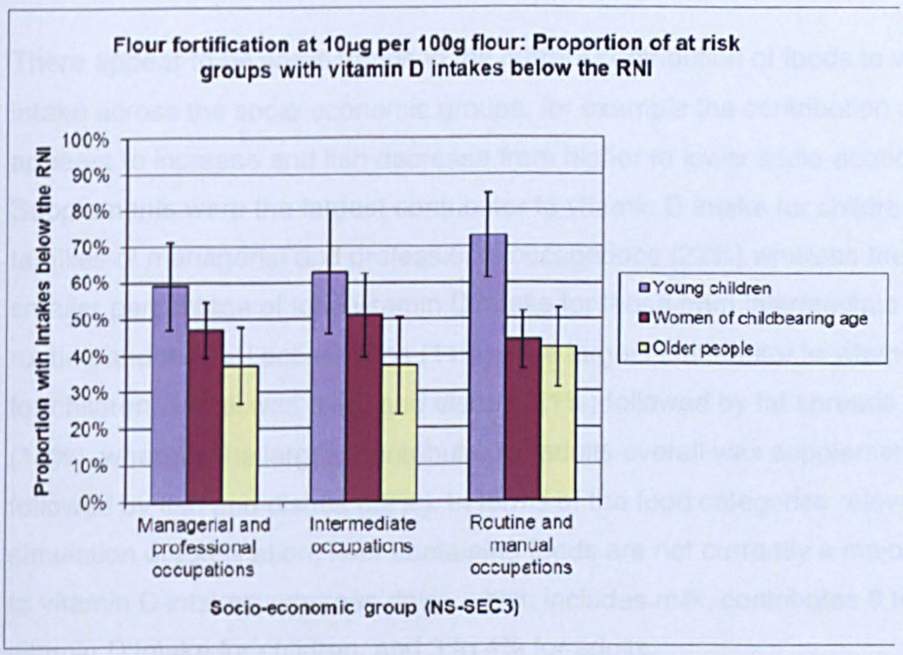


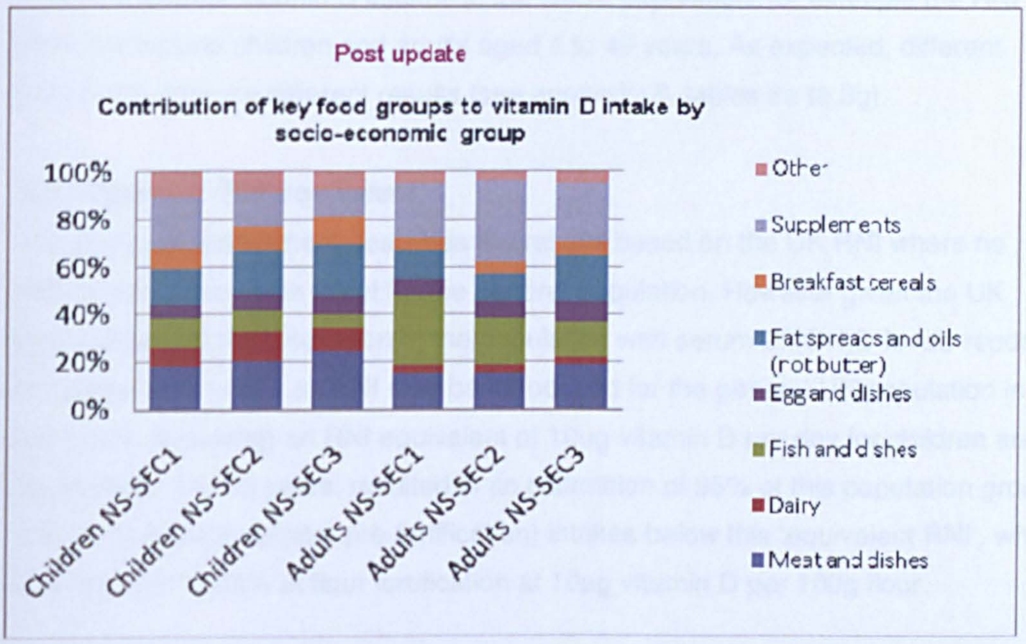
Figure 13: The proportion (%) of 'at risk' groups failing to achieve the RNI for fortification at 10µg vitamin D per 100g flour, by socio-economic group (NS-SEC 3) (170).Approximate confidence intervals were estimated based on a normal distribution.



[13] Managerial and professional occupations = NS-SEC 1; Intermediate occupations = NS-SEC 2; Routine and manual occupations = NS-SEC 3

The contribution of food groups and supplements to vitamin D intake by socio-economic group is presented in figure 14 and in Appendix 8 table 8j.

Figure 14: Sources of vitamin D intake by socio-economic group[12] (post-update of the vitamin D content of fortified foods and supplements).



There appear to be some trends in the current contribution of foods to vitamin D intake across the socio-economic groups, for example the contribution of meat appears to increase and fish decrease from higher to lower socio-economic groups. Supplements were the largest contributor to vitamin D intake for children from families of managerial and professional occupations (22%) whereas they provided a smaller percentage of total vitamin D intake for those from intermediate (14%) and routine and manual occupations (11%). The largest contributor to vitamin D intake for children overall was meat and dishes (21%) followed by fat spreads and oils (18%), whereas the largest contributor for adults overall was supplements (25%) followed by fish and dishes (22%). In terms of the food categories relevant to the simulation of fortification, flour containing foods are not currently a major contributor to vitamin D intakes, whereas dairy, which includes milk, contributes 8 to 13% of vitamin D intake for children, and 3 to 4% for adults.

5.7 Sensitivity analysis- Appendix 8 tables 8a to 8g.

Due to differing international recommendations, this analysis included an assessment of vitamin D intakes compared to a variety of international thresholds. The results presented thus far focus on current UK reference intake thresholds (option 1) however there is uncertainty regarding whether these are appropriate to ensure adequate vitamin D intakes in the whole population, for example the RNI does not include children and adults aged 4 to 49 years. As expected, different thresholds produce different results (see appendix 8, tables 8a to 8g).

5.7.1 Option 2 'RNI equivalent'

The previous assessment describes the results based on the UK RNI where no dietary reference value is set for the general population. However given the UK status data and the proportion of the population with serum 25(OH)D levels reported to be below 25nmol/l, an RNI may be introduced for the general UK population in the future. Assuming an RNI equivalent of 10μg vitamin D per day for children and adults aged 4 to 49 years, resulted in an estimation of 95% of this population group with current (post-update, pre-fortification) intakes below this 'equivalent RNI', which was reduced to 48% at flour fortification at 10μg vitamin D per 100g flour.

5.7.2 Option 3 Estimated Average Requirement (EAR)

The values set for the EAR by IOM differ to the UK RNI only for the youngest age group, but include the general population, i.e. an EAR is set at 10μg vitamin D for the whole population. The results for option 3 are therefore equivalent to those for option 2, with the exception of young children as 93% of this age group had intakes below the RNI, whereas 96% had intakes below the EAR.

5.7.3 Option 4 Recommended Dietary Allowance (RDA)

The RDA is set higher than the EAR and the UK RNI and therefore 99% of the population are currently estimated to have vitamin D intakes below the RDA, which was reduced to 84% at flour fortification at 10μg vitamin D per 100g flour.

5.7.4 Tolerable Upper Intake Level (UL)

The UL set by the IOM for the US and Canada is much higher than the UL set in Europe used in this analysis, more than double for some age groups, see table 3. The only fortification scenarios to cause any population groups to exceed the UL set by IOM were fortification of milk at 5μg and 7μg/100ml milk.

5.7.5 Option 5 Simulation -Figure 15, 16 and 17 and Appendix 10

As there is uncertainty in the recommendations for vitamin D intake and reference values vary internationally, the true level of intake required for optimum health may lie anywhere between the lower end (UK) and the higher end (US) of the range of reference thresholds.

Figure 15 graphically represents the proportion of 'at risk' groups with vitamin D intakes below specific hypothetical thresholds, ranging from the age specific UK RNI up to the US/Canadian RDA. This simulation illustrates the increase in the proportion of these groups considered to have low vitamin D intakes as the hypothetical threshold increases. For example, at a given level of vitamin D intake a smaller proportion of the population is considered to have 'low' vitamin D intakes set against the RNI compared to against the RDA.

Figure 16 illustrates the same as figure 15, but for fortification at 10µg vitamin D per 100g flour. Compared to figure 15, this illustrates the potential reduction in the proportion of these 'at risk' groups with intakes below the RNI and the RDA following fortification. It illustrates that, for fortification at 10µg vitamin D per 100g flour either 65% or 98% of young children; 61% or 90% of women of childbearing age; and 39% or 88% of older people would have intakes below the minimum threshold depending on whether the UK or US/Canadian reference values respectively are applied. These figures therefore demonstrate that even if population vitamin D intakes were equivalent in the UK and the US/Canada, because the reference values differ, the US/Canada would report a greater proportion of the population with poor vitamin D intakes compared to the UK.

Figure 15: Proportion (%) of 'at risk' groups with vitamin D intakes below minimum reference thresholds at current vitamin D intake (post-update)

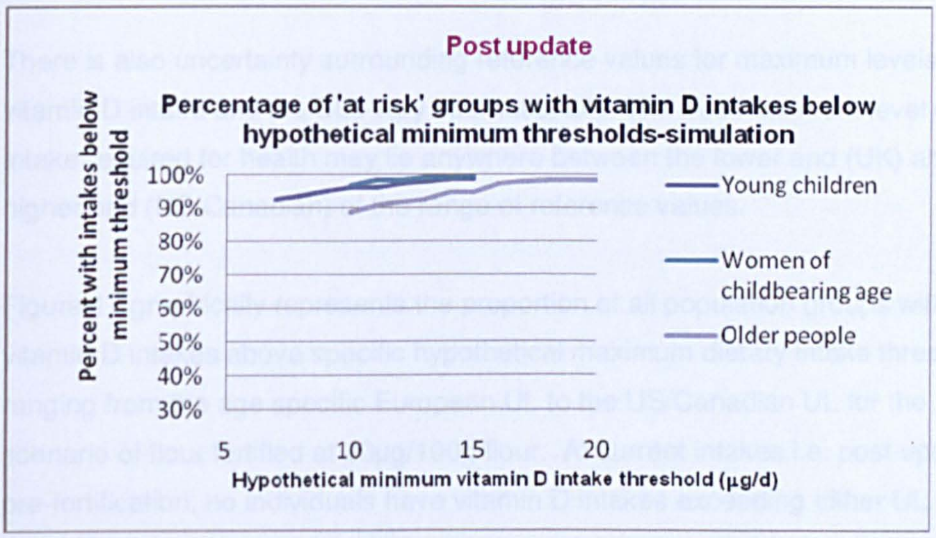
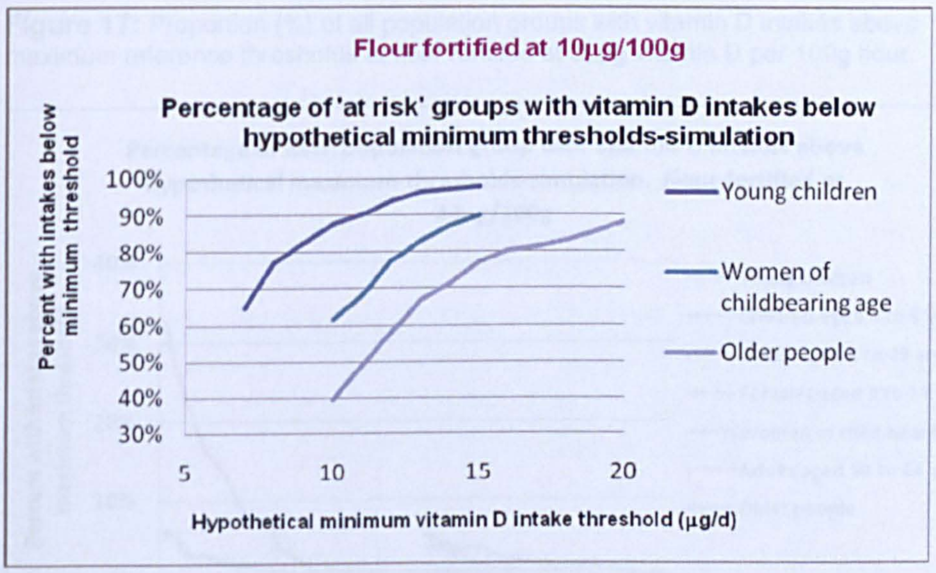


Figure 16: Proportion (%) of 'at risk' groups with vitamin D intakes below minimum reference thresholds at flour fortified at 10µg vitamin D per 100g flour.

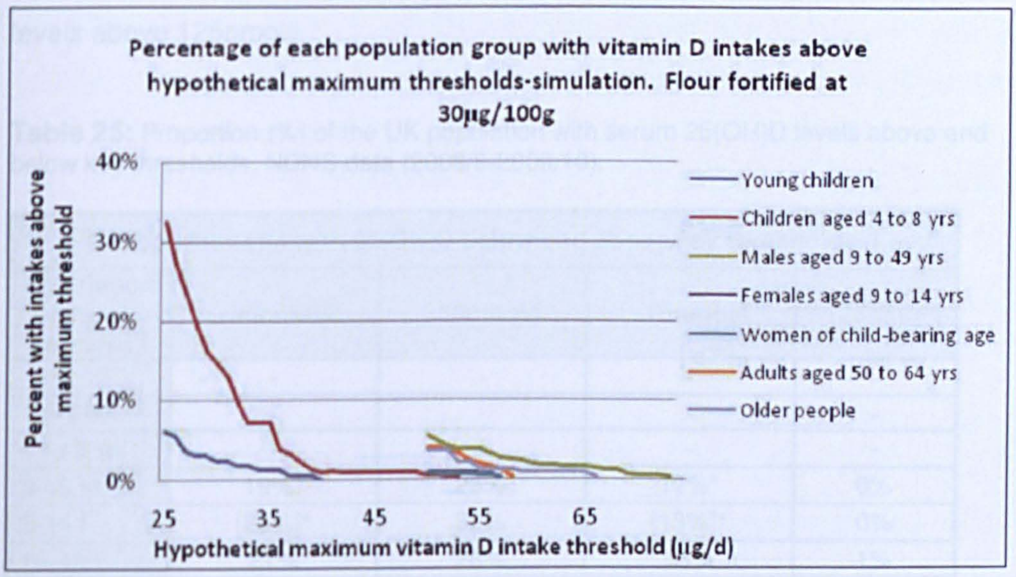


Figures 10a to 10p in appendix 10 illustrate these simulations for all levels of fortification for all population groups.

There is also uncertainty surrounding reference values for maximum levels of vitamin D intake and the ULs vary internationally. The true maximum level of intake required for health may lie anywhere between the lower end (UK) and the higher end (US/Canadian) of the range of reference values.

Figure 17 graphically represents the proportion of all population groups with vitamin D intakes above specific hypothetical maximum dietary intake thresholds ranging from the age specific European UL to the US/Canadian UL for the scenario of flour fortified at 30μg/100g flour. At current intakes i.e. post-update, pre-fortification, no individuals have vitamin D intakes exceeding either UL. This figure illustrates that the higher the maximum intake threshold is set, the lower the apparent risk of people exceeding maximum levels.

Figure 17: Proportion (%) of all population groups with vitamin D intakes above maximum reference thresholds at flour fortified at 30μg vitamin D per 100g flour.



Figures 10q to 10x in appendix 10 illustrate these simulations at all other levels of fortification where intakes exceed either the European and/or the US/Canadian ULs.

5.8 Thresholds for serum 25(OH)D–Table 25

The serum 25(OH)D level below which is considered inadequate by the IOM is 30nmol/l, which is 5nmol/l higher than in the UK. Table 25 illustrates that the proportion of the population with serum 25(OH)D levels below 30nmol, using NDNS blood data ranged from 25% to 32% of population groups, compared to 14% to 26% of the population with serum 25(OH)D levels below 25nmol/l.

Although there is no threshold for maximum serum 25(OH)D levels set in the UK, serum 25(OH)D levels above 75nmol/l to 125nmol/l may be associated with adverse effects (as discussed previously the lower threshold of 75nmol/l seems to have been misinterpreted by IOM and serum 25(OH)D levels above a threshold of 125nmol/l may be more likely to cause risk of excess (70)). Using NDNS blood data, 12% to 14% of population groups had levels above 75nmol/l and 1% of women of childbearing age and adults aged 50 to 64 years had serum 25(OH)D levels above 125nmol/l.

Table 25: Proportion (%) of the UK population with serum 25(OH)D levels above and below key thresholds, NDNS data (2008/9-2009/10).

Proportion (%) with 25(OH)D below and above key thresholds				
Population group years/sex	<25nmol/l	<30nmol/l	>75nmol/l	>125nmol/l
	-	-	-	-
1.5-3 All	-	-	-	-
4 to 8 All	-	-	-	-
9-49 M	19%*	29%	12%*	0%
9-14 F	[26%]*	32%	[13%]*	0%
15-49 F	21%	28%	13%	1%
50-64 All	14%	25%	14%	1%
65 + All	-	-	-	-

* NDNS blood data only available from 11 to 64 years of age.

Serum 25(OH)D levels estimated using the Cashman *et. al.* equations suggested that the 97.5th percentile level is currently below 75nmol/l in most age groups with the exception of adults aged over 50 years (see table 22), although NDNS blood data suggest the 97.5th percentile level ranges from 76nmol/l to 115nmol/l (see table 20) and that 12% to 14% of the population have levels above 75nmol/l with

1% of some groups exceeding 125nmol/l (see table 25). In most fortification scenarios the 97.5th percentile estimated using the equations rose above 75nmol/l in most population groups and rose above 125nmol/l in some age groups at the highest levels of fortification (see tables 8d to 8g of appendix 8). In addition, it seems using the equations may underestimate serum 25(OH)D levels at the high end of the distribution, so in reality a greater proportion of individuals are likely to be at risk of exceeding 75nmol/l and 125mol/l at a given level of fortification, the implications of this are discussed in section 5.2.

5.9 Optimum level of fortification using IOM reference thresholds

Using UK reference thresholds for vitamin D intake, the optimum scenario of fortification was found to be fortification at 10µg vitamin D per 100g flour. Based on the IOM thresholds, the optimum scenario would be fortification at 30µg vitamin D per 100g flour. At this level of fortification, no individuals exceed the UL set by IOM, and the proportion of the population with intakes below the RDA was reduced from 99% to 22%, although looking at individual population groups, 61% of young children still have intakes below the RDA at this level of fortification. It has been suggested that using the EAR may be more appropriate for assessing the proportion of the population at risk compared to the RDA (17). At this level of fortification the proportion exceeding the EAR was reduced from pre-fortification levels of 82% to 7%. Serum 25(OH)D levels at this level of fortification suggest mean winter serum 25(OH)D levels were above 75nmol/l and the 97.5th percentile levels were above 125nmol/l in most age groups, although the Cashman *et. al.* equations could not be used to estimate serum 25(OH)D levels for some age groups as vitamin D exceeded 25µg per day.

5.10 Determining mean winter serum 25(OH)D levels based on minimum reference thresholds for vitamin D intake–Table 26

The Cashman *et. al.* equations were used to estimate mean winter serum 25(OH)D levels for each of the reference levels of vitamin D intake, in order to determine the winter status levels likely to be achieved if dietary reference values were met (see table 26). At a vitamin D intake equivalent to the UK RNI, mean winter serum 25(OH)D levels ranged from 44nmol/l to 57nmol/l across population groups. At a vitamin D intake equivalent to the RDA set in US/Canada the mean winter serum 25(OH)D levels ranged from 60nmol/l up to 81nmol/l across population groups.

The mean winter serum 25(OH)D level corresponding to the European UL for children aged under 4 years was 86nmol/l. Unfortunately as the equations were not suitable for use against vitamin D intakes above 25µg per day they were inappropriate for use in estimating mean winter serum 25(OH)D levels at maximum vitamin D intakes for all other age groups.

Table 26: Mean winter serum 25(OH)D levels (and upper and lower 95% CIs of the mean) estimated at the minimum (RNI and RDA) and maximum (UL) reference vitamin D intake levels using Cashman equations.

UK reference values and estimated mean winter serum 25(OH)D level				
Age/Sex groups	**RNI** (3) **(µg/d)**	**Estimated 25(OH)D (nmol/l) (95% CIs of the mean)**	**UL** (66) **(µg/d)**	**Estimated 25(OH)D (nmol/l) (95%CIs)**
1.5 to 3 All	7	44 (38, 51)	25	86 (65, 113)
4 to 8 All	-	-	25	86 (65, 113)
9 to 49 Males	-	-	50*	-
9 to 14 Females	-	-	50*	-
15 to 49 Females	10	50 (42, 59)	50*	-
50 to 64 All	10	50 (42, 59)	50*	-
65+ Males	10	57 (43, 72)	50*	-
65+ Females	10	55 (45, 56)	50*	-
US/Canadian reference values and estimated serum 25(OH)D level				
Age/Sex groups	**RDA** (1) **(µg/d)**	**Estimated 25(OH)D (nmol/l) (95% CIs of the mean)**	**UL** (1) **(µg/d)**	**Estimated 25(OH)D (nmol/l) (95%CIs)**
1.5 to 3 All	15	60 (49, 73)	62.5*	-
4 to 8 All	15	60 (49, 73)	75*	-
9 to 49 Males	15	60 (49, 73)	100*	-
9 to 14 Females	15	60 (49, 73)	100*	-
15 to 49 Females	15	60 (49, 73)	100*	-
50 to 64 All	15	60 (49, 73)	100*	-
65+ Males	20	71 (51, 95)	100*	-
65+ Females	20	81 (64, 101)	100*	-

*The Cashman *et. al.* equations (table 11) are not suitable to estimate serum 25(OH)D levels above a mean intake of 25µg vitamin D per day.

CHAPTER 6: DISCUSSION

Significant proportions of the UK population have poor vitamin D status. The UK population may therefore benefit from introducing fortification of more foods with vitamin D. There is however, little evidence available as to whether national fortification strategies improve vitamin D intakes of groups most at risk of deficiency, let alone whether they improve vitamin D status or have an impact on health. There is also uncertainty around the impact of vitamin D deficiency on bone health and the potential impact on other chronic diseases as well as surrounding recommended intake and status thresholds. This study aimed to assess whether introducing fortification of more foods with vitamin D in the UK would reduce the proportion of groups at risk of vitamin D deficiency failing to achieve minimum intake and status thresholds without causing excess in the rest of the population. It focused on three key objectives:

- A systematic review to identify whether fortification of foods with vitamin D is an effective way of improving population vitamin D status, particularly for groups at risk of deficiency;
- An update of an existing food composition dataset to improve the quality of information on vitamin D fortification;
- A data processing exercise to simulate the effect of fortifying specific foods with vitamin D and identify the effects on vitamin D intakes and status specifically for 'at risk' groups.

This chapter will summarise the methods, findings and implications in relation to the potential impact of fortifying more foods with vitamin D in the UK, and discuss the various policy options, including recommendations, for improving the vitamin D intakes and status of the UK population.

6.1 Systematic review

6.1.1 Summary of methods and description of included studies

A systematic review was carried out of studies measuring vitamin D status in healthy subjects following consumption of vitamin D fortified foods or drinks. The review included 30 studies: 15 randomised controlled trials (RCTs); five cluster RCTs; a double arm and six single arm trials; and three studies (two longitudinal and a repeat cross-sectional) investigating the impact of a national fortification programme. Settings included Europe, the US and Canada, Australia, New Zealand and Asia. Vehicles of fortification included milk and dairy products, bread and other cereal products, fats, orange juice, fruit and dairy based products and pureed vegetables and meat. Study populations included groups at risk of vitamin D deficiency such as children, women of childbearing age and older people. No studies focused on ethnic minorities or pregnant and breast-feeding women.

6.1.2 Summary of systematic review findings

Seventeen of the 20 RCTs and cluster RCTs observed statistically significant increases in serum 25(OH)D concentration from baseline post-intervention, compared to a control group. The inconsistent findings for the remaining three could be explained by weaknesses in survey designs. The conclusion that consumption of foods or drinks fortified with vitamin D improves serum 25(OH)D concentration was consistent with the O'Donnell *et. al.* (43) and Black *et. al.* (44) systematic reviews of RCTs. As RCTs are considered to be robust in design this finding is considered reliable. The studies focusing on the impact of Finland's vitamin D fortification programme of margarine and milk, provided evidence of the scheme's success in young men and children aged 4 years, but not teenage girls. The review did not find any evidence of the impact of national vitamin D fortification schemes in other countries or in other 'at risk' groups.

6.1.3 Implications of systematic review findings

The systematic review therefore extends existing evidence that consumption of vitamin D fortified foods leads to improved vitamin D status in individuals as it demonstrates it can also be effective at improving status at a population effectiveness level rather than just at a level of efficacy. It also highlights that data demonstrating the impact of national fortification schemes on groups at risk of vitamin D deficiency are lacking. The Finnish national vitamin D fortification scheme was found to improve the vitamin D status of some, but not all groups of the population. Although a wide variety of foods were shown to be effective at improving vitamin D status, identification of a vehicle consumed by the target population in sufficient quantities is essential in determining the success of a national fortification strategy. Milk and spreads, for example, were consumed in insufficient quantity by teenage girls in Finland to improve serum 25(OH)D concentration at the level of fortification used. These findings put into context the importance of selecting suitable vehicles for use in the simulation of vitamin D fortification in this analysis.

6.1.4 Strengths and limitations of the systematic review

A wide variety of studies were included ranging from RCTs to repeat cross-sectional studies. This was a strength as it allowed a broad assessment of the success of fortification schemes, however it also meant that the studies were heterogeneous in nature restricting the potential for accurate inter-study comparison. This could be resolved by restricting the review to RCTs, but the scope of the review to assess the impact of national schemes would be reduced. The review was only carried out by one person introducing the potential for human error in data extraction, and it was restricted to studies published in English excluding any relevant studies published in other languages. Autoalerts were only checked up until February 2011, so a number of relevant studies may have since been published that have not been included.

6.2 Update of an existing food composition dataset for vitamin D fortified foods and supplements

Composition data for fortified foods and supplements used in dietary surveys such as the National Diet and Nutrition Survey (NDNS) quickly expire due to recipe reformulation. It was therefore necessary to update the vitamin D content of fortified foods and supplements within the NDNS food composition database, prior to simulating fortification.

6.2.1 Summary of methods to update of the vitamin D content of fortified foods and supplements

Food composition data held within the NDNS Nutrient Databank were used to identify vitamin D fortified foods and supplements. Two hundred and eighty nine vitamin D fortified food codes and vitamin D containing supplement codes were identified. Website data and in-store labels were checked and trade associations and manufacturers were contacted in order to confirm the data collected reflected the most up-to-date values. A suitable level of 'overage' (the term for an additional amount of the nutrient added during manufacture to allow for processing losses and degradation over time) to apply to the vitamin D content of all fortified foods and supplements was also determined.

Food consumption data from the first two years of the NDNS Rolling Programme (2008/10) were used to determine vitamin D intakes for policy relevant age and sex specific UK population sub-groups, both pre- and post- the update of the vitamin D content of fortified foods and supplements.

6.2.2 Summary of findings for the update of vitamin D content of fortified foods and supplements

An up-to-date vitamin D content was obtained for 257 (89%) of the fortified/supplement codes, 31 (11%) had changed and a further eight were identified as being fortified with vitamin D. A 12.5% 'overage' was determined and applied to the vitamin D content of all fortified foods and supplements in the analysis.

Population mean daily vitamin D intakes pre-update were estimated at 3.5µg (ranging from 2.3µg to 4.7µg across population sub-groups), compared to a post-update mean of 3.7µg (ranging from 2.5µg to 5µg). About half of the difference in these estimates could be explained by the application of 'overage', which increased daily vitamin D intakes by between 0.1µg to 0.2µg across population groups, 3% overall. The update excluding consideration of 'overage' also increased population mean vitamin D intakes by about 3%.

6.2.3 Implications of findings of the update of vitamin D content of fortified foods and supplements

The Department of Health annually updates the NDNS Nutrient Databank using label data for fortified foods and analytical data where available. As it is not feasible to review all fortified products each year, some changes may not be picked up until a year or more after they have been implemented by manufacturers. Estimated intakes of fortified nutrients such as vitamin D in the NDNS may therefore be out of date soon after, or even at the time of publication. The degree by which intakes are under- or over- estimated due to use of out-of-date data is likely to vary by the age of data used and nutrient assessed. This analysis identified that mean population vitamin D intakes were underestimated by only 3% when food composition data were used that had not been updated for three years (i.e. between 2008 and 2011, 6% including the addition of overage). Although this is relatively insignificant for this nutrient, the update was worthwhile to ensure that baseline vitamin D intakes were as up-to-date as possible prior to simulating fortification.

It is important for accurate monitoring of the population's health that food composition data held by the Department of Health is kept as up-to-date as feasibly possible, to ensure resulting dietary surveys, such as the NDNS, reflect accurate nutrient intakes. Data from analytical food composition surveys have been made publically available in the *McCance and Widdowson's Composition of Foods* series since 1940 (176). The current 6th edition was published in 2002 (15) and a 7th edition is due to be published in 2013 (177). Revised editions are required to incorporate new data as they become available to keep up-to-date with a number of factors:

- A wider variety of foods being analysed;
- New and improved analytical methods;
- Changing definitions of nutrients;
- Changes to the composition of foods through changing farming practices and alterations to the recipes of composite foods (15, 177).

In the 1990s the vitamin D content of meat was estimated to have increased due to the inclusion of an additional metabolite not previously analysed (178). Values for raw beef mince increased from <0.01µg per 100g to 0.5µg per 100g (179, 180). An analytical survey of the nutrient content of eggs, published in 2012, found a higher vitamin D content of raw chicken egg yolk (12.8µg per 100g) (181) compared to values published in 1989 (4.9µg per 100g) (182). This difference is likely caused by changes in egg production processes and the composition of chicken feed (181).

In the absence of recent analytical data for fortified foods such as breakfast cereals, editors of the 7th Edition of the McCance and Widdowson's Composition of Foods have contacted manufacturers for up-to-date label data, so as to include the most up-to-date values in the latest edition (177). Using label data in the update of the NDNS Nutrient Databank and the McCance and Widdowson's Composition of Foods does not consider any 'overage' remaining after processing. Published data on the levels of 'overage' typically applied, remaining after processing and at consumption are lacking. To consider levels of 'overage' in food composition updates, manufacturers would be required to provide details of 'overage', which may not be readily available. The issue of manufacturers applying very large 'overages' is diminishing as the cost of fortificants (i.e. nutrients) is rising, and manufacturers therefore aim to reduce wastage (164). The impact of not considering 'overage' for an individual would vary greatly depending on whether they regularly consume fortified foods and supplements, however the impact on population intakes overall may be relatively small. This analysis identified that including an estimate of 'overage' increased the population mean vitamin D intake by only 3%. If population intakes are under-estimated to a similar degree for other nutrients used in food fortification and supplements it is unlikely the Department of Health would consider the work required to determine accurate 'overages' to be worthwhile.

Published examples of other simulations of fortification have also included updates of fortified food composition data (101, 104, 110). Crane *et. al.* (104) reported updating the folic acid[14] composition of fortified ready to eat cereals prior to simulating folic acid fortification in the US. Values were updated where labels and existing data differed by more than 15%, resulting in a change to 4% of food codes. The analysis presented in this thesis updated the vitamin D value if the labels and existing data differed by even 1µg, 11% of food codes were updated and 8 new fortified food codes were identified. Crane *et. al.* (104) do not seem to have considered 'overage', other folic acid fortified foods or supplements, or sought confirmation of the updated values from manufacturers, all of which were carried out in this analysis.

In preparation for simulating folic acid fortification of flour, the UK Scientific Advisory Committee in Nutrition (SACN) carried out a similar exercise as presented here to update the folic acid content of fortified foods and supplements, by checking website and in-store labels, contacting manufacturers and considering 'overage' (110). The impact of the update on estimated folate intakes was not reported.

The update presented in this thesis therefore provides a comparatively thorough consideration of the issues that may have affected the vitamin D content of fortified foods and supplements since the NDNS was carried out. These updated

[14] Folic acid is the synthetic form of folate used in fortified foods and supplements

data enabled the calculation of a reliable estimate of baseline vitamin D intakes on which to simulate fortification.

6.2.4. Strengths and limitations of the update of the vitamin D content of fortified foods and supplements

The exercise to update vitamin D data was as thorough as was feasible given the expanding UK market of fortified foods and supplements. It considered levels of 'overage' likely to be remaining at consumption, reformulation changes, recent changes that were not reflected in label values in-store or on websites.

Composition data for natural sources of vitamin D date back as far as the 1980s, and may have since changed (177) as may the vitamin D content of composite foods containing fortified foods. A level of judgement was used when deciding which codes were likely to be fortified with vitamin D and it was not possible to search for every product on the market, it is therefore likely a number of vitamin D fortified foods were excluded. Confirmation was not received for 11% of products included in the update, which may have resulted in some out-of-date values being used. Due to the international sale of supplements over the internet it was not possible to consider all of those available in the UK. Fortified foods introduced since the survey was carried out were not considered. In addition, a blanket level of 'overage' was applied to all fortified foods and supplements, whereas the actual level applied and remaining at consumption will vary depending on: the degree of processing involved in manufacture; stage of shelf life at consumption; type of packaging, and moisture content of the food (164). All of these issues are likely to affect how closely the vitamin D intakes estimated in this analysis compare to actual current intakes of the UK population.

6.3 Simulation of fortification

The third and main objective of this thesis was to manipulate the vitamin D content of specific foods to simulate fortification and assess the impact on vitamin D intakes and status specifically for 'at risk' groups.

6.3.1 Summary of methods for the simulation of fortification

Published food composition data were assessed to determine the foods most likely to be successful vehicles in improving intakes of population sub-groups most at risk of vitamin D deficiency. In this analysis these groups were defined as young children, pregnant and breast-feeding women, who were represented by women of childbearing age, older people and ethnic minorities. Milk and flour were selected as suitable vehicles for vitamin D fortification for the following reasons:

- Milk is consumed in large quantities in the UK (270g to 560g per day across population sub-groups) and flour is consumed by a wide proportion of the population (white bread consumed by 74% to 83% of population sub-groups) (see table 15);
- Both were shown to be potentially suitable vehicles for vitamin D fortification by improving vitamin D status in efficacy studies;
- Both have been used as vehicles for national fortification schemes either in the UK or in other countries.

Vitamin D intake and food composition data were then assessed to determine a range of suitable levels to test for fortification of flour and milk in the simulation. Vitamin D fortification was simulated for three scenarios:

(1) Flour- at levels ranging between 5µg and 30µg per 100g flour,
(2) Milk - at levels ranging between 0.5µg and 7µg per 100g flour
(3) Flour and milk - at half the respective levels assessed for separate flour and milk fortification.

All flour and milk containing foods were also affected by fortification. Vitamin D intakes were determined for all scenarios for different sub-groups of the population, focusing on those known to be at risk from poor vitamin D status, except ethnic minorities. The impact of fortification on serum 25(OH)D concentration was determined using equations derived from relationships between vitamin D intake and status established by Cashman *et. al.* (117, 118) up to a maximum daily vitamin D intake of 25µg (119, 171). Blood data within the NDNS dataset were also used to determine baseline serum 25(OH)D levels.

6.3.2 Summary of findings of the simulation of vitamin D fortification

Fortification at 10µg vitamin D per 100g flour was found to increase vitamin D intakes and reduce the proportion of 'at risk' groups from having intakes below the daily minimum Reference Nutrient Intakes (RNIs) by nearly 50%, without putting any individuals at risk of exceeding the maximum Tolerable Upper Levels

(ULs). This translated into an increase in the 2.5th percentile of population winter serum 25(OH)D levels to above the UK minimum threshold of 25nmol/l, and the 97.5th percentile increased to below the maximum status threshold of 125nmoll suggested by the Institute of Medicine (IOM) (1).

Fortification at higher levels, i.e. between 15µg and 30µg vitamin D per 100g flour, further reduced the proportion of the population with intakes below the RNI, but began to increase individuals above the UL (up to 5% of the population). Fortification of milk, and milk and flour combined, did not reduce the proportion of the population with low intakes to such an extent as fortification with flour alone at 10µg per 100g flour, without increasing the proportion of the population exceeding the UL.

6.3.2.1 'At risk' groups

Consumption of any fortified food in large enough quantities would reduce the proportion of the population with low vitamin D intakes, but it would also increase the proportion of the population with high intakes. In order to identify a vehicle and level of fortification suitable for all groups of the population it is necessary to establish a balance between those benefiting from fortification without increasing the risk of excess for others.

6.3.2.1.1 Ethnic minorities

Ethnic minority groups, specifically women and children in ethnic minority groups, are at a particular risk of vitamin D deficiency in the UK, largely due to the effect of skin pigmentation on the reduced ability to absorb ultra violet (UV) light (23, 24), but also due to the covering of their skin for religious reasons. Much of the data on the re-emergence of rickets have been documented in these groups (5). It would therefore be prudent that a national vitamin D fortification scheme should aim to reach these groups. Unfortunately, there are no current food consumption data representative of the UK for these groups, so the impact of fortification was not assessed for ethnic minorities.

Although these groups are seen to consume milk in the UK (table 15), they have a higher prevalence of lactose intolerance (up to 50% higher in late childhood and adulthood in African American, Hispanic, Asian, and American Indian populations) compared to Northern Europeans (183). Milk is therefore unlikely to be a suitable vehicle for fortification. A number of nutrients are already added to all white and brown wheat flour at the milling stage. Thiamine, nicotinic acid and iron are added to restore flour with the nutrients lost in the milling process and calcium is added as a fortificant (28). The most cost-effective method of fortifying flour with vitamin D would likely be to add vitamin D alongside these other vitamins in the mills. As all white and brown flour are processed in the same mills, chapatti flour, a type of wheat flour popular in Asian cooking, and other speciality wheat flours used by ethnic minorities, would also be fortified as would other flour containing products consumed by ethnic groups. If fortification were restricted to bread-making flour only, to enable consumer choice, speciality flours such as chapatti flour and other flour containing products would be excluded from fortification. Policy options are discussed further in section 6.6.

6.3.2.1.2 Young children, pregnant and breast-feeding women and older people.

For young children, milk would be an obvious vehicle for improving vitamin D intakes as it contributes to nearly a fifth of their total energy intake (91) and they have been shown to benefit from national fortification of milk and spreads in Finland (157). In this simulation, fortification at 5µg per 100ml milk reduced the proportion of this group with intakes below the RNI from 93% to 16%, however due to the high volumes consumed, a fifth (21%) exceeded the UL.

The two most preferable scenarios for women of childbearing age were fortification at 15µg per 100g flour and fortification of milk and flour at 10µg per 100g flour and 2.5µg per 100ml milk. Both scenarios reduced the proportion below the RNI from 98% to 35% without anyone in this group exceeding the UL. The same scenario of milk and flour fortification was also the most preferable for older people, reducing the proportion of adults aged over 50 years below the RNI from 89% to 11%, without anyone in this group exceeding the UL. However, 7% of young children had intakes above the UL at this level of fortification.

For certain scenarios therefore, considerable benefit was seen for some groups, while a risk was posed to others. The fortification scenario with the greatest benefit observed to all groups assessed without posing a risk of excess was the scenario of fortification at 10µg vitamin D per 100g flour.

6.3.2.1.3 Socio-economic groups

An assessment of the impact of fortification at 10µg vitamin D per 100g flour was carried out across the UK split into three socio-economic groups. People living on low incomes have been seen to have poorer diets than those on higher incomes (26) therefore individuals in lower socio-economic groups may be at a higher risk of vitamin D deficiency than those in higher socio-economic groups. The analysis suggested there was no significant difference in the effect of fortification of flour by socio-economic group, suggesting that flour fortification would be effective in reaching across the UK socio-economic gradient. This is likely to be explained by the ubiquitous nature of flour containing foods within diets of even those on lower incomes.

The assessment of the contribution of dietary sources (foods and supplements) to current vitamin D intakes highlighted the variation in the diets between children and adults and some variation between socio-economic groups. Fortified foods such as fat spreads and breakfast cereals provided a greater contribution to children's vitamin D intakes (18% and 10% respectively) compared to adults (14% and 5% respectively), as adults obtain a greater proportion of their vitamin D from naturally rich food sources and supplements. The assessment also highlighted that flour containing foods are not currently a major contributor to vitamin D intakes, which would change if flour were to be fortified.

6.3.2.1.4 Vegans

Although not a group considered to be traditionally at risk of vitamin D deficiency, a strategy to fortify a food with vitamin D may impact on the diet of vegans. Many foods naturally rich in vitamin D are not suitable for a vegan diet (oily fish, meat and eggs). If they have little exposure to sunlight, vegans are likely to rely on artificial sources in the form of fortified foods and supplements. However, D_3, a form of vitamin D used in fortification and supplements, is derived from animal wool (184) and is therefore not suitable for a vegan diet. A recently published systematic review and meta-analysis indicated that D_3 is more effective at raising serum 25(OH)D concentrations compared to D_2 (47) and a number of manufacturers already choose to use D_3 in voluntary fortification because of the belief that it is more effective (see table 14), which further reduces the number of vitamin D rich food products suitable for a vegan diet. If vitamin D_3 were chosen as a fortificant of a ubiquitous food such as flour, the total range of foods suitable for vegans would be significantly reduced. Milk would not be a suitable vehicle for reaching this group.

Animal products not only contain vitamin D in the form of D_3, they also contain amounts of the hydroxylated vitamin D metabolite 25(OH)D_3, which has been shown to be four to five times more effective at raising serum 25(OH)D levels in adults compared to D_3 (185). Vegans therefore do not benefit from this even more potent form of vitamin D.

6.3.2.2 Fortification of flour

Vitamin D is a fat-soluble vitamin, requiring dietary fat for absorption, however use of a cold-water soluble dry vitamin D powder in low fat foods and drinks has been shown to be effective at improving serum 25(OH)D concentration (128, 141). The systematic review in chapter 2 included two studies demonstrating vitamin D to be heat stable and endure processing in bread (141, 151). A single arm study involving 40 older people in Romania illustrated considerable increases in vitamin D status after a daily dose of 125µg vitamin D_3 over a 12 month period (mean serum 25(OH)D levels increased by 99nmol/l). At a more realistic daily intake level of 10µg, a randomised control trial in young women in Finland found consumption of vitamin D_3 fortified wheat (mean increase in serum 25(OH)D levels of 16nmol/l) and rye bread (mean increase of 15nmol/l) to be as effective as taking a supplement (mean increase in serum 25(OH)D levels of 20nmol/l) over a three week period (141).

There are likely to be challenges in achieving a standard level of flour fortification, at 10µg vitamin D per 100g flour for example, given the variability in the analysis of the vitamin D content of foods. A study by Byrdwell *et. al.* identified a variation of 10% across laboratories in the UK for the vitamin D content of standard reference materials (186). The issue of varying levels of overage added by manufacturers during fortification would also influence whether the 10µg per 100g of flour fortification could be achieved in practice.

As discussed previously, the success of a fortification strategy to improve vitamin D status of 'at risk' groups, may depend on which type of vitamin D (D_2 or D_3) is used. In order to ensure fortified flour containing foods are suitable for a vegan diet, use of D_2 would be preferable. However as found by Tripkovic *et. al.* (47) D_2 may not be as effective at improving serum 25(OH)D levels as D_3, and as the Cashman studies used supplemental D_3, the impact on serum 25(OH)D levels observed in this study as a result of increased vitamin D intake through fortification, maybe reduced.

6.3.3 Sensitivity analysis.

The simulation looked at the effect of fortification on the proportion of the population failing to reach and exceed a range of thresholds, including a comparison of international reference intake thresholds. The issue of individuals failing to achieve minimum thresholds is more severe using those set in the US and Canada (Recommended Dietary Allowance (RDA) and Estimated Average Requirement (EAR)) compared to using the UK RNIs, and intakes can reach much higher levels before exceeding maximum thresholds when using the US/Canadian UL compared to the European UL. A much higher level of fortification could therefore be adopted, i.e. flour fortification at 30µg per 100g flour appears the most favourable scenario using the US/Canadian thresholds, which is 20µg per 100g flour higher than using UK thresholds. As this analysis is relevant to the UK population, the outcomes focus on current UK RNIs and ULs. It is however worth considering the level of uncertainty in these reference thresholds and the impact that using different thresholds could have on risk management options chosen by policy makers in different countries. A fortification strategy implemented in the US/Canada based on their higher dietary thresholds could result in high vitamin D intakes and dangerously high serum 25(OH)D levels in some population groups. It should however be noted that the level of mandatory and voluntary fortification of milk currently in place in Canada and the US is at the lower end of the ranges of fortification assessed in this analysis (<1.5µg per 100ml milk, see table 2). The revised ULs published by the European Food Safety Authority (EFSA) in July 2012 (67) are double the previous values set by the European Scientific Committee on Food (SCF), which were used in this analysis. If the analysis were repeated with these revised figures then results would be similar to those observed using the ULs set by IOM and fortification of flour at 30µg per 100g would likely be the most preferable fortification scenario. It is not yet known whether these revised European ULs will be adopted for use in the UK.

It is possible that as a result of their current risk assessment, SACN may recommend the introduction of an RNI for the general population similar to the scenario assessed in option 2, which assumes an RNI of 10µg vitamin D per day for all adults and older children. It is therefore useful to establish the effect of fortification on the proportion failing to achieve these thresholds, i.e. fortification at 10µg/100g flour would reduce the proportion of the whole population with intakes below this 'equivalent RNI' from close to the entire population (95%) to just under half (48%).

6.3.4 The importance of vitamin D intakes vs. status for health

Reference dietary intakes in the form of RNIs, EARs and RDAs are set as a guide with the aim of achieving adequate vitamin D status. If however an individual obtains sufficient vitamin D through sun exposure, they may have a vitamin D intake below dietary reference values, while achieving an adequate vitamin D status. Therefore looking at the proportion of the population with dietary intakes below a given threshold is not as valid an indicator of the proportion of the population at risk of deficiency compared to looking at serum 25(OH)D concentrations.

Applying the Cashman *et. al.* equations to a daily vitamin D intake equivalent to the RNI resulted in a mean winter population serum 25(OH)D level of about 50nmol/l, which seems reasonable as IOM considered this serum 25(OH)D level to be adequate for 97.5% of the population (1). However at vitamin D intakes equivalent to the RDA, mean serum 25(OH)D levels were estimated to be in the range of 60nmol/l to 81nmol/l. IOM concluded that serum 25(OH)D levels between 75nmol/l and 125nmol/l may have adverse effects on health from excess vitamin D (1), so the mean serum 25(OH)D levels associated with RDAs overlap into the lower end of this range. Unfortunately the equations were not appropriate for estimating serum 25(OH)D levels above intakes of 25µg/d and therefore levels equivalent to the UL. Data obtained from NDNS blood samples suggested that up to 15% of some population groups currently have serum 25(OH)D levels above 75nmol/l and up to 1% have levels above 125nmol/l. Vitamin D intakes are however currently well below the UL. This suggests that 25(OH)D levels at vitamin D intakes equivalent to the UL are likely to exceed 125nmol/l. As an example, at fortification of 30µg vitamin D per 100g of flour the 97.5th percentile of winter serum 25(OH)D estimated for young females exceeded 150nmol/l, but vitamin D intakes for all individuals remained below the UL. It is likely that the Cashman *et. al.* (117, 118) relationships over and underestimate vitamin D status levels at the 2.5th and 97.5th percentiles respectively (potential reasons for this are discussed in section 6.3.7.1). In addition, this is an estimate of vitamin D status during winter, so the spring, summer and autumn serum 25(OH)D concentrations maybe a further third or 25nmol/l greater and could therefore increase to 175nmol/l, with vitamin D intakes still below the UL for this age group.

ULs are designed to be 'Tolerable Intake levels', at which no known harm is considered likely from excess consumption. Based on results from using the Cashman *et. al.* intake/status equations it is however likely that a level of vitamin D intake well below either the SCF, IOM or new EFSA ULs would result in population serum 25(OH)D levels above 125nmol/l. The ULs therefore seem to be set too high given the serum 25(OH)D levels considered by IOM to be associated with chronic adverse health effects.

In re-evaluating the European ULs, EFSA state that in addition to the risk of developing toxicity in the form of hypercalcaemia and hypercalciuria, they considered the impact of vitamin D intake on long-term health outcomes (including all-cause mortality, cardiovascular disease, cancer as well as other conditions), although the studies were considered to be inconsistent (67). More research is therefore required to identify a serum 25(OH)D level at which chronic adverse health effects are observed, and a full assessment of the dietary vitamin D intake that would be required to reach and exceed these levels, in the absence of vitamin D obtained from the sun, is necessary.

6.3.5. Implications of findings

This simulation provides evidence for the first time that a national scheme to fortify a staple food with vitamin D in the UK would improve the vitamin D intakes and status of groups at risk of deficiency without increasing the risk of other groups from exceeding current maximum intake and status levels. Prior to implementing any fortification strategy policy makers would have to weigh up their decision for which fortification scenario to implement. It is likely they would choose a scenario that benefits as many people as possible without putting any individuals at risk, which seems to be met by fortification at 10μg vitamin D per

100g flour. Flour is a ubiquitous food consumed in a large variety of composite foods. Although some individuals are unable to eat wheat flour, including individuals with coeliac disease (1% of the UK population (187, 188)) and wheat intolerance (unknown proportion (189)), the proportion of the population is likely to be relatively small. The majority of the population therefore, including vulnerable groups, would likely benefit from flour fortification. Use of the D_2 form would be preferable to ensure flour containing foods remain suitable for the vegan diet, although this form may not be as effective at improving vitamin D status as D_3. It is important to consider these results in the context of the uncertainty surrounding the recommendations for vitamin D intakes and status.

It should be noted that fortified foods consumed in large quantities (e.g. flour and milk) tend to have low levels of fortification (<5µg vitamin D per 100g) whereas products consumed in smaller quantities (such as margarines) tend to be fortified at higher levels (5 to 13µg vitamin D per 100g) (see table 2). The 10µg vitamin D per 100g flour reflects label fortification (excluding 'overage') at 8.9µg per 100g flour. As a comparison, the one brand of bread known to be fortified with vitamin D in UK is fortified at the equivalent of only 3.2µg per 100g flour. It is therefore possible that a level lower than 10µg (8.9µg excluding 'overage') per 100g would be chosen for fortification in order to minimise the risk of excess consumption of vitamin D. This would have a reduced impact on intakes and status.

6.3.6. Other examples of fortification simulation

There are a number of published examples of fortification simulation (101-104). A similar approach to this analysis was taken by Crane *et. al.* in their model of the impact of folic acid fortification of cereal grain products and ready to eat cereals in the US (104). Food consumption data from a national food consumption survey, equivalent to the NDNS, were used to simulate fortification for a variety of scenarios by manipulating individual dietary data, as was carried out in this thesis. Fortification of breakfast cereals were found to increase folate intakes of those at the high end of the distribution (95^{th} percentile), but not those at the low end (25^{th} percentile), whereas fortification of cereal grain products increased intakes across the distribution. The analysis presented in this thesis supports Crane's *et. al.* finding that cereal grains, such as flour, are suitable vehicles for reaching vulnerable groups of the population due to their wide use in the diet. The conclusion that fortification of ready to eat breakfast cereals only served to improve intakes of those already sufficient for folate (104), supports the idea that voluntary fortification of foods such as breakfast cereals is less effective at reaching those with poor nutrient intakes compared to more staple foods.

The exercise to simulate fortification of flour with folic acid published by SACN used very similar methods as described in this analysis. Updated NDNS data were used to simulate fortification at a range of different levels by manipulating the folate levels of flour containing foods consumed by individuals (110). Changes in population mean folate intakes were assessed as well as the proportion of the population failing to meet the RNI for folate and exceeding the UL for folic acid at different levels of fortification. SACN also used published relationships between folate intake and folate status (111-113) to determine the potential reduction in neural tube defect-affected pregnancies observed for fortification at a range of levels. This could be compared to the use of the Cashman *et. al.* intake/status relationships (117, 118) in this thesis, although the effect on neural tube defect-affected pregnancies takes the impact of fortification a step further by looking at health outcomes. SACN's analysis also demonstrated that flour was a suitable vehicle for improving nutrient intakes of those most at risk (i.e. women of childbearing age). The committee proposed that mandatory fortification of flour with 300µg folic acid per 100g without voluntary fortification would provide a more even distribution of intakes supplying necessary folate to those with low intakes at risk of neural tube defect-affected pregnancies, while preventing high intakes from voluntary fortification in others. This further supports the case for mandatory fortification over voluntary fortification as a policy option to improve nutrient intakes. This is discussed further in section 6.6.3.

With specific reference to vitamin D, simulation calculations involving fortification of milk, bread, spread and cheese seemed to influence the decision to introduce voluntary fortification of milk and spreads in Finland in 2003 (107). The Federal Office of Public Health in Switzerland also commissioned an analysis to look at the impact of increasing vitamin D intakes through manipulating dietary intake data including increasing levels of fortification. They concluded that controlled fortification of a restricted number of frequently consumed foods, at higher levels than currently permitted in Switzerland would result in sufficient and safe population vitamin D intakes. They highlight however that the consumption data used were limited, based on a dietary survey carried out in only 32 adults aged 24 to 59 years (108). This compares to data from the first two years of the NDNS Rolling Programme used in this thesis, which were based on information collected from a larger, and therefore more nationally representative sample, of 2127 adults and children aged over 18 months (108).

Studies that have looked at the impact of biofortification of plants with micronutrients have used population average consumption figures (190, 191) or household purchase data (114) to assess the impact on population micronutrient intakes. These methods are not as accurate in determining the real impact of fortification compared to using consumption data for individuals, used in this study and those mentioned above (104, 110). Population average figures do not account for individual variation in food consumption and nutrient intake and therefore do not provide an indication of the distribution of micronutrient intakes. Using expenditure data at a household level does not consider food wastage within the household, food consumed out of the home or variations in individual consumption within the household.

6.3.7 Strengths and limitations of the simulation of fortification

This analysis has a number of strengths. It provides for the first time an opportunity to assess whether groups of the UK population at risk of vitamin D deficiency would benefit from introducing more vitamin D fortified foods in the UK. It used robust UK food consumption data for individuals, updated for the vitamin D composition of fortified foods and supplements, including an estimation of 'overage', providing a realistic estimate of baseline vitamin D intakes. A variety of fortification vehicles were tested that were known to be consumed in sufficient quantities and by a sufficient proportion of 'at risk' groups, and had already been seen to be successful in improving vitamin D status in RCTs. This increased the likelihood of fortification reaching 'at risk' groups. Fortification was simulated at a range of different levels in order to identify the level achieving the most desirable effect. A published relationship between vitamin D intake and status obtained from a setting as close to representing the UK as possible (Northern Ireland and Ireland) was then used, which enabled an assessment of the impact of fortification on serum 25(OH)D concentration. The impact of fortification was assessed for the whole population, as well as for those known to be at risk of poor vitamin D status.

The analysis was however only a theoretical simulation of fortification and there are many limitations that may influence whether these observations would be seen in practice. The first is in relation to the 'at risk' groups assessed. It was not possible to consider the impact of fortification on ethnic minorities or children aged under 18 months due to lack of consumption data for these groups. It was assumed that the dietary habits of all women of childbearing age were equivalent to pregnant and breast-feeding women. As dietary advice regarding fish consumption and dietary supplements differs for pregnant and breast-feeding women, their diets, specifically vitamin D intake, may in fact differ to women of childbearing age.

Large scale dietary surveys such as the NDNS carry a number of limitations including bias in dietary self-reporting (192) and non-response. In addition, four days of data collection may not reliably reflect longer-term vitamin D intake. Withstanding these limitations, the NDNS is recognised as a high quality survey representative of the UK population and was the best available for use in this study.

The analysis considers changes in vitamin D intakes following fortification, however should mandatory fortification of a staple food be introduced, consumption patterns may also change. Consumption of the vehicle of fortification within composite foods was considered, however a number of assumptions had to be made regarding the composition of flour and milk containing foods, which may be an under- or overestimation for some foods. A further limitation is that the estimation of vitamin D obtained from fortified food and supplements did not include vitamin D from fortified foods where the food was an ingredient within a composite food.

As the current practice of flour fortification/restoration is restricted to white and brown flour only, it may have been more appropriate to exclude wholemeal flour, to provide a more realistic picture of the impact of fortification. Excluding wholemeal flour from folate fortification in SACN's simulation had little effect on the proportion of the population estimated to have low folate intakes (110) suggesting those consuming wholemeal flour already have sufficient folate intakes and consumption of wholemeal flour maybe indicative of a healthier diet overall. It is likely therefore that the impact of excluding wholemeal flour from vitamin D fortification would minimal.

The simulation of fortification only focused on a limited number of foods, fortified at a small number of different levels. It is possible that fortification of a different combination of foods, at different levels may have provided more favourable results.

Further limitations include the assumption that all dietary vitamin D is absorbed, although absorption may in fact depend on the fat content of the diet. It also assumed equal efficacy of the different types of vitamin D on status (1), but as discussed this may not be the case (47).

There are also issues surrounding whether a standard level of fortification of 10μg vitamin D per 100g of flour would be achievable given the variability in the analysis of the vitamin D content of foods.

Given the uncertainty surrounding international recommendations, the impact of fortification on intakes and status varies depending on which reference values are used. As the UL is set at a safe level it may be perfectly safe to exceed the UL as seen in some fortification scenarios. Conversely, the level of vitamin D intake considered 'safe' in relation to chronic health effects still remains largely unknown, therefore as more information on the impact of vitamin D excess on chronic health outcomes becomes available intake levels much lower than the current ULs may be more appropriate. It may be therefore that the RNI and UL values used in the analysis relevant to the UK are not the most appropriate for achieving adequate health. Until evidence based thresholds are determined it is not possible to accurately determine the proportion of the population at risk of poor health due to insufficient or excess vitamin D.

Models predicting a relationship between vitamin D intake and serum 25(OH)D concentration are limited in their application as they are specific to the characteristics of the population used to create the model. The model used to estimate serum 25(OH)D concentrations in this study is based on only two

RCTs carried out in Northern Ireland and Ireland, an area comparable, but not the same as the UK. Use of the Cashman *et. al.* equations assumed many similarities between the UK population and the Cashman *et. al.* (117, 118) populations. The possible inaccuracies of this assumption are discussed in detail in the following section, resulting in uncertainty regarding the level of precision in the winter estimates of serum 25(OH)D concentration obtained in this analysis at a given level of vitamin D intake.

It would have been useful to assess the impact of fortification on the proportion of the population with predicted serum 25(OH)D levels above and below certain thresholds (i.e. below 25nmol/l and 30nmol/l and above 75nmol/l, and 125nmol/l) to determine the prevalence of deficiency and risk of excess at varying levels of fortification. Having received the Cashman *et. al.* equations and tested their use, it was evident that they were inappropriate for estimating status at the individual level. It was not possible therefore, to determine the distribution of serum 25(OH)D within the population or the proportion with serum 25(OH)D levels below or above set thresholds.

The variability of assays used to assess serum 25(OH)D levels result in difficulties in comparing results between laboratories. This not only raises further concerns regarding the use of the Cashman *et. al.* relationships to predict serum 25(OH)D levels determined in laboratories in Ireland and Northern Ireland, but also regarding comparing serum 25(OH)D levels achieved in the NDNS with other studies, specifically in countries where laboratories may not be signed up to schemes such as the Vitamin D External Quality Assessment Scheme (DEQAS). Comparisons of the prevalence of deficiency defined by comparing serum 25(OH)D levels to minimum status thresholds such as 25nmol/l may risk being inaccurate.

In relation to estimating the impact of vitamin D deficiency on bone health, there is limited evidence of a dose-response relationship for vitamin D intake and status for health outcomes. In addition, little is known about the effect vitamin D has on health on its own or in combination with calcium deficiency. This analysis assumes that if vitamin D intakes improve, vitamin D status improves and therefore bone health is likely to be improved, but it is not known the extent to which this is the case, especially if calcium remains deficient.

6.3.7.1 Limitations of the relationship between vitamin D intake and status

The comparison of serum 25(OH)D data from NDNS blood samples for individuals aged 11 to 64 years and winter estimates derived from the Cashman *et. al.* equation in adults aged 20 to 40 years shows similar mean values ranging from 41nmol/l to 48nmol/l across groups from blood data, compared to 38nmol/l to 41nmol/l using the equation. This suggests the average level of sun exposure and vitamin D intake is comparable between the NDNS and Cashman *et. al.* populations (117). The 2.5th and 97.5th percentile of serum 25(OH)D concentrations however, suggest a wider range from blood analysis compared to estimates using the equation. This suggests that the NDNS population is more diverse in its dietary vitamin D intake and sun exposure compared to the Cashman *et. al.* population (117).[15] The Cashman equation is based on winter serum levels, whereas the NDNS blood samples were collected throughout the year. The highest levels seen in the NDNS are likely to reflect summer samples,[16] and the lowest levels are likely to reflect the winter samples, although this suggests winter serum levels are lower in the NDNS population compared to the Cashman *et. al.* population. Cashman *et. al.* (117) found that even in winter, serum 25(OH)D levels of adults often exposed to summer sunshine were higher than those who avoided the sun, suggesting that summer sun exposure does have an impact on winter serum 25(OH)D levels. Therefore differences in the composition of the NDNS and Cashman populations may have influenced the serum 25(OH)D levels observed in the winter depending on the abilities of individuals to convert vitamin D in the skin during the summer months. For example, as older adults have a poorer efficiency at converting vitamin D in the skin compared to younger adults, using the relationship established in younger adults (aged 20 to 40 years) may not be appropriate for adults up to 65 years. A greater ethnic diversity in the larger NDNS population may also have resulted in more individuals with lower serum 25(OH)D concentrations compared to the Cashman *et. al.* (117) population. These factors may explain why the 2.5th percentile in the NDNS was lower than predicted using the Cashman relationship.

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[15] The vitamin D intake/status equations were based on bloods collected in 215 individuals aged 20 to 40 years (Cashman *et. al.* 2008) and 204 individuals aged 64 years and above (Cashman *et. al.* 2009). The NDNS data were based on 526 individuals aged 11 to 64 years (Bates *et. al.*, 2011b).

[16] Unfortunately, it was not possible to test this, as data for the month in which the blood samples were collected were not available within the NDNS data

In this analysis the Cashman *et. al.* relationship for adults aged 20 to 40 years was used for determining serum 25(OH)D levels in all children and adults under the age of 65 years. IOM concluded that all ages under minimal sun exposure with similar vitamin D intakes have similar serum 25(OH)D levels (1), however Cashman *et .al.* found differing relationships for younger (117) compared to older adults (118), which may be explained by the reduced dermal conversion in older adults during the summer (1) resulting in reduced stores during the winter. Cashman *et. al.* (118) also found differences in the relationship between sexes in older adults. This could be due to variations between the sexes in summer sun exposure or varying dermal conversion due to the effect of hormones or some other factor/s. Such differences in the relationship between intake and status suggest there may also be variations between ethnicities, for children (as they have a larger skin surface area to body volume ratio compared to adults), and perhaps between sexes at other ages.

Identification of accurate relationships between vitamin D intake and status is critical in determining suitable dietary intakes required to maintain serum 25(OH)D levels above 25nmol/l. The most reliable approach would be to exclude the contribution from the sun, as this varies due to level of exposure (affected by season, use of sunscreen and clothing), latitude, ethnicity and age. This would be difficult to do in practice as the role and mechanism of vitamin D storage is so uncertain and there would be practical and ethical implications of designing a study requiring no sun exposure. Even in the absence of sun exposure, a number of additional factors may affect the vitamin D intake/status relationship in individuals such genetic variations and body mass index (BMI), making it difficult to establish a universal relationship to fit the whole population.

6.4 Research contribution

Over recent years there has been much discussion surrounding whether the UK population, specifically groups at risk of vitamin D deficiency, would benefit from further vitamin D fortification. The systematic review extends existing evidence of increasing serum 25(OH)D concentrations observed following ingestion of vitamin D fortified foods and drinks by identifying that fortification can improve status at a population level for some groups. It provides new evidence of a lack of data on the impact of national vitamin D fortification schemes, particularly in groups at risk of vitamin D deficiency.

The exercise to update food composition data for vitamin D provides evidence that UK composition data require updating regularly to keep abreast of changes in fortification, analytical methods and farming practices and that not taking into account 'overages' added during fortification and in supplementation underestimates vitamin D intakes by only 3%.

The outcomes of the simulation of vitamin D fortification provides evidence for the first time that vitamin D fortification of a staple food such as flour in the UK would be a viable option for improving vitamin D intakes and status of population groups at risk of deficiency without increasing the risk of others exceeding current reference thresholds. It may therefore be a useful option for potentially reducing vitamin D diseases in the UK.

This thesis provides useful evidence to policy makers that flour, more so than milk or milk and flour together, would be a suitable vehicle for vitamin D fortification as it would likely reach those known to be at risk of poor vitamin D status including young children, older people and pregnant and breastfeeding women; and that fortification at 10µg per 100g of flour would be likely to reduce the proportion of the population at risk of deficiency without putting others at risk of exceeding current maximum intake reference thresholds.

6.5 Further research requirements

The requirement for further research surrounding vitamin D is substantial. There is still much to be confirmed in relation to its biology; the potency of different forms of vitamin D; the relationship between intake and serum 25(OH)D levels; the effect of stores on winter serum 25(OH)D levels; the potential impact of deficiency on bone health and other chronic diseases, both in the presence and absence of calcium deficiency; and the potential impact of excess vitamin D intake on chronic disease risk at levels below those seen to cause toxicity. As a result of these uncertainties, there is also uncertainty in the reference thresholds for minimum (RNI, RDA, EAR) and maximum intake (UL) and status levels.

Further research is therefore required to identify a range of serum 25(OH)D levels that would achieve greatest benefit to the health of the population as a whole and the vitamin D intake levels required to reach these serum levels.

Assessment of the association between vitamin D intake and serum 25(OH)D levels is needed, specifically whether the associations vary between sexes and for different population groups such as children, pregnant and breast-feeding women and ethnic minorities.

It is also essential that more research is carried out into the impact of stores on vitamin D status, and whether the body is able to utilise in the winter vitamin D sequestered within adipose tissue during the summer months. It should also be determined as to whether there are in fact any beneficial effects of having reduced vitamin D status during the winter months, and whether supplementation or fortification to improve poor vitamin D status may be detrimental in any circumstances.

Further research is required in relation to establishing reliable analyses of vitamin D status to ensure that data can reliably be compared nationally and internationally. Detailed national data on the dietary habits and serum 25(OH)D concentration of ethnic minorities and pregnant and breast-feeding women living in the UK are essential in order to accurately determine the extent of the issue of vitamin D deficiency, and the effect that any fortification strategy would have on intakes for these groups.

Renwick *et. al.* (109) proposed a more desirable method for assessing risk in relation to intake of a nutrient, by providing a range of values rather than comparing point estimates such as the RNI and UL. This would be useful for policy makers in assessing the risks of deficiency and excess in relation to vitamin D. Once more evidence becomes available on the dose-response relationship between vitamin D intake and health outcomes an assessment using such a method is recommended.

The impact of national vitamin D fortification schemes in relation to intakes and status of population sub-groups known to be at risk of deficiency such as ethnic minorities, young children, pregnant and breast-feeding women and older people, as well as the impact of fortification on long term health outcomes particularly bone health should be monitored.

Prior to introducing a scheme to mandatorily fortify a food with vitamin D consumer research on the public acceptability of vitamin D fortification would need to be carried out, similar to the research carried out by the Food Standards Agency in relation to folic acid fortification (193).

6.6 Policy options for improving vitamin D status

The following section looks at the various options to improve vitamin D status of the UK population in the context of these findings. In setting their recommendations, the IOM committee assumed individuals do not receive vitamin D from the sun, but that they rely solely on dietary intake (1). This is in contrast to the UK approach, which assumed individuals aged 4 to 50 years achieve reference levels through summer sunshine exposure alone (3). Blood data from the NDNS indicate that low serum 25(OH)D levels are not just an issue for groups of the population traditionally considered at risk of vitamin D deficiency, as nearly a fifth of male adults, for whom no RNI is set, had serum 25(OH)D levels below 25nmol/l. The reality therefore must lie somewhere between the US/Canadian and UK approaches i.e. sun exposure is likely to contribute to serum 25(OH)D concentrations during the summer months, but dietary vitamin D may be required to ensure adequate status throughout the rest of the winter.

6.6.1 Supplementation

The current UK policy to improve vitamin D status in groups considered at risk of deficiency is supplementation. Given that the majority of 'at risk' groups currently have intakes below minimum reference nutrient intakes and a high proportion of them will have low intakes after fortification, it is unrealistic that these levels can be met through a change in diet alone. Supplementation may therefore be the only way to achieve RNIs intakes at a population level. Supplement uptake is however poor amongst groups most at risk of deficiency. The assessment of the contribution of dietary sources to vitamin D intake suggested that parents from higher socio-economic groups were more likely to provide their children with vitamin D supplements than parents from lower socio-economic groups even though these children might be at a greater risk of deficiency. As supplement use requires an active behaviour change, 'at risk' population groups need to be educated of the risks of vitamin D deficiency and recommendations for supplementation should be reinforced by health professionals. In 2012 UK Chief

Medical Officers wrote to health practitioners advising universal prescription of vitamin D supplements to groups at risk of deficiency (87), with the aim of improving vitamin D status of those most at risk.

If however, all individuals within 'at risk' population groups took a supplement, individuals with an adequate vitamin D status may be putting themselves at the risk of consuming excess vitamin D. Prospective studies have found adverse effects, in terms of allergic outcomes (e.g. asthma and eczema), in children whose mothers had high vitamin D status (>75nmol/l) during pregnancy (194) and those supplemented during infancy (195). A number of observational studies have also found high levels of vitamin D intake to be associated with increased cancer risk (including pancreatic, prostate, oesophageal and colorectal cancers), as has also been seen with a number of other nutrients with anti-oxidative properties such as selenium and vitamin E (69). Although these pieces of evidence are limited in their quality, they highlight a potential risk that blanket supplementation of sub-groups of the population may be putting individuals who are sufficient in vitamin D at risk from being exposed to excess. A more tailored approach to improving the vitamin D status of groups of the UK population at risk may therefore be required.

6.6.2. Sun exposure

Due to the poor uptake of dietary supplements, the poor variety of foods naturally rich in vitamin D and the specificity of voluntarily fortified foods, the sun remains the best source for maintaining adequate serum 25(OH)D levels during the summer in the UK. Although it provides an excellent source of vitamin D in small doses, in excess, the sun can cause considerable damage to the skin leading to skin cancer. Unfortunately, the time of the year and time of day when the sun offers the greatest potential for synthesis of vitamin D in the skin is the time when the risk of skin cancer is also at its greatest. The Department of Health therefore recommends individuals take action to avoid harmful UVB rays by avoiding the midday sun, covering up and using sunscreen (196). However the Department also recommends 10 to 15 minutes of daily sun exposure during the summer without sunscreen to maintain healthy vitamin D levels, covering up before turning red or beginning to burn, with the most effective time of day being between 11am and 3pm (197). These mixed messages appear on different sections of the NHS Choices website and may be confusing to readers. They should be incorporated, so that an individual reading about how to protect themselves in the sun to avoid skin cancer can also read about the benefits of the sun as a source of vitamin D and vice versa. A general statement available on both the skin cancer and vitamin D sites along the following lines would be useful: *10 to 15 minutes of daily summer sun exposure without sunscreen is recommended to maintain healthy vitamin D levels, with the most effective time of day being between 11am and 3pm. To prevent skin cancer avoid spending long periods in the midday sun and apply sun cream or cover up before turning red or beginning to burn.*

Although this message is generally reflective of the available evidence in relation to skin cancer risk and level of sun exposure required for vitamin D synthesis, it is not a risk-free message. Individuals vary in the length of time they can withstand being in the sun unprotected before they burn, and for some individuals with fair skin this maybe only one minute. It is therefore difficult to balance guidance for some sun exposure to ensure adequate vitamin D status with no risk of skin cancer. Policy makers are therefore unlikely to relax their guidance on sun exposure to improve the vitamin D status of specific population groups.

6.6.3 Mandatory vs. voluntary fortification

A policy option to regulate the mandatory fortification of staple foods with vitamin D is more likely to increase intakes of 'at risk' groups compared to the current approach of recommending supplements, because individuals would need to make an active choice not to consume the fortified food. The risk from consuming excess vitamin D from fortified or supplemental sources (as opposed to sun exposure and natural sources, which do not seem to pose a risk, see section 1.2.6) would however be equivalent for fortified foods as for supplements. A policy to encourage consumption of more foods naturally rich in vitamin D may be considered more attractive to minimise risk, although, as natural sources of vitamin D are few this is unlikely to be practicable.

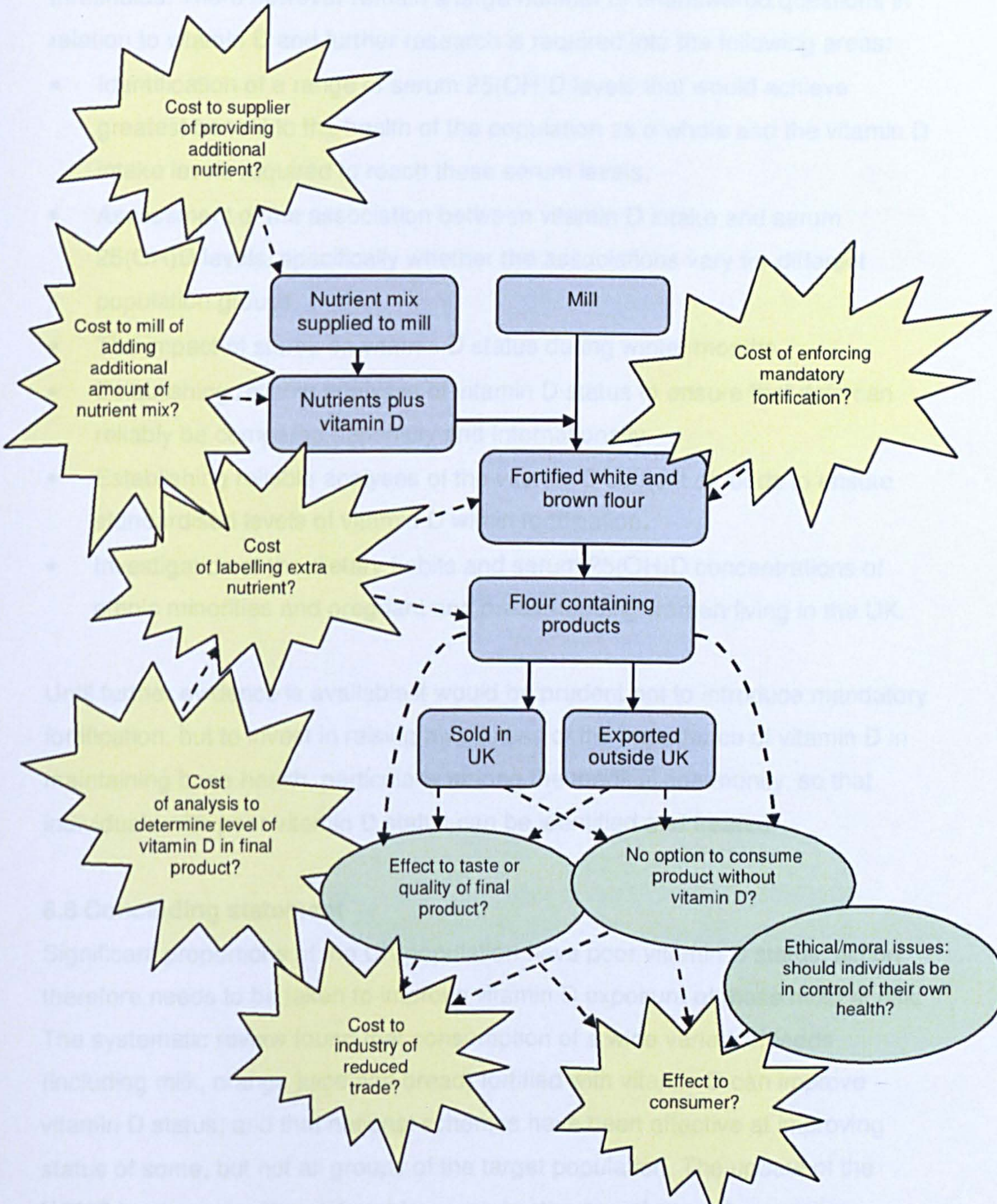
Even though fortification seems to provide a solution to improving nutrient intakes of those most at risk, the future of mandatory fortification in the UK is unclear. As part of the Government's '*Red Tape Challenge*' to reduce the level of enforced regulation, current legislation enforcing mandatory fortification of foods is under review and maybe abolished (198). In addition to this, in 2006, SACN advised mandatory fortification of flour with folic acid would reduce neural tube defect-affected pregnancies (110). In spite of this advice, folic acid fortification has yet to be agreed by Health Ministers six years later. A voluntary approach to fortification may therefore be a more realistic prediction of a future policy initiative to improve vitamin D intakes. Practices of voluntary fortification in the UK are however unpredictable. Manufacturers choose which foods to fortify, at which levels and often choose premium products that are less likely to be consumed by vulnerable groups of the population. The impact of voluntary fortification is difficult to simulate as it is impossible to accurately predict which foods would be fortified and at what levels. It has been shown that fortifying ready to eat cereals only served to improve the nutrient intakes of those who were already sufficient (104) and voluntary fortification has been seen to cause significant proportions of the population to exceed maximum intake thresholds for nutrients (110). A voluntary approach to fortification may result in a greater range of foods being fortified with vitamin D, however as this analysis demonstrates, fortifying both flour and milk simultaneously at the levels assessed, did not provide a more favourable outcome than fortifying with flour alone at the right level. This suggests that fortification of one food consumed by a large proportion of the population, particularly those at risk of deficiency, is more effective at reaching those with low vitamin D intakes compared to fortifying a wide range of foods. Little is known about the difference in the impact mandatory (e.g. in Canada and Israel) compared to voluntary (e.g. in Finland and the US) schemes to fortify staple foods with vitamin D have had on vitamin D intakes and status. A mandatory scheme would however be preferable for the UK as it would be possible to regulate the foods fortified and levels of fortification used, minimising the risk of excessive consumption.

Before considering introducing mandatory fortification there are many issues policy makers would have to consider. If vitamin D were added to flour alongside existing nutrients in the mill there would be practical and economic implications to a number of parties, presented in figure 18:

- The supplier of the nutrients would need to include an additional vitamin into the 'nutrient mix' supplied to the mill;
- The milling industry would need to increase the amount of the 'nutrient mix' added to the flour, and include vitamin D on the labelling of flour;
- The UK Government would need to oversee the enforcement of mandatory vitamin D fortification of flour;
- The food industry would need to label all white and brown flour-containing food products with vitamin D. There may be technical issues associated with adding vitamin D to foods, such as affecting the taste and quality of the product. There is also a risk to industry of a potential reduction in trade of flour and flour containing products both within and outside of the UK should consumers choose not to purchase vitamin D fortified products;
- Consumers may choose to change their purchasing habits in order to consume unfortified products for ethical or health reasons, or if the quality of the fortified food was affected.
- There is also the potential issue of over fortification to consider. A considerable risk from excess vitamin D would be posed to consumers should manufacturers overestimate the dose of vitamin D used in fortification (as has been seen in fortification of milk in the past (58)).

Many of these issues and more were raised in relation to the UK Food Standards Agency proposal to fortify flour with folic acid (199). There would be many other issues to consider if the current practice of adding nutrients to flour was discontinued or if fortification was restricted to bread-making flour only for example. UK ministers would all have to agree to mandatory fortification before a UK-wide strategy could be implemented.

Figure 18: Potential issues for policy makers to consider prior to implementing a strategy to fortify flour with vitamin D



6.7 Recommendation

The data simulation of fortification suggests that introducing mandatory fortification of flour at 10μg vitamin D per 100g flour in the UK would considerably reduce the proportion of individuals at risk of poor vitamin D status from having intakes below the UK minimum reference intake thresholds without risking other groups of the population from exceeding current maximum thresholds. There however remain a large number of unanswered questions in relation to vitamin D and further research is required into the following areas:

- Identification of a range of serum 25(OH)D levels that would achieve greatest benefit to the health of the population as a whole and the vitamin D intake levels required to reach these serum levels.
- Assessment of the association between vitamin D intake and serum 25(OH)D levels, specifically whether the associations vary for different population groups.
- The impact of stores on vitamin D status during winter months.
- Establishing reliable analyses of vitamin D status to ensure that data can reliably be compared nationally and internationally.
- Establishing reliable analyses of the vitamin D content of foods to ensure standardised levels of vitamin D within fortification.
- Investigation of the dietary habits and serum 25(OH)D concentrations of ethnic minorities and pregnant and breast-feeding women living in the UK.

Until further evidence is available it would be prudent not to introduce mandatory fortification, but to invest in raising awareness of the importance of vitamin D in maintaining bone health, particularly among the medical community, so that individuals with poor vitamin D status can be identified and treated.

6.8 Concluding statement

Significant proportions of the UK population have poor vitamin D status; action therefore needs to be taken to improve vitamin D exposure of those most at risk. The systematic review found that consumption of a wide variety of foods (including milk, orange juice and bread) fortified with vitamin D can improve vitamin D status; and that national schemes have been effective at improving status of some, but not all groups of the target population. The update of the NDNS food composition dataset increased estimates of current population vitamin D intakes by 3% and consideration of a standard level of 'overage' applied during fortification increased estimated population intakes by a further 3%. A computer-based data processing exercise to simulate the effect of fortifying flour with vitamin D at 10µg vitamin D per 100g flour showed that the proportion with vitamin D intakes below the UK RNI would be reduced from a current level of 97% to 53%, without anyone exceeding the European UL. Fortification of flour at this level improved intakes across all socio-economic groups and was found to be more effective than fortification of milk, as well as simultaneous fortification of milk and flour.

Fortification would provide an opportunity for improving vitamin D intakes and status in the UK, however further research is required prior to taking such action, in particular to clarify vitamin D intake and status levels associated with optimum health and the analytical methods used to measure these quantities. In the meantime, the UK Government should invest in raising awareness of the importance of vitamin D in maintaining bone health and identifying and treating those with poor status.

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APPENDICES

Appendix 1: NDNS food codes containing greater than 1µg of vitamin D per 100g/ml known to contain foods naturally rich in vitamin D that were excluded from extract of vitamin D fortified foods and supplements.

Food Code	Food code name	Vitamin D content µg per 100g/ml
1500	Bloater grilled	25.00
1487	Herring no bones coated blended	21.70
1488	Herring no bone coated dripping	20.10
1489	Herring no bone coated fry lard	20.10
1490	Herring no bone coated fry PUFA	20.10
9292	Cods roes fresh grilled	19.35
1486	Herring raw	19.00
1622	Roe cod hard raw	18.00
1491	Herring coated flour fried blend veg oil with bone	16.70
1501	Bloater grilled weighed with bones	16.20
1495	Herring grilled no bones	16.10
1499	Herrings pickled	16.00
1493	Herring with bones coated fried in lard	15.48
1494	Herring with bones coated fried in PUFA oil	15.48
9264	Pilchards in tomato sauce canned	14.00
1527	Sprats coated fried in dripping	13.00
1528	Sprats fried in lard	13.00
1529	Sprats fried in PUFA oil	13.00
9265	Salmon red canned in brine fish only	12.50
8837	Trout fried in polyunsaturated oil	12.38
1535	Whitebait coated fried in blended oil	12.30
1536	Whitebait coated flour fried in dripping	12.30
1537	Whitebait coated flour fried lard	12.30
1538	Whitebait coated fried in PUFA oil	12.30
10428	Sardines, fresh, grilled	12.30
1497	Herring canned in tomato sauce	11.97
1625	Roe cod hard battered fry lard	11.37
1626	Roe cod hard battered fry PUFA	11.37
1623	Roe cod hard battered blended	11.01
1530	Trout steamed fish only	11.00
2729	Swordfish, grilled	11.00
8272	Trout smoked baked etc no bones	11.00
1496	Herring grilled weighed with bones	10.90
9267	Salmon unspecified canned in brine fish only	10.85
621	Milk dried skimmed with added non milk fat	10.50
5936	Curried canned pilchards	10.04
1502	Kipper baked	9.40
7826	Salmon, pink, canned in brine fish only	9.20
7827	Salmon canned in brine fish and backbone	9.20
9266	Salmon red canned in brine fish and bones	9.20
9268	Salmon unspecified canned in brine with bones	9.20

Food Code	Food code name	Vitamin D content µg per 100g/ml
2737	Rock salmon/dogfish raw	9.10
9932	Fresh tuna steak grilled	9.00
1504	Kipper no bones baked butter	8.99
1644	Mackerel unsmoked baked/grilled no bones no butter	8.80
1603	Fish paste not smoked mackerel or smoked trout pate	8.75
1640	Roe cod hard batter fry comm	8.62
1507	Mackerel no bone coated blended	8.58
1508	Mackerel no bones coated dripping	8.58
1509	Mackerel no bones coated lard	8.58
1510	Mackerel no bones coated PUFA	8.58
4028	Fresh tuna fried in vegetable oil	8.49
1506	Mackerel raw	8.20
3304	Mackerel cooked in white wine, no bones, no skin	8.05
1525	Sardines brisling sild canned in tomato sauce	8.00
1531	Trout steamed weighed with bones	8.00
1647	Mackerel smoked not canned	8.00
8270	Mackerel smoked canned in oil fish only	8.00
8273	Trout smoked baked etc with bones	8.00
7825	Kipper boil in bag boiled	7.90
9541	Salmon, grilled or baked	7.83
1598	Curried oily fish	7.50
9936	Tuna fresh raw	7.20
1539	Dogfish battered fried blended oil no bones	6.83
1540	Dogfish battered fried in dripping no bones	6.83
1541	Dogfish battered no bones fried in lard	6.83
1542	Dogfish battered no bones fried in PUFA oil	6.83
1543	Dogfish battered no bones fried commercial oil	6.83
752	Egg whole dried	6.75
3847	Mackerel canned in mustard sauce, fish and sauce	6.48
1544	Dogfish battered with bones fried blended oil	6.35
1545	Dogfish battered with bones fried in lard	6.35
1546	Dogfish battered with bones fried in dripping	6.35
1547	Dogfish battered with bones fried in PUFA oil	6.35
1548	Dogfish battered with bones fried commercial oil	6.35
1628	Roe herring soft fry blended	6.30
1511	Mackerel with bones coated fried in blended oil	6.26
1513	Mackerel with bones fried in lard	6.26
1514	Mackerel with bones fried in PUFA oil	6.26
1484	Eel stewed flesh only	6.13
1503	Kipper baked weighed with bones	5.90
1594	Caviar	5.87
1505	Kipper with bones baked butter	5.66
9153	Sushi, salmon based	5.63
1517	Mackerel canned in brine fish only	5.60
8745	Smoked mackerel fillets canned in brine	5.60
3734	Egg yolk fried in butter	5.48
3948	Egg yolk only, fried in vegetable oil	5.41

Food Code	Food code name	Vitamin D content µg per 100g/ml
619	Milk condensed whole sweetened	5.40
1515	Mackerel canned in oil fish only	5.40
1632	Roe herring soft fried hard margarine	5.32
1520	Salmon steamed no bones	5.24
1498	Herring canned in oil fish only	5.00
1523	Sardines brisling slid canned in oil, fish only	5.00
1526	Sprats fried in blended oil	5.00
1593	Anchovies, canned, fish only	5.00
1645	Mackerel unsmoked baked/grilled with bones no butter	5.00
9905	Herring roe grilled	5.00
753	Egg yolk raw	4.94
785	Egg yolk only boiled	4.94
4105	Salmon fried in vegetable oil	4.94
1483	Eel raw	4.90
8081	Salmon mousse purchased	4.90
2796	Marinated huss	4.88
1629	Roe herring soft fry in butter	4.74
1518	Mackerel in tomato sauce	4.70
1631	Roe herring soft fried in lard	4.67
1633	Roe herring soft fried PUFA	4.67
1519	Salmon, raw	4.65
3169	Sardines, canned, in brine	4.60
7828	Pilchards canned in brine fish only	4.60
1521	Salmon steamed weighed with bone	4.55
1516	Mackerel unsmoked canned fish and oil	4.43
1524	Sardines canned in oil fish and oil	4.10
1627	Roe herring soft raw	4.00
622	Milk evaporated	3.95
1534	Tuna canned in brine fish only	3.60
3960	Tuna, canned, in spring water, fish only	3.60
2820	Sushi, tuna based	3.57
6644	Salmon fishcakes retail	3.55
2823	Salmon in batter	3.52
1639	Smoked mackerel pate	3.30
5902	Salmon en croute with sauce & puff pastry	3.15
4713	Evaporated milk low fat canned	3.14
7837	Red snapper fried	3.00
1533	Tuna canned in oil fish only	3.00
10222	Tuna canned in olive oil fish only	3.00
1485	Eel jellied	3.00
2831	Salmon ocean pie e.g. youngs	2.98
9666	Salmon in watercress sauce	2.98
8130	Tuna mayonnaise homemade	2.95
9699	Salmon steaks in aparagus sauce	2.93
9271	Tuna pate	2.90
1038	Pork fat average cooked	2.69
5250	Salmon crumble	2.69

Food Code	Food code name	Vitamin D content µg per 100g/ml
760	Egg fried in margarine	2.61
761	Egg fried in PUFA	2.60
9856	Tuna twist in Mediterranean tomato & herb dressing (john west)	2.59
9332	Egg fried in solid sunflower oil	2.58
6555	Scrambled eggs with reduced fat spread and whole milk	2.47
4050	Egg fried in reduced fat PUFA spread (70-80% fat)	2.44
780	Scrambled egg marg & milk	2.39
8638	Scrambled egg with skimmed milk and PUFA marg	2.38
1532	Tuna in oil fish and oil	2.37
9402	Pork crackling cooked	2.31
6138	Salmon fishcakes grilled	2.24
765	Omelette cooked in margarine	2.20
8598	Egg poached in water with added fat	2.17
8149	Dried skimmed milk powder	2.10
1189	Liver chicken fried no coating	2.10
7763	Egg fried without fat	2.07
757	Egg fried in butter	2.04
1634	Taramasalata	2.00
756	Egg fried in blended oil	1.97
758	Egg fried in dripping	1.97
759	Egg fried in lard	1.97
8732	Egg fried in olive oil	1.97
9356	Egg fried in compound cooking fat	1.97
9683	Egg fried in palm oil	1.97
9698	Salmon fishcakes fried in olive oil	1.97
769	Omelette sweet fried marg	1.96
770	Omelette sweet fried PUFA	1.95
777	Omelette ham fried in marg	1.93
778	Omelette ham fried in PUFA	1.92
1266	Beefburgers 100% fried	1.90
7765	Scrambled egg without milk	1.88
5683	Sausages roll s. Pastry made with all margarine	1.88
773	Omelette cheese fried marg	1.87
774	Omelette cheese fried PUFA	1.87
8727	Scrambled egg with semi skimmed milk & PUFA marg	1.87
9845	Egg fried in ccf	1.83
2889	Tuna mousse with mayonnaise	1.83
751	Egg whole raw	1.80
782	Scrambled egg milk no fat	1.80
2611	Egg after baking/boiling	1.80
1289	Grillsteaks beef fried or grilled	1.80
8264	Beefburger 100% grilled	1.80
3883	Tuna burgers coated in batter/breadcrumbs grilled	1.80
7008	Salmon and broccoli in puff pastry, purchased	1.77
2721	Scrambled eggs with skimmed milk and no fat	1.76
10141	Smoked salmon pate	1.76
755	Eggs boiled	1.75

Food Code	Food code name	Vitamin D content µg per 100g/ml
762	Egg poached	1.75
784	Duck egg boiled	1.75
9200	Quail eggs boiled	1.75
10445	Eggs, chicken, with omega 3	1.75
6509	Cheese omelette fried in flora	1.70
8735	Scrambled eggs with semi skimmed milk & olive oil	1.66
5388	Omelette pepperoni	1.64
763	Omelette cooked in blended oil	1.61
766	Omelette cooked in PUFA	1.61
779	Scrambled egg with whole milk	1.61
8779	Cheese & onion quiche homemade	1.61
9303	Scrambled egg with semi-skimmed milk	1.61
9334	Omelette (plain) fried in olive oil	1.61
9639	Omelette plain fried in lard	1.61
9930	Omelette fried in ccf	1.61
8099	Tuna mayonnaise sandwich fillers	1.60
783	Egg boiled weighed with shell	1.56
6315	Tuna quiche	1.56
781	Scrambled egg PUFA& milk	1.54
2755	Hollandaise sauce	1.54
2808	Tomato sauce with sardines	1.53
4218	Tuna and potato fish cakes	1.51
9672	Quiche, salmon based, purchased	1.50
776	Omelette ham fried in butter	1.50
816	Plain soufflé	1.50
9428	Veal mince stewed fat not skimmed	1.50
768	Omelette sweet cooked in butter	1.49
6989	Chicken tikka masala, takeaway	1.48
8066	Egg mayonnaise purchased	1.46
767	Omelette sweet fried blended	1.44
772	Omelette cheese cooked in butter	1.44
775	Omelette ham fried in blended	1.44
3741	Scrambled egg with semi-skimmed milk and spreadable butter	1.43
9387	Chicken curry ready meal frozen chilled no rice	1.43
1052	Veal fillet raw	1.40
771	Omelette cheese fried blended	1.39
8037	Salmon and new potato steamed ready meal	1.39
9090	Omelette-fried in lard	1.37
7766	Curried omelette /egg masala	1.36
1199	Liver pig fried no coating	1.36
1037	Pork fat average raw	1.35
1051	Veal fillet escalope schnitzel fried lean only	1.35
8608	Tuna in coronation style dressing	1.32
8798	Liver ox baked in oven no fat	1.31
1331	Spare ribs in barbecue sauce no bones	1.30
1235	Corned beef	1.30
1341	Corned beef not canned	1.30

Food Code	Food code name	Vitamin D content µg per 100g/ml
4015	Sausage and onion pie, iceland only	1.29
4086	Chicken omelette cooked in blended vegetable oil	1.27
1157	Sausage, chicken and turkey, grilled, fried	1.27
6857	Omelette, ham & onion, fried in butter	1.26
8846	Corned beef pasty purchased	1.25
8667	Corned beef pie	1.25
4108	Chopped ham and pork with egg	1.25
5735	Pork escalope pork in e&c fried in vegetable oil	1.23
8711	Scrambled egg no fat semi skimmed milk	1.22
2809	Tuna pasta	1.22
8071	Sausage roll flaky pastry purchased	1.21
1306	Sausage roll flaky pastry	1.21
1257	Liver pate deli	1.20
1258	Liver pate plastic wrapped	1.20
1256	Liver pate canned	1.20
4001	Ox liver fried in blended	1.20
1200	Liver pig coated fry blended	1.19
1203	Liver pig coated fry PUFA oil	1.19
3165	Pigs liver (coated) fried in olive oil	1.19
10498	Semi-skimmed dried milk powder	1.17
2710	Quiche, cheese and onion, purchased	1.16
9861	Cheese & tomato quiche	1.15
1026	Pork loin chops steaks grilled lean & fat no bone	1.15
9463	Pork spare ribs belly grilled lean & fat	1.15
8860	Chicken & mushroom pancakes purchased grilled oil	1.14
1205	Liver pig raw	1.13
9875	Turkey & ham crispbakes (eg Tesco)	1.12
1020	Pork belly rashers slices roast lean & fat no bone	1.10
1226	Ox liver raw	1.10
1276	Sausages beef fried	1.10
3784	Pork sausages, very low fat, grilled	1.10
7792	Sausages premium pork fried	1.10
7790	Sausages beef skinless fried	1.10
1314	Steak & kid pie 2 crusts s/c pastry not ind. Or ca	1.10
8731	Steak pie lean two crusts shortcrust PUFA marg	1.10
1263	White pudding	1.10

Appendix 2: NDNS food and supplement codes identified as fortified/containing vitamin D

Food Code	Food code name	Vitamin D content µg per 100g/ml
201	All Bran Kellogg's only	3.20
202	Branflakes Kelloggs only	4.20
203	Sultana Bran Kellogg's only	3.20
206	Cornflakes own brand not Kellogg's	5.00
210	Grapenuts	1.70
223	Special K Kellogg's	8.40
228	Multigrain start Kellogg's	4.20
649	Buildup slender slimming drink powder	4.50
860	Hard block margarines and fats (75-90% fat)	7.90
862	Hard margarine unspecified/recipes	7.90
2305	Complan	4.40
2310	Horlicks Original powder	4.00
2635	Horlicks low fat instant dry weight	3.10
2718	Calcium tablets (600mg) plus vitamin D (3 micro gram)	3.00
2739	Slimfast rtd meal replacement drink	0.54
2849	Flora Pro Activ Light spread only	7.50
2970	Special K with red berries	7.50
3008	Honey & nut bran flakes own brand	6.30
3220	Slimfast drink (powder only)	10.34
3243	Benecol light spread	7.50
3246	Chewable calcium (500 mg) & vitamin D (10 microgram)	10.00
3364	Benecol olive oil spread	7.30
3410	So good, fortified soya drink	0.86
3769	Soya alternative to milk, fortified	0.75
3785	Ensure liquid vitamin + mineral supplement	1.73
3807	Fortisip protein nourishment drink	1.13
3848	Benecol buttery taste spread only	7.50
3891	Light spreadable butter (60% fat)	3.29
3892	Very low fat spread (20-25% fat), polyunsaturated, low in trans fatty acids, fortified	7.50
3922	Rusks original plain	13.00
4051	Vitamin d capsule 400iu (10mcg)	10.00
4084	Oat and bran flakes no additions own brand eg Asda	2.80
4331	Ricicles (Kellogg's)	4.20
5327	Fruit and fibre own brand fortified (not vit D) not Kellogg's	2.50
5440	Calcuim (400 mg) and vitamin d (5 microgram) capsule	5.00
5634	Dunn's River Nourishment	1.20
7019	Lighter Life Total Balance soup powder fortified	3.70
7025	Kelloggs All Bran crunchy oat bakes	3.20
7027	Flora no salt fat spread	7.50
7226	Chocolate energy and protein bars, fortified, with sweeteners eg Atkins Advantage	2.47
7623	Bran flakes, own brand, not Kellogg's	5.00
7624	Branflakes with sultanas, own brand	3.50
7626	Frosted cornflakes, own brand, not Kellogg's	5.00
7630	Rice Krispies own brand not Kellogg's	5.00

Food Code	Food code name	Vitamin D content µg per 100g/ml
7669	Rusks low sugar not flavoured	14.00
7670	Rusks flavoured not low sugar	13.00
7672	Rusks low sugar flavoured	15.00
7775	Reduced fat spread (41-62%) not polyunsaturated	5.83
7930	Aptamil first infant formula dry weight	8.70
7931	Cow & Gate first infant formula, dry weight	8.70
7932	Ostermilk (farley's) dry weight	13.55
7933	SMA first infant formula milk, dry weight (formerly Gold)	9.40
7934	SMA first infant milk ready to feed cartons	1.20
7935	Cow & Gate infant formula for hungrier babies, dry weight	8.50
7936	Ostermilk two (Farley's) dry weight	11.00
7937	Milumil dry weight	8.55
7938	SMA extra hungry infant milk formula dry weight (formerly SMA white)	8.73
7939	SMA extra hungry infant infant formula milk, ready to feed carton	1.10
7940	Oster soy (Farley's) dry weight	8.00
7941	Cow & Gate Infasoy infant formula dry weight	9.40
7942	Enfamil Prosobee dry weight	8.11
7943	SMA wysoy soya infant formula dry weight	8.33
7944	Junior milk (farley's) dry weight	7.80
7945	SMA follow-on formula milk, dry weight (formerly Progress)	12.00
7984	Boots follow on milk dry weight	16.04
8013	Special K Berries any fruit addition not choc or yogurt	7.45
8014	Special K Bliss with choc or yogurt pieces	7.05
8132	Ensure plus yogurt style	1.70
8151	Asda Golden Balls cereal fortified	5.00
8182	Frosted malted wheat cereal, eg. Frosted Shreddies	2.80
8383	Nestle Coco Shreddies	2.10
8427	Asda choco flakes fortified	5.00
8458	Ovaltine max for milk powder, any flavour	6.30
8481	All bran type cereal, Sainsbury's Hi-Fibre Bran only	5.00
8482	All bran type cereal, e.g. Tesco bran, not Sainsbury's, Nestle, Alpen crunchy bran	4.37
8483	Cocoa pops own brand not Kellogg's	5.00
8616	Sainsburys fruit and yogurt balance bar fortified	0.03
8699	Farleys bedtimers chocolate drink enriched powder	10.00
8729	Milupa cereal breakfasts fortified made up with water	1.36
8737	Cow & gate infasoy infant formula made up	1.20
8852	Instant savoury baby food fortified dry weight	4.33
8901	Milupa semolina with honey infant dessert dry weight	4.80
8910	Boulders breakfast cereal, Tesco's	5.00
8936	Galactomin 17 low lactose infant formula dry weight	8.40
8941	Milupa infant cereals fortified dry weight eg. Sunshine orange	4.80
8948	Milupa instant cereals dry weight eg oat & apple	3.40
9011	Heinz stage 1 breakfast cereals for babies, fortified	10.00
9182	Boots follow on milk drink-banana/strawberry flavour. Dry weight	9.80
9277	Horlicks light malt chocolate instant dry weight	3.20
9278	Horlicks chocolate not instant not low fat dry weight	2.50
9302	Calcichew (500 mg calcium, 5 microgram D3)	5.00

Food Code	Food code name	Vitamin D content µg per 100g/ml
9330	Solid sunflower oil	7.50
9498	Lighterlife total balance meal bars any fortified	4.20
9499	Lighter life total balance soya protein powder fortified	3.90
9544	Vitamin D (5 microgram) and calcium (800 mg) capsules only	5.00
9637	Fortisip nutritionally complete supplement drink	1.10
10040	Fat spread (62-72% fat) not polyunsaturated	6.40
10041	Pure sunflower brand fat spread	7.50
10042	Reduced fat spread (41-62% fat) not polyunsaturated, with olive oil	5.00
10043	Reduced fat spread (41-62% fat) polyunsaturated	7.80
10044	Reduced fat spread (41-62% fat) polyunsaturated, fortified with B6, B12, folic acid	7.50
10045	Vitalite only	8.00
10047	Low fat spread (26-39% fat) not polyunsaturated	5.00
10048	Low fat spread (26-39% fat) not polyunsaturated, olive	5.00
10049	Low fat spread (26-39% fat) polyunsaturated	8.40
10050	Low fat spread (26-39% fat) polyunsaturated, fortified with B6, B12, folic acid	7.50
10051	Low fat spread (26-39% fat) polyunsaturated, fortified with B6, B12, folic acid, omega 3 from fish	7.50
10052	Flora extra light	7.50
10053	Flora Pro Activ olive oil only	7.50
10054	Flora Pro Activ extra light only	7.50
10078	Bassetts soft and chewy vitamins A,C,D,E	5.00
10079	Boots complete A to Z	5.00
10081	Tesco multivitamin	5.00
10082	Multivitamins with iron	5.00
10083	Vitabiotics Pregnacare original	10.00
10085	Healthspan multivitamins and minerals '50 plus' with ginkgo	10.00
10087	Holland and Barrett ACB plus tablets only	5.00
10088	Holland and Barrett multivitamin tablet only	2.50
10090	Sanatogen vital 50+ tablet only	5.00
10091	Seven Seas multibionta probiotic multivitamin only	5.00
10093	Vitabiotics Osteocare tablets only	2.50
10094	Zipvit multivitamin and mineral tablets only	5.00
10097	Calcium 600mg and vitamin D3 10mcg only	10.00
10099	Asda multivitamins one a day only	5.00
10102	Boots childrens A to Z chewable multivitamins and minerals only	7.50
10103	Boots teenage A to Z chewable multivitamins and minerals only	10.00
10104	Boots multivitamin syrup 4 months to 12 years only	3.50
10107	Calcichew D3 forte 500mg calcium 10mcg vitamin D3 only	10.00
10108	Multivitamin and mineral; Centrum or Flinndal	5.00
10112	Seven Seas Haliborange multivitamin liquid only	3.50
10113	Seven Seas Haliborange vitamin A,C,D chewable tablet	5.00
10114	Healthspan hair and nails tablet	2.50
10116	Healthspan A to Z complete spectrum mulitvitamins and minerals	5.00
10120	Calcium 400mg and vitamin D 2.5mcg	2.50
10127	Tesco childrens multivitamins and minerals	5.00
10131	Tesco enriched fat spread with olive oil	5.00
10134	Seven seas cod liver oil extra strength 1050mg	5.00

Food Code	Food code name	Vitamin D content µg per 100g/ml
10135	Cod liver oil 525mg with vits A 800mcg, vitamin D 2.5mcg and vitamin E 0.3mg	2.50
10140	Half fat butter, salted, with vitamin A and D	5.00
10148	Cod liver oil liquid	5.00
10150	Seven Seas Probrain 700mg fish oil with ginkgo	1.47
10151	Cod liver oil 550mg with vitamins A,D,E	5.00
10159	Oat based milk alternative fortified	0.50
10160	Hipp organic stage 1 creamy porridge stage 1 dry weight fortified	8.00
10162	Cod liver oil 400mg with 800mcg vit A and 5mcg vit D	5.00
10164	Sanatogen kids A to Z multivitamin and mineral	5.00
10165	Cod liver oil oil 1000mg capsule with added vitamins A,D,E	5.00
10170	Vitabiotics Visionace multivitamin and mineral	2.50
10171	Vitabiotics Perfectil multivitamin and mineral	5.00
10172	Vitabiotics Menopace tablet	5.00
10173	Cod liver oil 615mg	1.67
10174	Extra high strength cod liver oil liquid	2.50
10175	Cod liver oil 1000mg with no added vitamins	2.10
10176	Cod liver oil 1000mg with added vitamins A and D	5.00
10185	Viper extreme energy bar	2.47
10191	Multivitamins with 15mg zinc	5.00
10193	Childrens fish oil 185mg with vits A,D,E	2.50
10194	Asda kids multivitamins and minerals	2.50
10197	Cornflake type cereals frosted unfortified	5.00
10199	Childrens fish oil 200mg with added vitamins A,C,D,E	2.50
10205	Lifeplan multivitamin tablets	5.00
10212	Multivitamin drops for babies and children	10.00
10217	Childrens fish oils 250mg with vitamins A,C,D,E	2.50
10218	Petit filous fromage frais	1.50
10224	Cod liver oil 500mg and evening primrose 500mg with vitamins A,D,E	5.00
10225	My protein multivitamin tablets	2.50
10228	Zipvit cod liver oil 1000mg only	6.75
10229	Cod liver oil 650mg and evening primrose oil 200mg with vitamins A,D	5.00
10238	Nestle Nestum honey cornflake cereal fortified	6.30
10241	Vivioptal junior multivitamin and mineral liquid	2.50
10243	Cow & Gate growing up milk, made up	1.70
10244	Abidec multivitamin syrup with omega 3	2.50
10246	Bassetts soft and chewy multivitamins blackcurrant flavour	5.00
10248	Aptamil follow on milk, made up	1.40
10249	Valupak multivitamins and minerals	5.00
10252	Cod liver oil 550mg with vitamins A,D	5.00
10257	New day honey hoops cereal fortified	5.00
10266	Childrens cod liver oil syrup with vitamins A,C,D,E	2.50
10274	Choco hoops cereal fortified	5.00
10278	Boots hair skin and nails supplement with EPO	5.00
10280	Cow and Gate sun moon and stars cereal 1 year+	13.30
10283	Shapeworks multivitamin and mineral complex	3.30
10290	Reduced fat spread (41-62% fat) not polyunsaturated, fortified with	4.90

Food Code	Food code name	Vitamin D content µg per 100g/ml
	omega 3 from fish oils	
10291	Cod liver oil 500mg and calcium 300mg supplement	3.13
10292	Superdrug 50+ multivitamins and minerals	5.00
10313	Boots 550mg cod liver oil with 400mg calcium and vits A,D,E,K	5.00
10314	Holland and Barrett cod liver oil and vitamins A and D	10.00
10321	Bertolli light fat spread	4.90
10322	Morrisons trim flakes breakfast cereal	8.00
10325	Pharmaton capsules	5.00
10337	Biocare multivitamin and mineral tablet	6.25
10339	Sainsburys multivitamin and mineral supplement	5.00
10340	Kordels junior time multivitamin and mineral	2.50
10345	Superdrug super one multivitamin and mineral supplement	10.00
10349	Coral calcium supreme supplement	6.80
10351	Boots gummy bears chewy multivitamin supplement	5.00
10353	Minadex vitamin and mineral tonic for children	1.63
10355	Kelloggs Special K Sustain cereal	4.20
10360	Sanatogen gold multivitamin and mineral tablet	5.00
10361	Calcium 500mg and vit D 1.25mcg	1.25
10362	Healthy Start childrens multivitamin drops	1.50
10363	Multivitamin bpc tablets	7.50
10364	Childrens multivitamin capsules with omega 3	2.50
10365	Bassetts early health vitamins A,B6,C,D,E	5.00
10369	Little man choco moon breakfast cereal fortified	5.00
10370	Cow and gate comfort follow-on milk, dry weight	9.40
10371	Aptamil growing-up milk ready to drink	1.70
10378	Superdrug time release multivitamin and mineral tablet	10.00
10379	Cow and Gate creamy porridge dry weight fortified	11.10
10382	Cod liver oil 500mg and multivitamins	5.00
10384	Healthspan multivitamin and mineral jelly bears	6.00
10386	Cow and gate my first muesli fortified	10.00
10387	Cod liver oil 410mg with vit A 375mcg and vit D 3.37mcg	3.37
10391	Malt extract and cod liver oil syrup	18.60
10393	Tesco chewburst omega 3 with vitamins A,C,D,E	2.50
10404	Multivitamin with iron and iodine	5.00
10408	Ketovite liquid	10.00
10411	Paediasure plus liquid (nutritionally complete)	1.10
10413	Cheese spreads, triangles, plain, Dairylea only	3.90
10415	Vitabiotics pregnacare breastfeeding capsules	10.00
10419	Higher nature true food supernutrition plus supplement	1.67
10423	Eniva vibe multivitamin and mineral liquid supplement	41.70
10432	Boots multivitamin and iron (includes other minerals)	5.00
10435	Crisp flake cereal with fruit and nuts fortified	1.10
10436	Reduced fat spread 59%, not PUFA, fortified with vitamins A/D/E/B1/B2/B6/B12	7.50
10439	Holland and Barrett ABC senior+ multivitamin and mineral	10.00
10443	Viridian Viridikid multivitamin and mineral tablets	7.00
10444	Cow and Gate follow on milk powder for infants 6+ months made up	1.40
10449	Vitabiotics wellkid smart multvitamins and minerals	5.00

Food Code	Food code name	Vitamin D content µg per 100g/ml
10450	Higher nature true food wise woman supplement	2.50
10452	Fortini 1.5kcal/ml nutritionally complete liquid supplement	1.50
10458	Solgar female multiple multivitamin and mineral	3.40
10466	Actimel probiotic drinking yogurt	0.05
10474	Bassetts omega 3 with vitamins A,C,D,E	5.00
10477	Calcia calcium supplement with vitamins and iron	2.50
10486	Tesco multivitamin and mineral supplement	5.00
10487	Morrisons right balance breakfast cereal fortified	5.00
10489	Holland and Barrett radiance multivitamin and mineral	2.50
10491	Dairylea strip cheese fortified with calcium and vitamin d	4.20
10494	Kirkland daily multivitamin and mineral supplement	10.00
10498	Semi-skimmed dried milk powder	1.17
10504	Processed cheese spread low fat, Dairylea only	3.90
10507	Processed cheese slices/singles Dairylea only	3.50
10509	Processed cheese slices/singles, low fat, Dairylea only	3.50
10511	Shreddies Nestle only, not frosted not coco	2.80
10513	Crunchy nut cornflakes own brand, not Kelloggs	5.00
10521	Hipp good night infant formula milk, stage 1 (6mth+) made up	1.20
10526	Bassetts active health vitamin and mineral chews	5.00
10528	Nutramigen infant formula (2) from 6 months, made up	1.10
10529	Nanny care growing up milk, 12 months+, dry powder	7.80
10532	Asda milkshake mix fortified	6.60
10533	Orovite 7 vitamin powder	2.50
10546	Floradix kindervital for children	1.80
10552	Wassen serenoa-c supplement	2.50
10555	Wellkid baby and infant vitamin and mineral liquid	2.50
10559	Forticreme complete	1.70
10605	SMA toddler milk, 1 year+, dry weight only	11.00
10606	SMA toddler milk, 1 year+, made up	1.50
10607	SMA follow-on infant formula milk, made up (previously progress)	1.50
10608	SMA extra hungry infant formula milk, made up (previously SMA white)	1.10
10609	SMA first infant formula milk, made up (previously SMA gold)	1.20
10610	SMA wysoy soya infant formula milk made up	1.10
10611	Cow and Gate first infant formula milk, made up	1.20
10612	Cow and Gate infant formula milk for hungrier babies, made up	1.20
10613	Cow and Gate follow-on milk, 6 months+, dry weight	9.70
10614	Cow and Gate growing up milk, 1 year+, dry weight	11.00
10615	Cow and Gate goodnight milk, 6 months+, dry weight	8.70
10616	Cow and Gate goodnight milk, 6 months+, made up	1.30
10617	Aptamil first infant formula, made up	1.20
10618	Aptamil extra hungry infant formula, dry weight	8.50
10619	Aptamil extra hungry infant formula, made up	1.20
10620	Aptamil follow-on infant formula milk, dry weight	9.70
10621	Aptamil growing-up milk formula, toddlers 1 year+, dry weight	11.00
10622	Aptamil growing-up milk formula, toddlers 1 year+, made up	1.70
10623	Hipp organic first infant milk formula, dry weight	8.15
10624	Hipp organic first infant milk formula, made up	1.10

Food Code	Food code name	Vitamin D content µg per 100g/ml
10625	Hipp organic follow on infant milk formula, dry weight	7.80
10626	Hipp organic follow on infant milk formula, made up	1.10
10627	Hipp organic follow on infant milk formula, ready to drink carton	1.40
10628	Hipp organic growing up milk, 10 months+, dry weight	8.50
10629	Hipp organic growing up milk, 10 months+, made up	1.20
10630	Hipp organic growing up milk, 10 months+, ready to drink carton	1.40
10631	Hipp organic goodnight milk, 6 months+, dry weight	8.51
10632	Nutramigen infant formula (2) from 6 months, dry powder	7.53
10645	Cow and Gate breakfast cereals, flavoured, stage 1 4 month+, dry	11.60
10657	Heinz dinners stage 2, golden vegetable and chicken, fortified, dry	10.00
10659	Heinz stage 2 breakfast cereals for babies, fortified	10.00
10660	Heinz stage 3/4 breakfast cereals for babies, fortified	6.00
10662	Cow and Gate tropical fruit cereal stage 2 fortified	9.30

Appendix 3: Spreadsheets sent to trade associations and manufacturers to obtain up-to-date vitamin D values for fortified foods and supplements

Table 3a: Spreadsheet sent to the British Retail consortium (BRC) to obtain up-to-date vitamin D values of fortified foods of members' brands

Company: British Retail Consortium (BRC)	Vitamin D (µg/100g or 100ml)	Source	Updated Vitamin D content (µg/100g or 100ml)
SAINSBURY'S			
Sainsbury's Olive spread	On ingredients list	Sainsbury's website	
Sainsbury's Butterlicious light (not butter)	5.0		
Sainsburys un/sweetened soya milk and basics	0.8		
Sainsbury's fresh soya milk	On ingredients list		
Sainsbury's Rice Pops	5.0		
Sainsbury's Choco Rice Pops (not value)	5.0		
Sainsbury's Cornflakes & Frosted flakes	5.0		
Sainsbury's Honey nut cornflakes	5.0		
Sainsbury's Choco Flakes	5.0		
Sainsbury's Bran Flakes	5.0		
Sainsbury's Hi Fibre Bran	5.0		
Sainsbury's Fruit and Fibre/Fruit and Fibre Basics	5.0		
Sainsbury's choc chip Balance cereal bar	4.1		
Sainsbury's red fruit Balance cereal bars	3.7		
Sainsbury's Sultana Bran	3.5		
Sainsbury's Basics cereal bar chocolate chip	On ingredients list		
Tesco Olive fat spread	7.5	Tesco website	
Tesco Olive fat spread light, enriched	5.0		
Tesco Butter me up & light	5.0		
Tesco sunflower fat spread & light/soft/value spread	On ingredients list		
Tesco Finest greek olive fat spread	6.6		
Tesco fresh sweetened soya milk	0.8		
Tesco Cornflakes	5.0		
Tesco Honey Nut Cornflakes	5.0		
Tesco Branflakes & Value	5.0		
Tesco Frosted Flakes	5.0		
Tesco Rice Snaps/Choco Snaps	5.0		
Tesco Sultana Bran	3.5		
Tesco Light Choices cereal bar (chocolate and orange flavour)	On ingredients list		
Asda sunflower & light fat spread	7.5	Asda website	
Asda Best for Baking soft margarine	On ingredients list		
Asda Olive spread & light	On ingredients list		
Asda Best for Baking You'd Butter Believe it	On ingredients list		

Company: British Retail Consortium (BRC)	Vitamin D (µg/100g or 100ml)	Source	Updated Vitamin D content (µg/100g or 100ml)
Asda You'd Butter Believe It Light	7.5		
Asda sweetened soya milk, smart price unsweetened	0.7		
Asda Vitality breakfast cereal	8.0		
Asda Vitality Banana	6.7		
Asda Vitality blueberry	6.4		
Asda Vitality Red berries	7.6		
Asda Frosties	5.0		
Asda Golden Balls	5.0		
Asda Chocoflakes/Chocohoops/Chocosnaps	5.0		
Asda Honey Hoops	5.0		
Asda Rice snaps	5.0		
Asda Cornflakes	5.0		
Asda Honey Nut Cornflakes	5.0		
Asda Vitality cereal bars, pomegranite, apple and raspberry, banoffee	On ingredients list		
Asda Measure up powder	3.5		
Asda Measure up drink	0.5		
Asda Measure up cereal bars	3.3		
Morrisons Soft Spread, Light better by far	On ingredients list	Morrisons store in Shepherd's Bush, London	
Morrisons Olive spread	7.5		
Morrisons Trim Flakes breakfast cereal with red berries	7.6		
Morrisons Right Balance breakfast cereal	6.4		
Morrisons Rice Crackles/Cornflakes	5		
Waitrose (Un)sweetened soya milk	On ingredients list	Ocado website	
Waitrose Cornflakes	On ingredients list		
Waitrose Honey Nut Cornflakes	On ingredients list		
Waitrose Fruit and Fibre	On ingredients list		
Waitrose Chocolate Rice Pops	On ingredients list		
Waitrose Rice Pops	On ingredients list		
Waitrose Frosted Flakes, Branflakes	5.0		

Table 3b: Spreadsheet sent to the British Specialist Nutrition Association (BSNA) to obtain up-to-date vitamin D values of fortified foods of members' brands

Company: British Specialist Nutrition Association (BSNA)	**Vitamin D (µg/100g or 100ml)**	**Source**	**Updated Vitamin D content (µg/100g or 100ml)**
Heinz Farleys rusks/Farleys biscuits/baby rice/creamy oat porridge/Breakfast porridge flavours/Breakfast sunrise banana/Breakfast fruit with yogurt/Breakfast Oat and Apple & Oat and banana & Summer fruits cereal/Mediterranean vegetables and rice	10.0	Heinz website	
Heinz Breakfast banana multigrain cereal/Mini berry flakes	6.0		
HIPP creamy porridge breakfast	On ingredients list	Asda website	
Aptimil multigrain breakfast/creamy porridge/with spelt	7.0		
Cow and Gate fruity crunch cereal	8.1		
Cow and Gate my first muesli/banana muesli/sunny start 10m	10.0		
Cow and Gate baby wheat flakes/multigrain banana porridge/tropical fruit cereal	9.3		
Cow and Gate baby's first muesli, banana and straw porridge 4m	7.0		
Cow and Gate banana/fruity porridge	11.6		
Cow and Gate creamy porridge	11.1		

Table 3c: Spreadsheet sent to the Food and Drink Federation (FDF) to obtain up-to-date vitamin D values of fortified foods of members' brands

Company: Food and Drink Federation (FDF)	Vitamin D (µg/100g or 100ml)	Source	Updated Vitamin D content (µg/100g or 100ml)
Product Name			
Weetabix			
Weetabix Alpen crunchy bran	4.3	Weetabix website	
Weetos	4.3		
Alpro			
Alpro soya milk original/light sweetened/sweetened soya drink(Sains only)/plus cholesterol/original and unsweetened long life/Junior milk	0.75	Alpro website	
Alpro soya milk light & unsweetened	0.76		
Alpro soya drink chocolate/Light 1l	0.75		
Alpro yogurt -all flavours	0.75		
Provamel soya drink unsweetened and sweetened with calcium (not flavoured)	0.8	Provamel website	
Provamel soya chocolate and vanilla dessert (not custard or caramel or mocha desserts)	On ingredients list	Provamel website	
Kraft			
Dairylea strip cheese	4.2	Sainsbury's website	
Dairylea Lunchables ham and cheese	1.05		
Dairylea lunchables chicken and cheese	1.14		
Dairylea Dunkers jumbo tubes/breadsticks	1.74		
Dairylea Ritz Dunkers	0.80		
Dairylea slices & light strip cheese/dunkers-Ritz/baked crisps/bread sticks/jumbo tubes/nachos	On ingredients list	Dairylea website	
Kerry Foods			
Pure sunflower/ soya fat spread	7.5	Pure website	
Danone			
Actimel yogurt drink strawberry/multi fruits	0.75	Actimel website	
Pepsico			
V Water Vital V Orange and Passion Fruit	0.5	V water website	

Table 3d: Spreadsheet sent to Glaxo Smith Kline (GSK) to obtain up-to-date vitamin D values of fortified foods of members' brands

Company: Glaxo Smith Kline (GSK)	Vitamin D (µg/100g or 100ml)	Source	Updated Vitamin D content (µg/100g or 100ml)
Product Name			
HORLICKS			
Horlicks original powder 300g	4.0	Horlicks website	
Horlick malted light refill/sachets Chocolate	3.2		

Table 3e: Spreadsheet sent to Kallo Foods to obtain up-to-date vitamin D values of fortified foods of members' brands

Company: Kallo foods	Vitamin D (µg/100g or 100ml)	Source	Updated Vitamin D content (µg/100g or 100ml)
Product Name			
SO GOOD			
So Good, sweetened/unsweetened drink/light/chocolate soya drink, SOYA life	0.3	So Good website	
So Good, Soya life	0.3		
So Good Soya milk Original/Light	0.85-0.9		
Oatly enriched drink/Chocolate drink	0.5	Oatly website	
Rice dream-Original	On ingredients list	Rice dream website	
Rice dream-Chocolate	On ingredients list		

Table 3f: Spreadsheet sent to Kellogg's to obtain up-to-date vitamin D values of fortified foods

Company: Kellogg's	Vitamin D (µg/100g or 100ml)	Source	Updated Vitamin D content (µg/100g or 100ml)
Product Name			
Kellogg's Branflakes	4.2	Kellogg's website	
Kellogg's Start	4.2		
Kellogg's All Bran	3.2		
Kellogg's Sultana Bran	3.2		
Kellogg's Special K	8.3		
Kellogg's Special K with Red Berries	7.5		
Kellogg's Special K peach and apricot	7.4		
Kellogg's Ricicles	4.2		
Kellogg's Choc and Roll	4.2		
Kellogg's Cornflakes	4.2		

Table 3g: Spreadsheet sent to Nestle and Cereal Partners to obtain up-to-date vitamin D values of fortified foods

Company: Nestle & Cereal Partners	Vitamin D (µg/100g or 100ml)	Source	Updated Vitamin D content (µg/100g or 100ml)
Product Name			
No Nestle breakfast cereals are fortified with vitamin D	0	Nesquik and Cereal Partners websites	
Nesquik strawberry/chocolate/banana milk shake dry mix	1.1 per 15g with 200ml semi skim milk	Nesquik website	
Milo chocolate energy drink	4.7	Sainsbury's website	
Nestle Cerelac rice with milk	5.0	Asda website	

Table 3h: Spreadsheet sent to Unilever to obtain up-to-date vitamin D values of fortified foods

Company: Unilever	Vitamin D (µg/100g or 100ml)	Source	Updated Vitamin D content (µg/100g or 100ml)
Product Name			
Unilever			
Stork fat spread	On ingredients list	Tesco /Asda websites	
Bertolli Olivio & light fat spread	On ingredients list	Sainsburys/ Tesco/Asda websites	
I Can't Believe it's Not Butter/Light fat spread	7.5		
Flora Original/Buttery/Light/proactive fat spread	7.5/8		
Slimfast rich chocolate/summer strawberry/café late/simply vanilla/blissful banana powder	11.5	Slimfast website	
Slimfast ready to drink blissful banana shake/Café latte/fruits of the forest/lemon meringue shake/raspberry crush/rich chocolate/simply vanilla/summer strawberry	0.6	Slimfast website	
Slimfast chocolate crunch meal bar Cinnamon and Raisin/Summer Berry/Chocolate Peanut	3.3	Slimfast website	

Table 3i: Spreadsheet sent to The Council for Responsible Nutrition (CRN), Proprietary Association of Great Britain (PAGB) and Health Food Manufacturers' Association (HFMA) to obtain up-to-date vitamin D values of supplements of members' brands

Company: The Council for Responsible Nutrition (CRN), Proprietary Association of Great Britain (PAGB) and Health Food Manufacturers' Association (HFMA)	**Vitamin D (µg/ capsule)**	**Source**	**Updated Vitamin D content (µg/capsule)**
Supplement code name- NDNS Nutrient Databank			
Superdrug super one multivitamin and mineral supplement		Superdrug store, Shepherd's Bush, London	
Superdrug time release multivitamin and mineral tablet			
Superdrug 50+ multivitamins and minerals			
Superdrug A-Z	5		
Superdrug calcium with vitamin D	2.50		
Boots 550mg cod liver oil with 400mg calcium and vitamins A,D,E,K	5	Boots store, Shepherd's Bush, London	
Boots gummy bears chewy multivitamin supplement	7.5		
Boots complete A to Z	5		
Boots multivitamin and iron (includes other minerals)	5		
Boots multivitamin syrup 4 months to 12 years only	3.5		
Boots hair skin and nails supplement with EPO			
Boots children's a to Z chewable multivitamins and minerals only			
Boots teenage A to Z chewable multivitamins and minerals only			
Holland and Barrett cod liver oil and vitamins A and D	15 & 5	Holland and Barratt store, Shepherd's Bush, London/ H&B website	
Holland and Barrett multivitamin tablet only	2.5	H&B website	
Holland and Barrett ABC plus tablets only	10		
Holland and Barrett ABC senior+ multivitamin and mineral	10		
Holland and Barrett Radiance multivitamin and mineral	2.5		
Sanatogen Vital 50+ tablet only	5	Tesco website	
Sanatogen kids A to Z multivitamin and mineral	5		
Sanatogen Gold multivitamin and mineral tablet	5	Sainsbury's website	
Bassetts omega 3 with vitamins A,C,D,E	5	Tesco website	
Bassetts soft and chewy multivitamins blackcurrant flavour	5		
Bassetts early health vitamins A,B6,C,D,E	5		
Bassetts active health vitamin and mineral	5	Asda	

Company: The Council for Responsible Nutrition (CRN), Proprietary Association of Great Britain (PAGB) and Health Food Manufacturers' Association (HFMA)	Vitamin D (µg/ capsule)	Source	Updated Vitamin D content (µg/capsule)
Supplement code name- NDNS Nutrient Databank			
chews		website	
Bassetts soft and chewy vitamins A,C,D,E	5		
Seven Seas multibionta probiotic multivitamin only	5	Tesco website	
Seven Seas Haliborange multivitamin liquid only	3.5	Sainsbury's website	
Seven Seas Haliborange vitamin A,C,D chewable tablet	5	Tesco website	
Seven Seas cod liver oil extra strength 1050mg	5		
Seven Seas Probrain 700mg fish oil with ginkgo		Could not find	
Multivitamin and mineral; Centrum or Flinndal	5	Sainsbury's website	
Healthspan multivitamin and mineral jelly bears	6	Health Span website	
Healthspan A to Z complete spectrum mulitvitamins and minerals	5		
Healthspan multivitamins and minerals '50 plus' with ginkgo	10		
Healthspan hair and nails tablet	2.5		
Sainsbury's multivitamin and mineral supplement	5	Sainsbury's website	
Asda Multivitamins one a day only	5	Asda website	
Tesco Multivitamin and mineral supplement	5	Tesco website	
Tesco Multivitamin	5		
Tesco Children's multivitamins and minerals	5		
Tesco Chewburst omega 3 with vitamins A,C,D,E	2.5		
Vitabiotics Pregnacare original	10		
Vitabiotics Perfectil multivitamin and mineral	5	Sainsbury's website	
Vitabiotics Menopace tablet	5	Tesco website	
Vitabiotics Osteocare tablets only	2.5	Boots store, Shepherd's Bush, London	
Vitabiotics Visionace multivitamin and mineral	2.5	H&B website	
Vitabiotics Pregnacare breastfeeding capsules	10	Tesco website	
Vitabiotics Wellkid Smart multvitamins and minerals	5	Boots store, Shepherd's Bush, London	
Wassen Serenoa-C supplement	2.5	H&B website	
Wellkid baby and infant vitamin and mineral	2.5	Boots	

Company: The Council for Responsible Nutrition (CRN), Proprietary Association of Great Britain (PAGB) and Health Food Manufacturers' Association (HFMA)	**Vitamin D (µg/ capsule)**	**Source**	**Updated Vitamin D content (µg/capsule)**
Supplement code name- NDNS Nutrient Databank			
liquid		store, Shepherd's Bush, London	
Minadex vitamin and mineral tonic for children	1.63	Sainsbury's website	
Zipvit cod liver oil 1000mg only	5	Zipvit website	
Zipvit multivitamin and mineral tablets only	5		
Abidec multivitamin syrup with omega 3	2.5	Asda website	
Lifeplan multivitamin tablets	5	Life plan website	
My protein multivitamin tablets	5	My Protein website	
Orovite 7 vitamin powder	2.5	Multipharmacy website	
Eniva Vibe multivitamin and mineral liquid supplement	84.5/42.3	Two flavours- fruit sensation and cardiac & life/ Enviva website	
Pharmaton capsules	5	Holland and Barratt store, Shepherd's Bush, London/ Website	
Floradix kindervital for children	0/1.8		
Coral calcium supreme supplement	0		
Kordels junior time multivitamin and mineral		Could not find	
Solgar female multiple multivitamin and mineral			
Shapeworks multivitamin and mineral complex			
Vivioptal junior multivitamin and mineral liquid			
Calcia calcium supplement with vitamins and iron			
Floradix Kindervital for children			
Higher Nature true food supernutrition plus supplement			
Higher nature true food wise woman supplement			
Ketovite liquid			
Healthy Start children's multivitamin drops			
Kirkland daily multivitamin and mineral supplement			
Viridian Viridikid multivitamin and mineral			

Company: The Council for Responsible Nutrition (CRN), Proprietary Association of Great Britain (PAGB) and Health Food Manufacturers' Association (HFMA)	**Vitamin D (µg/ capsule)**	**Source**	**Updated Vitamin D content (µg/capsule)**
Supplement code name- NDNS Nutrient Databank			
tablets			
Biocare multivitamin and mineral tablet			
Valupak multivitamins and minerals			
Calcichew D3 forte 500mg calcium 10mcg vitamin D3 only			
Calcichew (500 mg calcium, 5 microgram D3)			

Appendix 4: Summary of assumptions

Subject	Assumption	Comments
Natural vitamin D content of foods	The analytical values within the nutrient databank for vitamin D naturally present within foods reflect current values.	Variations in the content of naturally occurring vitamin D as a result of season or analytical methods were not accounted for.
Foods fortified with D and supplements	Vitamin D values available on the label and from manufacturers reflect up-to-date vitamin D levels of fortified foods and supplements.	Vitamin D values within the NDNS Nutrient Databank were compared to up-to-date values obtained from retailer and website information and updated where necessary to reflect current fortification practices. The updated codes were all brand-specific codes with the exception of baby rusks, so the vitamin D value was substituted for the new value. Three brands of rusks were identified, 2 unfortified and 1 fortified (at 10µg vitamin D per 100g). As the fortified brand was the brand leader (173), it was given double the weight of the other brands and fortification was assumed at half the label value of the fortified brand.
	A typical 'overage' of 12.5% for fortified foods and supplements at time of consumption.	• An 'overage' of **25%** was assumed for fortified foods and supplements on manufacture. • An average loss of **50%** of the 'overage' was assumed (through processing and degradation) at the time of consumption • An additional **12.5%** was added to the vitamin D content of fortified foods and supplements present within the NDNS Nutrient Databank (Appendix 5a&b). • This approach was approved by an expert in micronutrient 'overages' (164).
	No supplements or foods fortified with vitamin D were introduced into the market since the NDNS was carried out.	The following vitamin D fortified products were identified that were not represented by the NDNS nutrient databank: • 1 brand of fortified bread; • 1 own brand of fortified fruit juice, milk and yogurt; • 1 brand of processed cheese based snacks • a number of retailer own brand cereal bars. These vitamin D fortified foods were not considered within the analysis as it was not known in what quantity or frequency these foods would have been consumed, or by which individuals.

Subject	Assumption	Comments
Composite foods containing vitamin D fortified foods	Vitamin D values for composite products containing vitamin D fortified foods within the NDNS Nutrient Databank reflect current levels.	The proportion of vitamin D within some composite food products containing vitamin D fortified products such as margarine/fat spreads may have changed since the food composition data was obtained.
	No losses/gains in vitamin D content as a result of food processing.	Where recipes contain ingredients fortified with vitamin D such as margarine, fat spreads or fortified breakfast cereals, loss or gains in vitamin D through cooking or processing was not taken into account.
Proportion of vitamin D from fortified foods and supplements	All vitamin D in fortified foods is from fortification, no naturally vitamin D present.	In some vitamin D fortified foods there may be a natural level of vitamin D present such as fortified cheese.
Survey data	Dietary intake data from NDNS represents usual intake.	Dietary surveys such as the NDNS are prone to bias in reporting. No attempt was made to adjust the energy and nutrient intakes presented in the NDNS report to take account of under-reporting or non-response bias. In addition, natural food sources of vitamin D, such as oily fish, are often infrequently consumed, so four day diaries may not reflect longer term vitamin D intake.
Dietary patterns	Patterns of consumption following fortification did not change.	In reality introducing a mandatory scheme to introduce more foods fortified with vitamin D may encourage/discourage some individuals from consuming that food and therefore alter food habits.

<table>
<tr><th>Subject</th><th>Assumption</th><th colspan="2">Comments</th></tr>
<tr><td rowspan="20">Composition of foods containing flour and milk</td><td rowspan="20">Flour and milk are present at standard levels in composite foods, see table in comments box.

It was assumed other food codes consumed within the NDNS survey containing flour (pies, flans, quiches, breaded products) and milk not captured in these food groups contribute a minimal amount to total flour or milk consumption and were therefore excluded.</td><td>NDNS nutrient databank food group</td><td>Estimated % Flour (110)</td></tr>
<tr><td>White bread</td><td>63</td></tr>
<tr><td>Wholemeal & brown bread</td><td>60</td></tr>
<tr><td>Other breads</td><td>55</td></tr>
<tr><td>Pizzas</td><td>25</td></tr>
<tr><td>Other cereals, dumplings, Yorkshire puddings etc</td><td>25</td></tr>
<tr><td>Biscuits</td><td>50</td></tr>
<tr><td>Fruit pies</td><td>30</td></tr>
<tr><td>Buns Cakes & Pastries</td><td>45</td></tr>
<tr><td>Sponge type puddings</td><td>30</td></tr>
<tr><td>Other cereal based puddings (crumbles, bread pudding, pancakes, cheesecake trifle etc.</td><td>10</td></tr>
<tr><td>NDNS nutrient databank food group</td><td>Estimated % milk (NDNS nutrient databank)</td></tr>
<tr><td>Whole, semi-skimmed, skimmed milk</td><td>100</td></tr>
<tr><td>Milk based drinks (hot chocolate, milk shake etc.)</td><td>90</td></tr>
<tr><td>Cereal based milk puddings (rice puddings, blancmange, semolina etc.)*</td><td>62</td></tr>
<tr><td>Dairy desserts (crème caramel, egg custard etc.) *</td><td>60</td></tr>
<tr><td>Cream, Yogurt, cheese</td><td>0</td></tr>
<tr><td colspan="2">*only milk containing codes subgroups were identified for fortification.</td></tr>
<tr><td>Absorption of vitamin D</td><td>All dietary vitamin D is absorbed</td><td colspan="2">Actual absorption of vitamin D is likely to depend on the fat content of the diet.</td></tr>
<tr><td>Type of vitamin D</td><td>D_2 and D_3 are equally effective at increasing vitamin D status</td><td colspan="2">This was concluded by IOM (1), however recent evidence suggests D_3 may be more potent at raising serum 25(OH)D levels than D_2 (47).</td></tr>
</table>

Subject	Assumption	Comments
Population sample	Mid 2010 estimates were used to represent the UK population	Population estimates were based on Official National Statistics mid 2010 figures (175).
	It was assumed the groups most at risk from vitamin D deficiency in the UK are young children (1.5 to 3 years), pregnant and breast-feeding women (represented by women of childbearing age), and older people	As there are no recent dietary data available for infants aged under 18 months, the impact of fortification was focused on children aged 1.5 to 3 years, in line with RNIs. It is acknowledged that the Department of Health recommends supplements up to 5 years of age, however this analysis compared intakes to the RNI, which only relates to children up to 3 years.
		There are no national intake data available for pregnant and breast-feeding women as these groups are excluded from the national surveys. A large regional longitudinal study of pregnant women found that diets of pregnant women compared very closely to the diets of women aged 16 to 64 years, although vitamin D specifically was not mentioned in the report (165). Dietary advice for pregnant and breast-feeding women is the generally the same as for the general population, with the exception of supplemental vitamin D, exclusion of some foods for food safety reasons and a recommended limit of no more than two portions of oily fish per week. As supplement uptake and oily fish consumption are known to be low in women of childbearing age (21), it is assumed for the purposes of this analysis, that consumption patterns and dietary vitamin D intake of pregnant and breast-feeding women are equivalent to all women of childbearing age (aged 15 to 49 years).
		"Older people" were classified as adults aged 65 years and over, although an RNI is set for adults aged over 50 years.
		The analysis did not consider ethnic minorities among the 'at risk' groups There are no nationally representative data available for the diets of ethnic minority groups. The Low Income Diet and Nutrition Survey (LIDNS) provides a separate analysis for the Black and Asian population, however the number of subjects in each category are small and represents the low income population rather than the general UK ethnic minority population. Using a regional data would not be representative of the UK.
		Individuals at risk of vitamin D deficiency (due to poor sun exposure, living at northern latitudes, and in institutions, covering their skin for cultural reasons, excessive use of sunscreen, taking certain medication or with specific medical conditions that result in poor vitamin D status) were not included in this analysis as there were no consumption data available for these specific groups within the UK (5).

Subject	Assumption	Comments
Intake/status relationship	Sun exposure in the UK is equivalent to Ireland and Northern Ireland in winter	Using the Cashman *et. al.* (117, 118) vitamin D intake/status relationships assumed the UK population has an equivalent sun exposure compared to the population sampled in Ireland and Northern Ireland in winter. There may be inaccuracies in this assumption as there may be differences in sun seeking behaviour between the UK population as a whole as the population in Ireland and Northern Ireland and there may be differences in hours of sunshine experiences per year in the UK compared to Ireland and Northern Ireland. The resulting figures are an estimate of winter serum 25(OH)D levels and are not reflective of annual sun exposure.
	The vitamin D intake/status relationship proposed by Cashman *et. al.* (117) for adults aged 20 to 40 is applied to children and adults aged up to and including 64 years.	IOM found there was no effect of age on the response of serum 25(OH)D concentration to total vitamin D intake, concluding that all ages under minimal sun exposure with similar intakes have similar vitamin D serum status levels (1).
	Cashman *et. al.* (118) relationship identified for women aged 64 years and above is relevant for women aged 65 years and above	
	Cashman *et. al.*(118) relationship identified for men aged 64 years and above is relevant for men aged 65 years and above.	

Appendix 5a: List of fortified foods and supplements within the National Diet and Nutrition Survey (NDNS) nutrient databank updated in the analysis

		Vitamin D content (µg/100g)		
NDNS Food Code	NDNS Food code name	Previous NDNS nutrient databank value (no 'overage')	Updated label value 2011	Including addition of 12.5% 'overage'
10321	Bertolli light fat spread	4.9	7.5	8.4
10045	Vitalite only	8.0	0.0	0.0
7226	Chocolate energy and protein bars, fortified, with sweeteners e.g. Atkins advantage	2.5	0.0	0.0
3220	Slimfast drink (powder only)	10.3	11.5	12.9
2739	Slimfast rtd meal replacement drink	0.5	0.6	0.7
8458	Ovaltine max for milk powder, any flavour	6.3	0.0	0.0
2635	Horlicks low fat instant dry weight	3.1	3.2	3.6
9278	Horlicks chocolate not instant not low fat dry weight	2.5	3.2	3.6
10466	Actimel probiotic drinking yogurt	0.1	0.8	0.8
10355	Kelloggs Special K Sustain cereal	4.2	0.0	0.0
10322	Morrisons Trim flakes breakfast cereal	8.0	7.6	8.6
8014	Special K Bliss with choc or yogurt pieces	7.1	0.0	0.0
8383	Nestle Coco Shreddies	2.1	0.0	0.0
10511	Shreddies Nestle only, not frosted not coco	2.8	0.0	0.0
10487	Morrisons Right Balance breakfast cereal fortified	5.0	6.4	7.2
8182	Frosted malted wheat cereal, e.g. Frosted Shreddies	2.8	0.0	0.0
10413	Cheese spreads, triangles, plain, Dairylea only	3.9	0.0	0.0
10504	Processed cheese spread low fat, Dairylea only	3.9	0.0	0.0
7672	Rusks low sugar flavoured	15.0	5.0	5.6
7669	Rusks low sugar not flavoured	14.0	5.0	5.6
3922	Rusks original plain	13.0	5.0	5.6
7670	Rusks flavoured not low sugar	13.0	5.0	5.6
10415	Vitabiotics Pregnacare breastfeeding capsules	10.0	5.0	5.6
10093	Vitabiotics Oosteocare tablets only	2.5	5.0	5.6
10244	Abidec multivitamin syrup with omega 3	2.5	10.0	11.3
10450	Higher Nature true food wise woman supplement	2.5	0.8	0.9
10150	Seven Seas Probrain 700mg fish oil with ginkgo	1.5	0.0	0.0

		Vitamin D content (µg/100g)		
NDNS Food Code	**NDNS Food code name**	**Previous NDNS nutrient databank value (no 'overage')**	**Updated label value 2011**	**Including addition of 12.5% 'overage'**
10351	Boots gummy bears chewy multivitamin supplement	5.0	7.5	8.4
10443	Viridian Viridikid multivitamin and mineral tablets	7.0	7.4	8.3
10090	Sanatogen Vital 50+ tablet only	5.0	4.5	5.1
10498	Semi-skimmed dried milk powder	1.2	1.5	1.7
Previously unfortified codes				
10299	Slimfast bars; chocolate peanut and chocolate caramel	0.0	3.0	3.7
7235	Nesquik milk shake milk drink powder any flavour	0.0	4.7	5.3
2301	Nestle Milo choc malt drink fortified	0.0	4.7	5.3
8616	Sainsburys fruit and yogurt Balance bar fortified	0.0	3.7	4.2
205	Cornflakes Kellogg's only	0.0	4.2	4.7
7632	Weetos, chocolate covered rings	0.0	4.3	4.8
10493	Actimel probiotic yogurt drink 0.1% fat	0.0	0.8	0.8
9115	Alpro soya light yogurt, fruit, fortified	0.0	0.8	0.8

Note: Post analysis it was noticed that two supplement brands should have been updated:

- *My protein multivitamin tablets* (old value= 2.5µg; new value= 5µg)
- *Holland and Barrett ABC plus tablets only* (old value= 5µg; new value = 10µg). No one in the survey consumed the first of these, 5 individuals consumed the Holland and Barratt supplements.

Appendix 5b: List of fortified foods and supplements within the NDNS Nutrient Databank, not updated, with additional 12.5% 'overage' applied

		Vitamin D content (µg/100g/ml)	
NDNS Food Code	**Food Category**	**Previous NDNS nutrient databank value**	**Including addition of 12.5% 'overage'**
2849	Flora Pro Activ Light spread only	7.5	8.4
10052	Flora Extra Light	7.5	8.4
10054	Flora Pro Activ Extra Light only	7.5	8.4
10053	Flora Pro Activ Olive Oil only	7.5	8.4
7027	Flora No Salt fat spread	7.5	8.4
3243	Benecol light spread	7.5	8.4
3848	Benecol buttery taste spread only	7.5	8.4
3364	Benecol olive oil spread	7.3	8.2
10041	Pure sunflower brand fat spread	7.5	8.4
10131	Tesco enriched fat spread with olive oil	5.0	5.6
10140	Half fat butter, salted, with vitamin A and D	5.0	5.6
9330	Solid sunflower oil	7.5	8.4
10049	Low fat spread (26-39% fat) polyunsaturated	8.4	9.5
3892	Very low fat spread (20-25% fat), polyunsaturated, low in trans fatty acids, fortified	7.5	8.4
10050	Low fat spread (26-39% fat) polyunsaturated, fortified with B6, B12, folic acid	7.5	8.4
10051	Low fat spread (26-39% fat) polyunsaturated, fortified with B6, B12, folic acid, omega 3 from fish	7.5	8.4
10047	Low fat spread (26-39% fat) not polyunsaturated	5.0	5.6
10048	Low fat spread (26-39% fat) not polyunsaturated, olive	5.0	5.6
860	Hard block margarines and fats (75-90% fat)	7.9	8.9
862	Hard margarine unspecified/recipes	7.9	8.9
10043	Reduced fat spread (41-62% fat) polyunsaturated	7.8	8.8
10044	Reduced fat spread (41-62% fat) polyunsaturated, fortified with B6, B12, folic acid	7.5	8.4
10436	Reduced fat spread 59%, not PUFA, fortified with vitamins A/D/E/B1/B2/B6/B12	7.5	8.4
10040	Fat spread (62-72% fat) not polyunsaturated	6.4	7.2
7775	Reduced fat spread (41-62%) not polyunsaturated	5.8	6.6
10042	Reduced fat spread (41-62% fat) not polyunsaturated, with olive oil	5.0	5.6

		Vitamin D content (µg/100g/ml)	
NDNS Food Code	**Food Category**	**Previous NDNS nutrient databank value**	**Including addition of 12.5% 'overage'**
10290	Reduced fat spread (41-62% fat) not polyunsaturated, fortified with omega 3 from fish oils	4.9	5.5
3891	Light spreadable butter (60% fat)	3.3	3.7
10185	Viper Extreme energy bar	2.5	2.8
649	Buildup Slender slimming drink powder	4.5	5.1
2305	Complan	4.4	5.0
9498	Lighter Life Total Balance meal bars any fortified	4.2	4.7
9499	Lighter Life Total Balance soya protein powder fortified	3.9	4.4
7019	Lighter Life Total Balance soup powder fortified	3.7	4.2
9637	Fortisip nutritionally complete supplement drink	1.1	1.2
10411	Paediasure Plus liquid (nutritionally complete)	1.1	1.2
5634	Dunn's River nourishment	1.2	1.4
3807	Fortisip protein nourishment drink	1.1	1.3
3785	Ensure liquid vitamin + mineral supplement	1.7	2.0
8132	Ensure Plus yogurt style	1.7	1.9
10559	Forticreme complete	1.7	1.9
10452	Fortini 1.5kcal/ml nutritionally complete liquid supplement	1.5	1.7
2310	Horlicks Original powder	4.0	4.5
9277	Horlicks light malt chocolate instant dry weight	3.2	3.6
3410	So Good, fortified soya drink	0.9	1.0
3769	Soya alternative to milk, fortified	0.8	0.8
10159	Oat based milk alternative fortified	0.5	0.6
10218	Petit Filous fromage frais	1.5	1.7
202	Branflakes Kellogg's only	4.2	4.7
228	Multigrain Start Kellogg's	4.2	4.7
210	Grapenuts	1.7	1.9
2970	Special K with Red Berries	7.5	8.4
8013	Special K Berries any fruit addition not choc or yogurt	7.5	8.4
201	All Bran Kellogg's only	3.2	3.6
203	Sultana Bran Kellogg's only	3.2	3.6
223	Special K Kellogg's	8.4	9.5
4331	Ricicles (Kellogg's)	4.2	4.7
8151	Asda Golden Balls cereal fortified	5.0	5.6
8427	Asda Choco flakes fortified	5.0	5.6
7623	Bran flakes, own brand, not Kellogg's	5.0	5.6
8481	All bran type cereal, Sainsbury's Hi-Fibre Bran only	5.0	5.6

		Vitamin D content (µg/100g/ml)	
NDNS Food Code	**Food Category**	**Previous NDNS nutrient databank value**	**Including addition of 12.5% 'overage'**
8482	All bran type cereal, e.g. Tesco Bran, not Sainsbury's, Nestle, Alpen Crunchy Bran	4.4	4.9
7624	Branflakes with sultanas, own brand	3.5	3.9
5327	Fruit and Fibre own brand fortified (not vit D) not Kellogg's	2.5	2.8
206	Cornflakes own brand not Kellogg's	5.0	5.6
7626	Frosted cornflakes, own brand, not Kellogg's	5.0	5.6
7630	Rice Krispies own brand not Kellogg's	5.0	5.6
8483	Cocoa Pops own brand not Kellogg's	5.0	5.6
10197	Cornflake type cereals frosted unfortified	5.0	5.6
10274	Choco Hoops cereal fortified	5.0	5.6
10513	Crunchy Nut Cornflakes own brand, not Kellogg's	5.0	5.6
10491	Dairylea strip cheese fortified with calcium and vitamin D	4.2	4.7
10507	Processed cheese slices/singles Dairylea only	3.5	3.9
10509	Processed cheese slices/singles, low fat, Dairylea only	3.5	3.9
8910	Boulders breakfast cereal, Tesco's	5.0	5.6
10369	Little Man choco moon breakfast cereal fortified	5.0	5.6
10257	New day honey hoops cereal fortified	5.0	5.6
10435	Crisp flake cereal with fruit and nuts fortified	1.1	1.2
7025	Kelloggs All Bran crunchy oat bakes	3.2	3.6
4084	Oat and bran flakes no additions own brand e.g. Asda	2.8	3.2
3008	Honey & nut bran flakes own brand	6.3	7.1
8699	Farleys Bedtimers chocolate drink enriched powder	10.0	11.3
10532	Asda milkshake mix fortified	6.6	7.4
7984	Boots follow on milk dry weight	16.0	18.1
7932	Ostermilk (Farley's) dry weight	13.6	15.2
7945	SMA follow-on formula milk, dry weight (formerly Progress)	12.0	13.5
7936	Ostermilk two (Farley's) dry weight	11.0	12.4
10605	SMA toddler milk, 1 year+, dry weight only	11.0	12.4
10614	Cow and Gate growing up milk, 1 year+, dry weight	11.0	12.4
10621	Aptamil growing-up milk formula, toddlers 1 year+, dry weight	11.0	12.4
9182	Boots follow on milk drink-banana/strawberry flavour. Dry weight	9.8	11.0

		Vitamin D content (µg/100g/ml)	
NDNS Food Code	**Food Category**	**Previous NDNS nutrient databank value**	**Including addition of 12.5% 'overage'**
10613	Cow and Gate follow-on milk, 6 months+, dry weight	9.7	10.9
10620	Aptamil follow-on infant formula milk, dry weight	9.7	10.9
7933	SMA first infant formula milk, dry weight (formerly Gold)	9.4	10.6
7941	Cow & Gate infasoy infant formula dry weight	9.4	10.6
10370	Cow and Gate comfort follow-on milk, dry weight	9.4	10.6
7938	SMA extra hungry infant milk formula dry weight (formerly SMA white)	8.7	9.8
7930	Aptamil first infant formula dry weight	8.7	9.8
7931	Cow & Gate first infant formula, dry weight	8.7	9.8
10615	Cow and Gate goodnight milk, 6 months+, dry weight	8.7	9.8
7937	Milumil dry weight	8.6	9.6
10631	Hipp Organic goodnight milk, 6 months+, dry weight	8.5	9.6
7935	Cow & Gate infant formula for hungrier babies, dry weight	8.5	9.6
10618	Aptamil extra hungry infant formula, dry weight	8.5	9.6
10628	Hipp Organic growing up milk, 10 months+, dry weight	8.5	9.6
8936	Galactomin 17 low lactose infant formula dry weight	8.4	9.5
7943	SMA wysoy soya infant formula dry weight	8.3	9.4
10623	Hipp Organic first infant milk formula, dry weight	8.2	9.2
7942	Enfamil Prosobee dry weight	8.1	9.1
7940	Oster soy (Farley's) dry weight	8.0	9.0
7944	Junior milk (Farley's) dry weight	7.8	8.8
10529	Nanny Care growing up milk, 12 months+, dry powder	7.8	8.8
10625	Hipp Organic follow on infant milk formula, dry weight	7.8	8.8
10632	Nutramigen infant formula (2) from 6 months, dry powder	7.5	8.5
10243	Cow & Gate growing up milk, made up	1.7	1.9
10371	Aptamil growing-up milk ready to drink	1.7	1.9
10622	Aptamil growing-up milk formula, toddlers 1 year+, made up	1.7	1.9
10606	SMA toddler milk, 1 year+, made up	1.5	1.7

		Vitamin D content (µg/100g/ml)	
NDNS Food Code	**Food Category**	**Previous NDNS nutrient databank value**	**Including addition of 12.5% 'overage'**
10607	SMA follow-on infant formula milk, made up (previously progress)	1.5	1.7
10248	Aptamil follow on milk, made up	1.4	1.6
10444	Cow and Gate follow on milk powder for infants 6+ months made up	1.4	1.6
10627	Hipp Organic follow on infant milk formula, ready to drink carton	1.4	1.6
10630	Hipp Organic growing up milk, 10 months+, ready to drink carton	1.4	1.6
10616	Cow and Gate goodnight milk, 6 months+, made up	1.3	1.5
7934	SMA first infant milk ready to feed cartons	1.2	1.4
8737	Cow & Gate infasoy infant formula made up	1.2	1.4
10521	Hipp good night infant formula milk, stage 1 (6mth+) made up	1.2	1.4
10609	SMA first infant formula milk, made up (previously SMA Gold)	1.2	1.4
10611	Cow and Gate first infant formula milk, made up	1.2	1.4
10612	Cow and Gate infant formula milk for hungrier babies, made up	1.2	1.4
10617	Aptamil first infant formula, made up	1.2	1.4
10619	Aptamil extra hungry infant formula, made up	1.2	1.4
10629	Hipp Organic growing up milk, 10 months+, made up	1.2	1.4
7939	SMA extra hungry infant formula milk, ready to feed carton	1.1	1.2
10528	Nutramigen infant formula (2) from 6 months, made up	1.1	1.2
10608	SMA extra hungry infant formula milk, made up (previously SMA white)	1.1	1.2
10610	SMA wysoy soya infant formula milk made up	1.1	1.2
10624	Hipp Organic first infant milk formula, made up	1.1	1.2
10626	Hipp Organic follow on infant milk formula, made up	1.1	1.2
10280	Cow and Gate sun moon and stars cereal 1 year+	13.3	15.0
10645	Cow and Gate breakfast cereals, flavoured, stage 1 4 month+, dry	11.6	13.1
10379	Cow and Gate creamy porridge dry weight fortified	11.1	12.5
10386	Cow and Gate my first muesli fortified	10.0	11.3
10662	Cow and Gate tropical fruit cereal stage 2 fortified	9.3	10.5

		Vitamin D content (µg/100g/ml)	
NDNS Food Code	**Food Category**	**Previous NDNS nutrient databank value**	**Including addition of 12.5% 'overage'**
9011	Heinz stage 1 breakfast cereals for babies, fortified	10.0	11.3
10660	Heinz stage 3/4 breakfast cereals for babies, fortified	6.0	6.8
10657	Heinz dinners stage 2, golden vegetable and chicken, fortified, dry	10.0	11.3
10659	Heinz stage 2 breakfast cereals for babies, fortified	10.0	11.3
10160	Hipp organic stage 1 creamy porridge stage 1 dry weight fortified	8.0	9.0
10238	Nestle Nestum honey cornflake cereal fortified	6.3	7.1
8901	Milupa semolina with honey infant dessert dry weight	4.8	5.4
8941	Milupa infant cereals fortified dry weight e.g. Sunshine orange	4.8	5.4
8948	Milupa instant cereals dry weight e.g. oat & apple	3.4	3.8
8729	Milupa cereal breakfasts fortified made up with water	1.4	1.5
8852	Instant savoury baby food fortified dry weight	4.3	4.9
10391	Malt extract and cod liver oil syrup	18.6	20.9
10314	Holland and Barrett cod liver oil and vitamins A and D	10.0	11.3
10228	Zipvit cod liver oil 1000mg only	6.8	7.6
10134	Seven Seas cod liver oil extra strength 1050mg	5.0	5.6
10148	Cod liver oil liquid	5.0	5.6
10151	Cod liver oil 550mg with vitamins A,D,E	5.0	5.6
10162	Cod liver oil 400mg with 800mcg vit A and 5mcg vit D	5.0	5.6
10165	Cod liver oil oil 1000mg capsule with added vitamins A,D,E	5.0	5.6
10176	Cod liver oil 1000mg with added vitamins A and D	5.0	5.6
10224	Cod liver oil 500mg and evening primrose 500mg with vitamins A,D,E	5.0	5.6
10229	Cod liver oil 650mg and evening primrose oil 200mg with vitamins A,D	5.0	5.6
10252	Cod liver oil 550mg with vitamins A,D	5.0	5.6
10313	Boots 550mg cod liver oil with 400mg calcium and vits A, D,E,K	5.0	5.6
10382	Cod liver oil 500mg and multivitamins	5.0	5.6
10474	Bassetts omega 3 with vitamins A,C,D,E	5.0	5.6

		Vitamin D content (µg/100g/ml)	
NDNS Food Code	**Food Category**	**Previous NDNS nutrient databank value**	**Including addition of 12.5% 'overage'**
10387	Cod liver oil 410mg with vit A 375mcg and vit D 3.37mcg	3.4	3.8
10291	Cod liver oil 500mg and calcium 300mg supplement	3.1	3.5
10135	Cod liver oil 525mg with vits A 800mcg, vitamin D 2.5mcg and vitamin E 0.3mg	2.5	2.8
10174	Extra high strength cod liver oil liquid	2.5	2.8
10193	Childrens fish oil 185mg with vits A,D,E	2.5	2.8
10199	Children's fish oil 200mg with added vitamins A,C,D,E	2.5	2.8
10217	Children's fish oils 250mg with vitamins A,C,D,E	2.5	2.8
10266	Children's cod liver oil syrup with vitamins A,C,D,E	2.5	2.8
10364	Children's multivitamin capsules with omega 3	2.5	2.8
10393	Tesco Chewburst omega 3 with vitamins A,C,D,E	2.5	2.8
10175	Cod liver oil 1000mg with no added vitamins	2.1	2.4
10173	Cod liver oil 615mg	1.7	1.9
10449	Vitabiotics Wellkid Smart multvitamins and minerals	5.0	5.6
4051	Vitamin D capsule 400IU (10mcg)	10.0	11.3
3246	Chewable calcium (500 mg) & vitamin D (10 microgram)	10.0	11.3
10097	Calcium 600mg and vitamin D3 10mcg only	10.0	11.3
10107	Calcichew D3 forte 500mg calcium 10mcg vitamin D3 only	10.0	11.3
5440	Calcuim (400 mg) and vitamin D (5 microgram) capsule	5.0	5.6
9302	Calcichew (500 mg calcium, 5 microgram D3)	5.0	5.6
9544	Vitamin D (5 microgram) and calcium (800 mg) capsules only	5.0	5.6
2718	Calcium tablets (600mg) plus vitamin D (3 micro gram)	3.0	3.4
10120	Calcium 400mg and vitamin D 2.5mcg	2.5	2.8
10361	Calcium 500mg and vit D 1.25mcg	1.3	1.4
10212	Multivitamin drops for babies and children	10.0	11.3
10408	Ketovite liquid	10.0	11.3
10363	Multivitamin BPC tablets	7.5	8.4
10078	Bassetts Soft and Chewy vitamins A,C,D,E	5.0	5.6
10081	Tesco multivitamin	5.0	5.6

		Vitamin D content (µg/100g/ml)	
NDNS Food Code	**Food Category**	**Previous NDNS nutrient databank value**	**Including addition of 12.5% 'overage'**
10099	Asda multivitamins one a day only	5.0	5.6
10113	Seven Seas Haliborange vitamin A,C,D chewable tablet	5.0	5.6
10205	Lifeplan multivitamin tablets	5.0	5.6
10246	Bassetts Soft and Chewy multivitamins blackcurrant flavour	5.0	5.6
10365	Bassetts Early Health vitamins A,B6,C,D,E	5.0	5.6
10104	Boots multivitamin syrup 4 months to 12 years only	3.5	3.9
10112	Seven Seas Haliborange multivitamin liquid only	3.5	3.9
10088	Holland and Barrett multivitamin tablet only	2.5	2.8
10225	My Protein multivitamin tablets	2.5	2.8
10533	Orovite 7 vitamin powder	2.5	2.8
10362	Healthy Start childrens multivitamin drops	1.5	1.7
10423	Eniva Vibe multivitamin and mineral liquid supplement	41.7	46.9
10083	Vitabiotics Pregnacare original	10.0	11.3
10085	Healthspan multivitamins and minerals '50 plus' with ginkgo	10.0	11.3
10103	Boots teenage A to Z chewable multivitamins and minerals only	10.0	11.3
10345	Superdrug super one multivitamin and mineral supplement	10.0	11.3
10378	Superdrug time release multivitamin and mineral tablet	10.0	11.3
10439	Holland and Barrett ABC senior+ multivitamin and mineral	10.0	11.3
10494	Kirkland daily multivitamin and mineral supplement	10.0	11.3
10102	Boots childrens A to Z chewable multivitamins and minerals only	7.5	8.4
10349	Coral calcium supreme supplement	6.8	7.7
10337	Biocare multivitamin and mineral tablet	6.3	7.0
10384	Healthspan multivitamin and mineral jelly bears	6.0	6.8
10079	Boots complete A to Z	5.0	5.6
10082	Multivitamins with iron	5.0	5.6
10087	Holland and Barrett ABC plus tablets only	5.0	5.6
10091	Seven Seas Multibionta probiotic multivitamin only	5.0	5.6
10094	Zipvit multivitamin and mineral tablets only	5.0	5.6

		Vitamin D content (µg/100g/ml)	
NDNS Food Code	**Food Category**	**Previous NDNS nutrient databank value**	**Including addition of 12.5% 'overage'**
10108	Multivitamin and mineral; Centrum or Flinndal	5.0	5.6
10116	Healthspan A to Z complete spectrum mulitvitamins and minerals	5.0	5.6
10127	Tesco Children's multivitamins and minerals	5.0	5.6
10164	Sanatogen Kids A to Z multivitamin and mineral	5.0	5.6
10171	Vitabiotics Perfectil multivitamin and mineral	5.0	5.6
10172	Vitabiotics Menopace tablet	5.0	5.6
10191	Multivitamins with 15mg zinc	5.0	5.6
10249	Valupak multivitamins and minerals	5.0	5.6
10278	Boots hair skin and nails supplement with EPO	5.0	5.6
10292	Superdrug 50+ multivitamins and minerals	5.0	5.6
10325	Pharmaton capsules	5.0	5.6
10339	Sainsburys multivitamin and mineral supplement	5.0	5.6
10360	Sanatogen Gold multivitamin and mineral tablet	5.0	5.6
10404	Multivitamin with iron and iodine	5.0	5.6
10432	Boots multivitamin and iron (includes other minerals)	5.0	5.6
10486	Tesco multivitamin and mineral supplement	5.0	5.6
10526	Bassetts Active health vitamin and mineral chews	5.0	5.6
10458	Solgar Female multiple multivitamin and mineral	3.4	3.8
10283	Shapeworks multivitamin and mineral complex	3.3	3.7
10114	Healthspan Hair and Nails tablet	2.5	2.8
10170	Vitabiotics Visionace multivitamin and mineral	2.5	2.8
10194	Asda Kids multivitamins and minerals	2.5	2.8
10241	Vivioptal Junior multivitamin and mineral liquid	2.5	2.8
10340	Kordels Junior Time multivitamin and mineral	2.5	2.8
10477	Calcia calcium supplement with vitamins and iron	2.5	2.8
10489	Holland and Barrett radiance multivitamin and mineral	2.5	2.8
10552	Wassen Serenoa-C supplement	2.5	2.8
10555	Wellkid baby and infant vitamin and mineral liquid	2.5	2.8
10546	Floradix Kindervital for children	1.8	2.0

		Vitamin D content (µg/100g/ml)	
NDNS Food Code	**Food Category**	**Previous NDNS nutrient databank value**	**Including addition of 12.5% 'overage'**
10419	Higher Nature true food supernutrition plus supplement	1.7	1.9
10353	Minadex vitamin and mineral tonic for children	1.6	1.8

Appendix 6a: Levels of vitamin D added for fortification of flour only

Code	Food sub-group/Food name	% flour	Level of vitamin D added to each food sub-group/food code (µg per 100g flour)				
			5µg/100g flour	10µg/100g flour	15µg/100g flour	20µg/100g flour	30µg/100g flour
Sub-group codes							
2R	White bread	63	3.15	6.3	9.45	12.6	18.9
3R	Wholemeal bread	60	3	6	9	12	18
59R	Brown, granary and wheatgerm	60	3	6	9	12	18
4R	Other breads	55	2.75	5.5	8.25	11	16.5
1C	Pizzas	25	1.25	2.5	3.75	5	7.5
7A	Biscuits	50	2.5	5	7.5	10	15
7B	Biscuits	50	2.5	5	7.5	10	15
8A	Fruit pies	30	1.5	3	4.5	6	9
8B	Fruit pies	30	1.5	3	4.5	6	9
8D	Buns cakes & pastries	45	2.25	4.5	6.75	9	13.5
8E	Buns cakes & pastries	45	2.25	4.5	6.75	9	13.5
9E&F	Sponge type puddings	30	1.5	3	4.5	6	9
9F	Sponge type puddings	30	1.5	3	4.5	6	9
9C	Cereal based milk puddings	10	0.5	1	1.5	2	3
9D	Cereal based milk puddings	10	0.5	1	1.5	2	3
9G	Other cereal based puddings	10	0.5	1	1.5	2	3
9H	Other cereal based puddings	10	0.5	1	1.5	2	3
Food codes							
12	Flour brown (85%)	100	5	10	15	20	30
13	Flour chapati brown	100	5	10	15	20	30

Code	Food sub-group/Food name	% flour	Level of vitamin D added to each food sub-group/food code (μg per 100g flour)				
			5μg/100g flour	10μg/100g flour	15μg/100g flour	20μg/100g flour	30μg/100g flour
14	Flour chapati white	100	5	10	15	20	30
15	Flour white household plain	100	5	10	15	20	30
16	Flour white self raising	100	5	10	15	20	30
21	Flour white breadmaking	100	5	10	15	20	30
22	Flour wholemeal (100%)	100	5	10	15	20	30
2603	Plain flour after baking	100	5	10	15	20	30
2604	Sr flour after baking	100	5	10	15	20	30
2643	Wholemeal flour with losses	100	5	10	15	20	30
9210	Strong bread flour with cooking losses	100	5	10	15	20	30
9211	Brown flour with cooking losses	100	5	10	15	20	30
10021	Flour wholemeal, breadmaking	100	5	10	15	20	30
10022	Self raising wholemeal flour	100	5	10	15	20	30
10023	Flour brown breadmaking	100	5	10	15	20	30
74	Dumplings made with animal suet	25	1.25	2.5	3.75	5	7.5
576	Yorkshire pudding made with whole milk	25	1.25	2.5	3.75	5	7.5
817	Welsh rarebit on white toast	25	1.25	2.5	3.75	5	7.5
821	Cheese & onion pasty purchased	25	1.25	2.5	3.75	5	7.5
2607	Batter with cooking losses	25	1.25	2.5	3.75	5	7.5

Code	Food sub-group/Food name	% flour	Level of vitamin D added to each food sub-group/food code (µg per 100g flour)				
			5µg/100g flour	10µg/100g flour	15µg/100g flour	20µg/100g flour	30µg/100g flour
2728	Pancakes, served with duck, crispy, Chinese only	25	1.25	2.5	3.75	5	7.5
3205	Findus savoury cheese pancakes	25	1.25	2.5	3.75	5	7.5
3240	Semolina packet mix e.g. birds. Dry weight	25	1.25	2.5	3.75	5	7.5
3430	West Indian dumplings, fried	25	1.25	2.5	3.75	5	7.5
3831	Cous cous boiled in milk	25	1.25	2.5	3.75	5	7.5
3959	Yorkshire pudding, semi-skimmed milk, eggs, lard	25	1.25	2.5	3.75	5	7.5
3964	Yorkshire pudding, whole milk, egg, packet mix	25	1.25	2.5	3.75	5	7.5
4104	Cheese and onion puffs, made with puff pastry	25	1.25	2.5	3.75	5	7.5
4112	Yorkshire pudding made with skimmed milk	25	1.25	2.5	3.75	5	7.5
5047	Cheese and onion pasty	25	1.25	2.5	3.75	5	7.5
5184	Dumplings with vegetable suet wholemeal flour.	25	1.25	2.5	3.75	5	7.5
5215	Yorkshire pudding made with s skim milk and PUFA	25	1.25	2.5	3.75	5	7.5
5386	Dumplings made with PUFA spread	25	1.25	2.5	3.75	5	7.5
5675	Cheesy crisp bake m and s	25	1.25	2.5	3.75	5	7.5
5715	Yorkshire pudding made	25	1.25	2.5	3.75	5	7.5

Code	Food sub-group/Food name	% flour	Level of vitamin D added to each food sub-group/food code (µg per 100g flour)				
			5µg/100g flour	10µg/100g flour	15µg/100g flour	20µg/100g flour	30µg/100g flour
	with water and lard						
5862	Dumplings with plain & wholemeal flour and marg	25	1.25	2.5	3.75	5	7.5
6223	Yorkshire pudd with s/s milk no fat	25	1.25	2.5	3.75	5	7.5
7603	Yorkshire pudding made with semi-skimmed milk	25	1.25	2.5	3.75	5	7.5
7773	Welsh rarebit made with wholemeal toast	25	1.25	2.5	3.75	5	7.5
8364	Yorkshire pudding packet mix made up	25	1.25	2.5	3.75	5	7.5
8365	Yorkshire pudding frozen	25	1.25	2.5	3.75	5	7.5
8614	Yorkshire pudding mix made up with egg & water	25	1.25	2.5	3.75	5	7.5
8643	Yorkshire pudding made without fat	25	1.25	2.5	3.75	5	7.5
8719	Dumplings made with vegetable suet	25	1.25	2.5	3.75	5	7.5
8900	Dumplings made with soft margarine not PUFA	25	1.25	2.5	3.75	5	7.5
9121	West Indian dumpling no fat	25	1.25	2.5	3.75	5	7.5
10399	Chocolate filled crepes/pancakes purchased	25	1.25	2.5	3.75	5	7.5

Appendix 6b: Levels of vitamin D added for fortification of milk only

Code	Food sub-group/Food name	% milk	Level of vitamin D added to each food sub-group/food code (µg per 100ml milk)				
			0.5µg/100ml milk	1µg/100ml mik	2µg/100ml milk	5µg/100ml milk	7µg/100ml milk
Sub-group codes							
10R	Whole milk	100	0.5	1	2	5	7
11R	Semi-skimmed milk	100	0.5	1	2	5	7
12R	Skimmed milk	100	0.5	1	2	5	7
13R	Other milk including soya etc!	100	0.5	1	2	5	7
9C	Cereal based milk puddings (rice puddings, blancmange, semolina etc.)	62	0.31	0.62	1.24	3.1	4.34
9D	Cereal based milk puddings	62	0.31	0.62	1.24	3.1	4.34
Food codes							
7702	Jelly made with semi-skimmed milk	60	0.3	0.6	1.2	3	4.2
7703	Jelly made with skimmed milk	60	0.3	0.6	1.2	3	4.2
7705	Jelly low sugar made with whole milk	60	0.3	0.6	1.2	3	4.2
7706	Jelly low sugar made with semi-skimmed milk	60	0.3	0.6	1.2	3	4.2
7707	Jelly low sugar made with skimmed milk	60	0.3	0.6	1.2	3	4.2
554	Jelly made with whole milk	60	0.3	0.6	1.2	3	4.2
9627	Creme caramel made w s/skimmed milk	60	0.3	0.6	1.2	3	4.2
9819	Baked egg custard (with semi-skimmed milk)	60	0.3	0.6	1.2	3	4.2
612	Milk drink pasteurised/sterilised not chocolate flavour	90	0.45	0.9	1.8	4.5	6.3
627	Milkshake	90	0.45	0.9	1.8	4.5	6.3

Code	Food sub-group/Food name	% milk	Level of vitamin D added to each food sub-group/food code (µg per 100ml milk)				
			0.5µg/100ml milk	1µg/100ml mik	2µg/100ml milk	5µg/100ml milk	7µg/100ml milk
628	Milk shake whole milk with icecream	90	0.45	0.9	1.8	4.5	6.3
650	Soya alternative to milk unsweetened	90	0.45	0.9	1.8	4.5	6.3
696	Milk, skimmed, dried, with non milk fat, made up	90	0.45	0.9	1.8	4.5	6.3
3554	Milkshake with skimmed milk + artificial sweeteners	90	0.45	0.9	1.8	4.5	6.3
7714	Mars bar milk	90	0.45	0.9	1.8	4.5	6.3
7715	Soya alternative to milk flavoured	90	0.45	0.9	1.8	4.5	6.3
7891	Coffee iced of frappe	90	0.45	0.9	1.8	4.5	6.3
8063	Hot chocolate (no cream) whole milk takeaway only	90	0.45	0.9	1.8	4.5	6.3
8064	Hot chocolate (no cream) skimmed milk takeaway only	90	0.45	0.9	1.8	4.5	6.3
8065	Hot chocolate (with cream) whole milk takeaway only	90	0.45	0.9	1.8	4.5	6.3
8212	Milk drink pasteurised/sterilised chocolate flavour	90	0.45	0.9	1.8	4.5	6.3
8214	Milkshake UHT purchased made with wholemilk	90	0.45	0.9	1.8	4.5	6.3
8215	Milkshake purchased made with semi-skimmed milk	90	0.45	0.9	1.8	4.5	6.3
8217	Cadbury's chocolate milk drink-low fat	90	0.45	0.9	1.8	4.5	6.3
9072	Sainsbury's thick milk shake pasteurised	90	0.45	0.9	1.8	4.5	6.3
10256	Flavoured milk drinks, NAS, made with semi-skimmed milk	90	0.45	0.9	1.8	4.5	6.3

Appendix 6c: Levels of vitamin D added for fortification of both flour and milk

Code	Food sub-group name/Food name	% flour/milk content	Level of vitamin D added to each food sub-group/food code (µg per 100ml milk/100g flour)			
			2.5µg/100g flour & 0.25µg/100ml milk	5µg/100g flour & 1µg/100ml milk	10µg/100g flour & 2.5µg/100ml milk	15µg/100g flour & 3.5µg/100ml milk
Sub-group codes						
2R	White bread	63	1.575	3.15	6.3	9.45
3R	Wholemeal bread	60	1.5	3	6	9
59R	Brown, granary and wheatgerm	60	1.5	3	6	9
4R	Other breads	55	1.375	2.75	5.5	8.25
1C	Pizzas	25	0.625	1.25	2.5	3.75
7A	Biscuits	50	1.25	2.5	5	7.5
7B	Biscuits	50	1.25	2.5	5	7.5
8A	Fruit pies	30	0.75	1.5	3	4.5
8B	Fruit pies	30	0.75	1.5	3	4.5
8D	Buns cakes & pastries	45	1.125	2.25	4.5	6.75
8E	Buns cakes & pastries	45	1.125	2.25	4.5	6.75
9E&F	Sponge type puddings	30	0.75	1.5	3	4.5
9F	Sponge type puddings	30	0.75	1.5	3	4.5
9C	Cereal based milk puddings	10	0.25	0.5	1	1.5
9D	Cereal based milk puddings	10	0.25	0.5	1	1.5
9G	Other cereal based puddings	10	0.25	0.5	1	1.5
9H	Other cereal based puddings	10	0.25	0.5	1	1.5
Food codes						
12	Flour brown (85%)	100	2.5	5	10	15
13	Flour chapati brown	100	2.5	5	10	15

Code	Food sub-group name/Food name	% flour/milk content	Level of vitamin D added to each food sub-group/food code (µg per 100ml milk/100g flour)			
			2.5µg/100g flour & 0.25µg/100ml milk	5µg/100g flour & 1µg/100ml milk	10µg/100g flour & 2.5µg/100ml milk	15µg/100g flour & 3.5µg/100ml milk
14	Flour chapati white	100	2.5	5	10	15
15	Flour white household plain	100	2.5	5	10	15
16	Flour white self raising	100	2.5	5	10	15
21	Flour white breadmaking	100	2.5	5	10	15
22	Flour wholemeal (100%)	100	2.5	5	10	15
2603	Plain flour after baking	100	2.5	5	10	15
2604	Sr flour after baking	100	2.5	5	10	15
2643	Wholemeal flour with losses	100	2.5	5	10	15
9210	Strong bread flour with cooking losses	100	2.5	5	10	15
9211	Brown flour with cooking losses	100	2.5	5	10	15
10021	Flour wholemeal, breadmaking	100	2.5	5	10	15
10022	Self raising wholemeal flour	100	2.5	5	10	15
10023	Flour brown breadmaking	100	2.5	5	10	15
74	Dumplings made with animal suet	25	0.625	1.25	2.5	3.75
576	Yorkshire pudding made with whole milk	25	0.625	1.25	2.5	3.75
817	Welsh rarebit on white toast	25	0.625	1.25	2.5	3.75
821	Cheese & onion pasty purchased	25	0.625	1.25	2.5	3.75
2607	Batter with cooking losses	25	0.625	1.25	2.5	3.75
2728	Pancakes, served with duck, crispy, Chinese only	25	0.625	1.25	2.5	3.75

Code	Food sub-group name/Food name	% flour/milk content	Level of vitamin D added to each food sub-group/food code (µg per 100ml milk/100g flour)			
			2.5µg/100g flour & 0.25µg/100ml milk	5µg/100g flour & 1µg/100ml milk	10µg/100g flour & 2.5µg/100ml milk	15µg/100g flour & 3.5µg/100ml milk
3205	Findus savoury cheese pancakes	25	0.625	1.25	2.5	3.75
3240	Semolina packet mix e.g. birds. Dry weight	25	0.625	1.25	2.5	3.75
3430	West Indian dumplings, fried	25	0.625	1.25	2.5	3.75
3831	Cous cous boiled in milk	25	0.625	1.25	2.5	3.75
3959	Yorkshire pudding, semi-skimmed milk, eggs, lard	25	0.625	1.25	2.5	3.75
3964	Yorkshire pudding, whole milk, egg, packet mix	25	0.625	1.25	2.5	3.75
4104	Cheese and onion puffs, made with puff pastry	25	0.625	1.25	2.5	3.75
4112	Yorkshire pudding made with skimmed milk	25	0.625	1.25	2.5	3.75
5047	Cheese and onion pasty	25	0.625	1.25	2.5	3.75
5184	Dumplings with vegetable suet wholemeal flour.	25	0.625	1.25	2.5	3.75
5215	Yorkshire pudding made with s skim milk and PUFA	25	0.625	1.25	2.5	3.75
5386	Dumplings made with PUFA spread	25	0.625	1.25	2.5	3.75
5675	Cheesy crisp bake m and s	25	0.625	1.25	2.5	3.75
5715	Yorkshire pudding made with water and lard	25	0.625	1.25	2.5	3.75
5862	Dumplings with plain & wholemeal flour and marg	25	0.625	1.25	2.5	3.75
6223	Yorkshire pudd with s/s milk	25	0.625	1.25	2.5	3.75

Code	Food sub-group name/Food name	% flour/milk content	Level of vitamin D added to each food sub-group/food code (µg per 100ml milk/100g flour)			
			2.5µg/100g flour & 0.25µg/100ml milk	5µg/100g flour & 1µg/100ml milk	10µg/100g flour & 2.5µg/100ml milk	15µg/100g flour & 3.5µg/100ml milk
	no fat					
7603	Yorkshire pudding made with semi-skimmed milk	25	0.625	1.25	2.5	3.75
7773	Welsh rarebit made with wholemeal toast	25	0.625	1.25	2.5	3.75
8364	Yorkshire pudding packet mix made up	25	0.625	1.25	2.5	3.75
8365	Yorkshire pudding frozen	25	0.625	1.25	2.5	3.75
8614	Yorkshire pudding mix made up with egg & water	25	0.625	1.25	2.5	3.75
8643	Yorkshire pudding made without fat	25	0.625	1.25	2.5	3.75
8719	Dumplings made with vegetable suet	25	0.625	1.25	2.5	3.75
8900	Dumplings made with soft margarine not PUFA	25	0.625	1.25	2.5	3.75
9121	West Indian dumpling no fat	25	0.625	1.25	2.5	3.75
10399	Chocolate filled crepes/pancakes purchased	25	0.625	1.25	2.5	3.75
Sub-group codes						
10R	Whole milk	100	0.25	1	2.5	3.5
11R	Semi-skimmed milk	100	0.25	1	2.5	3.5
12R	Skimmed milk	100	0.25	1	2.5	3.5
13R	Other milk including soya etc!	100	0.25	1	2.5	3.5
9C	Cereal based milk puddings (rice puddings, blancmange,	62	0.155	0.62	1.55	2.17

Code	Food sub-group name/Food name	% flour/milk content	Level of vitamin D added to each food sub-group/food code (µg per 100ml milk/100g flour)			
			2.5µg/100g flour & 0.25µg/100ml milk	5µg/100g flour & 1µg/100ml milk	10µg/100g flour & 2.5µg/100ml milk	15µg/100g flour & 3.5µg/100ml milk
	semolina etc.)					
9D	Cereal based milk puddings	62	0.155	0.62	1.55	2.17
Food codes						
7702	Jelly made with semi-skimmed milk	60	0.15	0.6	1.5	2.1
7703	Jelly made with skimmed milk	60	0.15	0.6	1.5	2.1
7705	Jelly low sugar made with whole milk	60	0.15	0.6	1.5	2.1
7706	Jelly low sugar made with semi-skimmed milk	60	0.15	0.6	1.5	2.1
7707	Jelly low sugar made with skimmed milk	60	0.15	0.6	1.5	2.1
554	Jelly made with whole milk	60	0.15	0.6	1.5	2.1
9627	Creme caramel made w s/skimmed milk	60	0.15	0.6	1.5	2.1
9819	Baked egg custard (with semi-skimmed milk)	60	0.15	0.6	1.5	2.1
612	Milk drink pasteurised/sterilised not chocolate flavour	90	0.225	0.9	2.25	3.15
627	Milkshake	90	0.225	0.9	2.25	3.15
628	Milk shake whole milk with icecream	90	0.225	0.9	2.25	3.15
650	Soya alternative to milk unsweetened	90	0.225	0.9	2.25	3.15
696	Milk, skimmed, dried, with	90	0.225	0.9	2.25	3.15

Code	Food sub-group name/Food name	% flour/milk content	Level of vitamin D added to each food sub-group/food code (µg per 100ml milk/100g flour)			
			2.5µg/100g flour & 0.25µg/100ml milk	5µg/100g flour & 1µg/100ml milk	10µg/100g flour & 2.5µg/100ml milk	15µg/100g flour & 3.5µg/100ml milk
	non milk fat, made up					
3554	Milkshake with skimmed milk + artificial sweeteners	90	0.225	0.9	2.25	3.15
7714	Mars bar milk	90	0.225	0.9	2.25	3.15
7715	Soya alternative to milk flavoured	90	0.225	0.9	2.25	3.15
7891	Coffee iced of frappe	90	0.225	0.9	2.25	3.15
8063	Hot chocolate (no cream) whole milk takeaway only	90	0.225	0.9	2.25	3.15
8064	Hot chocolate (no cream) skimmed milk takeaway only	90	0.225	0.9	2.25	3.15
8065	Hot chocolate (with cream) whole milk takeaway only	90	0.225	0.9	2.25	3.15
8212	Milk drink pasteurised/sterilised chocolate flavour	90	0.225	0.9	2.25	3.15
8214	Milkshake UHT purchased made with wholemilk	90	0.225	0.9	2.25	3.15
8215	Milkshake purchased made with semi-skimmed milk	90	0.225	0.9	2.25	3.15
8217	Cadbury's chocolate milk drink-low fat	90	0.225	0.9	2.25	3.15
9072	Sainsbury's thick milk shake pasteurised	90	0.225	0.9	2.25	3.15
10256	Flavoured milk drinks, NAS, made with semi-skimmed milk	90	0.225	0.9	2.25	3.15

Appendix 7: Base numbers for data used in analyses

Table 7a: Weighted bases in yrs 1&2 NDNS dataset

	Number of weighted bases respondents in NDNS yrs 1&2			
Dietary data				
Age Group (yrs)	**Females**	**Males**	**Age/sex group**	
1.5-3	79	83	1.5-3 All *	162
4-8	141	160	4-8 All	301
9-14	183	180	9-49 Males	606
15-18	131	139	9-14 Females	183
19-49	285	287	15-49 Females*	416
50-64	123	119	50-64 All	242
65+	122	95	65+ All *	217
Total	1,064	1,063	Total	2127
Blood data				
Age Group (yrs)	**Females**	**Males**	**Age/sex group**	
1.5-3	-	-	1.5-3 All *	-
4-8	-	-	4-8 All	-
11-14**	31	33	11-49 Males**	198
15-18	32	39	11-14 Females**	31
19-49	129	126	15-49 Females*	161
50-64	62	56	50-64 All	118
65+	-	-	65+ All *	-
Total	254	254	Total	508

* 'At risk' group

** NDNS blood data only available from 11 years of age.

- Blood data not available for individuals aged 1.5-10 years and 65 years and over.

Weighted bases have been provided to illustrate proportions used in the analysis. Unweighted bases can be found in the NDNS report (84, 172)

Table 7b: Estimated numbers in UK population census (Mid 2010) (175)

Age (yrs) /sex group	Population estimate
1.5-3	1,937,000
4 to 8	3,512,000
9-49 M	17,148,000
9-14 F	2,069,000
15-49 F	14,780,000
50-64	11,323,000
65 +	10,305,000
total	61,075,000

Table 7c: NDNS weighted bases by NS-SEC 3 classification (170)

Age (yrs) /sex group	Managerial and professional occupation (NS-SEC 1)	Intermediate occupations (NS-SEC 2)	Routine and manual occupations (NS-SEC 3)	Other*	Total
1.5-3 All	64	[31]	54	[12]	162
4 to 8 All	124	61	104	[12]	301
9-49 M	255	112	209	[26]	602
9-14 F	75	[33]	59	[14]	181
15-49 F	164	72	149	[31]	416
50-64 All	103	[45]	87	[6]	241
65 + All	81	51	79	[6]	218
Total	865	407	740	108	2120

*'Never worked' and 'long-term unemployed' and 'other'. Data for this group were not presented due to small base sizes
7 individuals were excluded from the analysis as they were not assigned a valid NS-SEC group.
[ ] bracket values represent cell sizes at less than 50.

Appendix 8: Results tables

Table 8a: Vitamin D intakes for UK population sub-groups, for a range of intake thresholds. Data taken from years 1&2 of the NDNS rolling programme. Population figures have been estimated using census data and are rounded to the nearest 100,000.

Using data from years 1 &2 of the NDNS rolling programme							
Population group years/sex	**Vitamin D intakes (µg/day)**		**No. with intakes <RNI* (3)**	**No. with intakes <EAR (1)**	**No. with intakes <RDA (1)**	**No. with intakes >UL (66)**	**No. with intakes >UL (1)**
	Mean (s.d)	**Median**					
1.5-3 All	2.3 (2.4)	1.5	1,800,000 (94%)	1,700,000 (96%)	1,900,000 (100%)	0 (0%)	0 (0%)
4 to 8 All	2.5 (2.0)	2.0	3,500,000 (100%)*	3,500,000 (100%)	3,500,000 (100%)	0 (0%)	0 (0%)
9-49 M	2.9 (2.2)	2.3	16,900,000 (98%)*	16,900,000 (98%)	17,000,000 (99%)	0 (0%)	0 (0%)
9-14 F	2.4 (1.9)	1.9	2,100,000 (100%)*	2,100,000 (100%)	2,100,000 (100%)	0 (0%)	0 (0%)
15-49 F	2.8 (2.4)	2.2	14,400,000 (98%)	14,400,000 (98%)	14,700,000 (100%)	0 (0%)	0 (0%)
50-64 All	4.7 (3.6)	3.6	10,400,000 (92%)	10,400,000 (92%)	11,200,000 (99%)	0 (0%)	0 (0%)
65 + All	4.7 (3.9)	3.4	9,200,000 (89%)	9,200,000 (89%)	10,300,000 (100%)	0 (0%)	0 (0%)

*The RNI is only applicable to children between 1.5-3 years, pregnant and breast-feeding women (represented by women aged 15-49 years) and adults over 50 years, this analysis assumes an RNI of 10µg per day applies to all adults and older children.

Table 8b: Serum 25(OH)D levels for UK population sub-groups, for a range of intake thresholds. Data taken from years 1&2 of the NDNS rolling programme. Relationships for vitamin D intake/25(OH)D serum status (117, 118) were used to estimate winter serum 25(OH)D levels based on vitamin D intakes. Population figures have been estimated using census data and are rounded to the nearest 100,000.

Blood data from years 1 &2 of the NDNS rolling programme									Winter serum 25(OH)D levels estimated using Cashman equations		
Population group years/sex	25(OH)D status* (nmol/l)				No. with 25(OH)D below and above key thresholds				Mean (nmol/l) (95% CIs)	2.5%ile (nmol/l)	97.5%ile (nmol/l)
	Mean (s.d.)	Median	2.5th %ile	97.5th %ile	<25nmol/l	<30nmol/l	>75nmol/l	>125nmol/l			
1.5-3 All	-	-	-	-	-	-	-	-	37 (34, 42)	20	71
4 to 8 All	-	-	-	-	-	-	-	-	38 (34, 42)	20	71
9-49 M	45 (22)	42	12	91	3,100,000 (19%)**	4,900,000 (29%)	2,000,000 (12%)**	0%	38 (34, 43)	20	72
9-14 F	[41] (20)	[37]	14	76	[400,000] [26%]**	700,000 (32%)	[200,000] [13%]**	0%	38 (34, 42)	20	71
15-49 F	48 (26)	46	11	112	3,100,000 (21%)	4,100,000 (28%)	1,900,000 (13%)	100,000 (1%)	38 (34, 43)	20	72
50-64 All	48 (24)	45	9	115	1,600,000 (14%)	2,900,000 (25%)	1,600,000 (14%)	100,000 (1%)	41 (36, 47)	22	77
65 + All	-	-	-	-	-	-	-	-	46 (38, 55)	21	81

* NDNS blood data only available from 11 to 64 years of age. Status data only presented to the nearest whole number due to the variability of assays for 25(OH)D.
[ ] bracket values had cell sizes at less than 50.

Table 8c: Vitamin D intakes and winter serum 25(OH)D levels for UK population sub-groups using updated vitamin D composition of fortified foods and supplements, for a range of intake thresholds. Data from years 1&2 of the NDNS rolling programme were updated for vitamin D composition of fortified foods and supplements including an 'overage' of 12.5%. Relationships (117, 118) for vitamin D intake/25(OH)D serum status were used to estimate serum 25(OH)D levels. Population figures have been estimated using census data and are rounded to the nearest 100,000.

Using updated NDNS data years 1 &2 of the rolling programme								Winter serum 25(OH)D levels estimated using Cashman equations (nmol/l)		
Population group years /sex	Vitamin D intakes (µg/day)		No. with intakes below and above key thresholds							
	Mean (s.d.)	Median	<RNI* (3)	<EAR (1)	<RDA (1)	>UL (66)	>UL (1)	Mean (95% CIs)	2.5%ile	97.5%ile
1.5-3 All	2.5 (2.6)	1.7	1,800,000 (93%)	1,900,000 (96%)	1,900,000 (99%)	0 (0%)	0 (0%)	38 (34,42)	20	71
4 to 8 All	2.7 (1.9)	2.1	3,500,000 (100%)*	3,500,000 (100%)	3,500,000 (100%)	0 (0%)	0 (0%)	38 (34,43)	20	72
9-49 M	3.1 (2.4)	2.5	16,800,000 (98%)*	16,800,000 (98%)	17,000,000 (99%)	0 (0%)	0 (0%)	39 (34,43)	20	73
9-14 F	2.6 (2.2)	2.0	2,100,000 (99%)*	2,100,000 (99%)	2,100,000 (100%)	0 (0%)	0 (0%)	38 (34,42)	20	72
15-49 F	3.0 (2.6)	2.2	14,400,000 (97%)	14,400,000 (97%)	14,700,000 (100%)	0 (0%)	0 (0%)	39 (34,43)	20	73
50-64 All	5.0 (3.8)	3.9	10,200,000 (90%)	10,300,000 (90%)	11,100,000 (98%)	0 (0%)	0 (0%)	41 (36,47)	22	78
65 + All	5.0 (4.1)	3.7	9,200,000 (89%)	9,200,000 (89%)	10,200,000 (99%)	0 (0%)	0 (0%)	46 (38,56)	21	82

*The RNI is only applicable to children between 1.5-3 years, pregnant and breast-feeding women (represented by women aged 15-49 years) and adults over 50 years, this analysis assumes an RNI of 10µg per day applies to all adults and older children.

Table 8d: Vitamin D intakes and winter serum 25(OH)D levels for UK population sub-groups assuming fortification of flour at various levels, for a range of intake thresholds. Data from years 1&2 of the NDNS rolling programme were updated for vitamin D composition of fortified foods and supplements. Population mean, lower 2.5th and upper 97.5th percentile relationships (117, 118) for vitamin D intake/25(OH)D serum status were used to estimate serum 25(OH)D levels. Population figures have been estimated using census data and rounded to the nearest 100,000.

Using updated NDNS data years 1 &2 of the rolling programme								Winter serum 25(OH)D levels estimated using Cashman equations (nmol/l)		
Population group yrs/sex	Vitamin D intakes (µg/day)		No. with intakes below and above key thresholds *(thousands)*					Mean (95% CIs)	2.5%ile	97.5%ile
	Mean (s.d.)	Median	<RNI* (3)	<EAR (1)	<RDA (1)	>UL (66)	>UL (1)			
5µg vitamin D per 100g flour										
1.5-3 All	4.4 (2.8)	3.7	1,700 (88%)	1,800 (93%)	1,900 (99%)	0 (0%)	0 (0%)	40 (36,46)	21	76
4 to 8 All	5.9 (2.4)	5.6	3,200 (92%)*	3,200 (92%)	3,500 (100%)	0 (0%)	0 (0%)	43 (37,49)	23	81
9-49 M	7.3 (3.2)	6.9	14,800 (86%)*	14,800 (86%)	16,600 (97%)	0 (0%)	0 (0%)	45 (39,52)	24	85
9-14 F	6.1 (2.8)	5.8	1,900 (93%)*	1,900 (93%)	2,100 (99%)	0 (0%)	0 (0%)	43 (37,50)	23	81
15-49 F	6.2 (3.1)	5.6	13,300 (90%)	13,300 (90%)	14,500 (98%)	0 (0%)	0 (0%)	43 (38, 50)	23	82
50-64 All	8.5 (4.5)	7.6	7,600 (67%)	7,600 (67%)	10,400 (92%)	0 (0%)	0 (0%)	47 (40,55)	25	89
65 + All	8.6 (4.5)	7.5	7,600 (74%)	7,600 (74%)	10,100 (98%)	0 (0%)	0 (0%)	53 (42,64)	25	90
10µg vitamin D per 100g flour										
1.5-3 All	6.3 (3.3)	5.6	1,300 (65%)	1,700 (88%)	1,900 (98%)	0 (0%)	0 (0%)	43 (38,50)	23	82
4 to 8 All	9.1(3.3)	8.7	2,200 (62%)*	2,200 (62%)	3,400 (96%)	0 (0%)	0 (0%)	48 (41,56)	25	91
9-49 M	11.5 (4.8)	11.3	6,700 (39%)*	6,700 (39%)	13,900 (81%)	0 (0%)	0 (0%)	52 (44,63)	28	99
9-14 F	9.7 (3.9)	9.3	1,200 (59%)*	1,200 (59%)	1,900 (90%)	0 (0%)	0 (0%)	49 (42,58)	26	93
15-49 F	9.4 (4.3)	8.8	9,100 (62%)	9,100 (62%)	13,300 (90%)	0 (0%)	0 (0%)	49 (41,57)	26	92
50-64 All	12.0 (5.5)	10.7	4,800 (43%)	4,800 (43%)	8,000 (71%)	0 (0%)	0 (0%)	53 (45,64)	28	101
65 + All	12.2 (5.3)	10.9	4,100 (40%)	4,100 (40%)	9,100 (88%)	0 (0%)	0 (0%)	59 (46,74)	30	99

Pop. grp	Mean (s.d.)	Median	<RNI*	<EAR	<RDA	>UL	>UL	Mean (CIs)	2.5%ile	97.5%ile
15µg vitamin D per 100g flour										
1.5-3 All	8.3 (4.0)	7.6	800 (43%)	1,400 (72%)	1,800 (94%)	0 (1%)	0 (0%)	47 (40,54)	25	88
4 to 8 All	12.3 (4.3)	12.0	1,000 (28%)*	1,000 (28%)	2,600 (75%)	0 (1%)	0 (0%)	54 (45, 65)	29	102
9-49 M	15.8 (6.7)	15.3	3,500 (20%)*	3,500 (20%)	8,300 (49%)	0 (0%)	0 (0%)	61 (50,76)	32	116
9-14 F	13.2 (5.2)	12.7	600 (30%)*	600 (30%)	1,300 (65%)	0 (0%)	0 (0%)	56 (46,68)	30	106
15-49 F	12.6 (5.7)	12.0	5,200 (35%)	5,200 (35%)	10,200 (69%)	0 (0%)	0 (0%)	55 (45,66)	29	103
50-64 All	15.6 (6.8)	14.5	2,700 (24%)	2,700 (24%)	5,900 (52%)	0 (0%)	0 (0%)	61 (49,75)	32	115
65 + All	15.8 (6.5)	14.5	2,100 (20%)	2,100 (20%)	7,900 (77%)	0 (0%)	0 (0%)	66 (51,84)	35	108
20µg vitamin D per 100g flour										
1.5-3 All	10.2 (4.9)	9.3	500(27%)	1,100 (54%)	1,600 (84%)	0 (1%)	0 (0%)	50 (42-59)	26	94
4 to 8 All	15.6 (5.5)	15.2	500 (13%)*	500 (13%)	1,700 (48%)	200 (4%)	0 (0%)	61 (49-75)	32	115
9-49 M	20.0 (8.6)	19.3	1,600 (9%)*	1,600 (9%)	5,000 (29%)	100 (0.3%)	0 (0%)	72 (56-91)	38	135
9-14 F	16.7 (6.5)	16.3	300 (15%)*	300 (15%)	1,000 (46%)	0 (0%)	0 (0%)	63 (51-79)	34	120
15-49 F	15.8 (7.2)	15.1	3,400 (23%)	3,400 (23%)	7,400 (50%)	100 (0.5%)	0 (0%)	61 (50-76)	32	116
50-64 All	19.1 (8.3)	18.0	1,300 (11%)	1,300 (11%)	4,400 (38%)	0 (0%)	0 (0%)	69 (55-87)	37	131
65 + All	19.3 (7.7)	17.9	1,000 (9%)	1,000 (9%)	6,000 (59%)	200 (2%)	0 (0%)	74 (56-95	40	117
30µg vitamin D per 100g flour										
1.5-3 All	14.0 (6.7)	13.2	200 (11%)	500 (27%)	1,200 (61%)	100 (6%)	0 (0%)	58 (47-70)	30	109
4 to 8 All	22.0 (7.9)	21.6	200 (7%)*	200 (7%)	600 (16%)	1,100 (33%)	0 (0%)	77 (60-99)	41	146
9-49 M	28.4 (12.5)	27.5	900 (5%)*	900 (5%)	2,000 (12%)	1,000 (6%)	0 (0%)	**~~97 (72-132)~~**	**~~52~~**	**~~184~~**
9-14 F	23.7 (9.4)	23.0	100 (5%)*	100 (5%)	400 (17%)	0 (1%)	0 (0%)	82 (63-107)	43	155
15-49 F	22.2 (10.3)	21.4	1,500 (10%)	1,500 (10%)	4,000 (27%)	200 (1%)	0 (0%)	78 (60-100)	41	147
50-64 All	26.1 (11.3)	24.7	500 (5%)	500 (5%)	1,900 (17%)	500 (4%)	0 (0%)	**~~89 (67-119)~~**	**~~47~~**	**~~169~~**
65 + All	26.5 (10.4)	24.9	300 (3%)	300 (3%)	3,400 (33%)	400 (4%)	0 (0%)	**~~90 (66-118)~~**	**~~53~~**	**~~137~~**

*The RNI is only applicable to children between 1.5-3 years, pregnant and breast-feeding women (represented by women aged 15-49 years) and adults over 50 years, this analysis assumes an RNI of 10µg per day applies to all adults and older children. The text highlighted in bold and strike through indicates scenarios where the mean vitamin D intake rises above 25µg per day. As the Cashman *et. al.* relationships (117, 118) are not appropriate above a mean intake of 25µg vitamin D per day, these results are not valid.

Table 8e: Vitamin D intakes and winter serum 25(OH)D levels for UK population sub-groups assuming fortification of milk at various levels, for a range of intake thresholds.. Data from years 1&2 of the NDNS rolling programme were updated for vitamin D composition of fortified foods and supplements. Mean, lower 2.5th and upper 97.5th percentile relationships (117, 118) for vitamin D intake/25(OH)D serum status were used to estimate serum 25(OH)D levels. Population figures have been estimated using census data and are rounded to the nearest 100,000.

Population group years/sex	Using updated NDNS data years 1 &2 of the rolling programme							Winter serum 25(OH)D estimated using Cashman equations		
	Vitamin D intake (µg/day)		No. with intakes below and above key thresholds *(thousands)*							
	Mean (s.d.)	Median	<RNI* (3)	<EAR (1)	<RDA (1)	>UL (66)	>UL (1)	Mean (nmol/l) (95% CIs)	2.5%ile (nmol/l)	97.5%ile (nmol/l)
0.5µg vitamin D per 100ml milk										
1.5-3 All	4.0 (2.6)	3.3	1,800 (91%)	1,800 (94%)	1,900 (99%)	0 (0%)	0 (0%)	40 (35, 45)	21	75
4 to 8 All	3.9 (2.2)	3.4	3,400 (98%)*	3,400 (98%)	3,500 (100%)	0 (0%)	0 (0%)	40 (35, 45)	21	75
9-49 M	4.0 (2.7)	3.2	16,500 (96%)*	16,500 (96%)	17,000 (99%)	0 (0%)	0 (0%)	40 (35, 45)	21	75
9-14 F	3.4 (2.4)	2.7	2,000 (98%)*	2,000 (98%)	2,100 (99%)	0 (0%)	0 (0%)	39 (35,44)	21	74
15-49 F	3.7 (2.7)	2.9	14,200 (96%)	14,200 (96%)	14,700 (99%)	0 (0%)	0 (0%)	39 (35,44)	21	74
50-64 All	5.9 (4.0)	4.7	9,600 (85%)	9,600 (85%)	11,000 (97%)	0 (0%)	0 (0%)	43 (37,49)	23	81
65 + All	6.1 (4.2)	4.9	8,700 (84%)	8,700 (84%)	10,200 (99%)	0 (0%)	0 (0%)	48 (39,58)	22	84
1µg vitamin D per 100ml milk										
1.5-3 All	5.6 (3.1)	4.9	1,500 (77%)	1,700 (88%)	1,900 (98%)	0 (0%)	0 (0%)	42 (37, 48)	22	80
4 to 8 All	5.2 (2.6)	4.7	3,300 (94%)*	3,300 (94%)	3,500 (100%)	0 (0%)	0 (0%)	42 (36, 47)	22	79
9-49 M	4.9 (3.1)	4.1	16,000 (93%)*	16,000 (93%)	16,900 (98%)	0 (0%)	0 (0%)	41 (36,47)	22	78
9-14 F	4.2 (2.7)	3.5	2,000 (96%)*	2,000 (96%)	2,100 (99%)	0 (0%)	0 (0%)	40 (35,46)	21	76
15-49 F	4.3 (2.9)	3.6	14,100 (95%)	14,100 (95%)	14,600 (99%)	0 (0%)	0 (0%)	40 (36,46)	21	76
50-64 All	6.8 (4.2)	5.7	9,100 (80%)	9,100 (80%)	10,900 (97%)	0 (0%)	0 (0%)	44 (38,51)	23	83
65 + All	7.3 (4.4)	6.2	8,300 (80%)	8,300 (80%)	10,200 (99%)	0 (0%)	0 (0%)	50 (41,61)	24	87

Pop. grp	Mean (s.d.)	Median	<RNI*	<EAR	<RDA	>UL	>UL	Mean (CIs)	2.5%ile	97.5%ile
2µg vitamin D per 100ml milk										
1.5-3 All	8.7 (4.9)	8.2	800 (44%)	1,300 (67%)	1,700 (89%)	0 (1%)	0 (0%)	47 (40, 55)	25	90
4 to 8 All	7.6 (3.9)	7.1	2,500 (72%)*	2,500 (72%)	3,400 (96%)	0 (0%)	0 (0%)	46 (39, 53)	24	86
9-49 M	6.7 (4.5)	5.5	14,300 (83%)*	14,300 (83%)	16,100 (94%)	0 (0%)	0 (0%)	44 (38, 51)	23	83
9-14 F	5.8 (3.7)	5.0	1,900 (90%)*	1,900 (90%)	2,000 (97%)	0 (0%)	0 (0%)	43 (37,49)	23	80
15-49 F	5.7 (3.6)	4.8	13,000 (88%)	13,000 (88%)	14,400 (97%)	0 (0%)	0 (0%)	42 (37,49)	22	80
50-64 All	8.5 (4.9)	7.3	7,700 (68%)	7,700 (68%)	10,100 (89%)	0 (0%)	0 (0%)	47 (40,55)	25	89
65 + All	9.5 (5.1)	8.4	6,600 (64%)	6,600 (64%)	10,000 (97%)	0 (0%)	0 (0%)	55 (43,67)	27	92
5µg vitamin D per 100ml milk										
1.5-3 All	18.1 (11.4)	16.3	300 (16%)	500 (28%)	900 (46%)	400 (21%)	0 (1%)	67 (53,83)	35	126
4 to 8 All	15.1 (8.4)	13.7	1,000 (30%)*	1,000 (30%)	2,000 (56%)	400 (12%)	0 (0%)	60 (49,73)	32	113
9-49 M	12.2 (9.4)	9.6	9,100 (53%)*	9,100 (53%)	12,400 (73%)	0 (0.2%)	0 (0%)	54 (45,64)	28	102
9-14 F	10.6 (7.5)	8.8	1,200 (57%)*	1,200 (57%)	1,600 (76%)	0 (0%)	0 (0%)	51 (43,60)	27	96
15-49 F	9.8 (6.7)	8.1	9,300 (63%)	9,300 (63%)	12,200 (82%)	0 (0%)	0 (0%)	49 (42,58)	26	93
50-64 All	13.7 (8.1)	11.9	4,100 (36%)	4,100 (36%)	7,200 (63%)	0 (0.4%)	0 (0%)	57 (47,69)	30	108
65 + All	16.3 (8.7)	15.3	2,500 (24%)	2,500 (24%)	7,500 (72%)	0 (0%)	0 (0%)	68 (52, 86)	36	110
7µg vitamin D per 100ml milk										
1.5-3 All	24.3 (16.0)	21.9	100 (7%)	400 (19%)	700 (35%)	800 (40%)	100 (3%)	84 (64,110)	44	158
4 to 8 All	20.1 (11.6)	18.3	700 (19%)*	700 (19%)	1,200 (35%)	1,100 (30%)	0 (0%)	72 (56,91)	38	136
9-49 M	15.8 (12.8)	12.2	7,000 (41%)*	7,000 (41%)	10,200 (60%)	500 (3%)	0 (0.2%)	61 (50,76)	32	116
9-14 F	13.7 (10.3)	11.6	900 (44%)*	900 (44%)	1,300 (62%)	0 (1%)	0 (0%)	57 (47,69)	30	108
15-49 F	12.5 (8.9)	10.3	7,200 (49%)	7,200 (49%)	10,600 (72%)	100 (0.5%)	0 (0%)	54 (45,65)	29	103
50-64 All	17.2 (10.5)	14.9	2,900 (25%)	2,900 (25%)	5,600 (50%)	200 (2%)	0 (0%)	65 (52,80)	34	122
65 + All	20.8 (11.5)	19.0	1,800 (18%)	1,800 (18%)	5,600 (54%)	300 (3%)	0 (0%)	78 (59,101)	44	123

*The RNI is only applicable to children between 1.5-3 years, pregnant and breast-feeding women (represented by women aged 15-49 years) and adults over 50 years, this analysis assumes an RNI of 10µg per day applies to all adults and older children.

Table 8f: Vitamin D intakes and winter serum 25(OH)D levels for UK population sub-groups assuming fortification of flour and milk at various levels, for a range of intake thresholds. Data from years 1&2 of the NDNS rolling programme were updated for vitamin D composition of fortified foods and supplements. Mean, lower 2.5th and upper 97.5th percentile relationships (117, 118) for vitamin D intake/25(OH)D serum status were used to estimate serum 25(OH)D levels. Population figures have been estimated using census data and are rounded to the nearest 100,000.

Using updated NDNS data years 1 &2 of the rolling programme								Winter serum 25(OH)D levels estimated using Cashman equations (nmol/l)		
Population group years/sex	Vitamin D intake (µg/day)		No. with intakes below and above key thresholds *(thousands)*					Mean (95% CIs)	2.5%ile	97.5% ile
	Mean (s.d.)	Median	<RNI* (3)	<EAR (1)	<RDA (1)	>UL (66)	>UL (1)			
2.5µg vitamin D per 100g flour & 0.25µg vitamin D per 100ml milk										
1.5-3 All	4.2 (2.6)	3.5	1,700 (90%)	1,800 (94%)	1,900 (99%)	0 (0%)	0 (0%)	40 (35,46)	21	76
4 to 8 All	4.9 (2.1)	4.5	3,400 (96%)*	3,400 (96%)	3,500 (100%)	0 (0%)	0 (0%)	41 (36,47)	22	78
9-49 M	5.7 (2.8)	5.1	16,200 (94%)*	16,200 (94%)	16,900 (98%)	0 (0%)	0 (0%)	42 (37,48)	22	80
9-14 F	4.8 (2.4)	4.3	2,000 (96%)*	2,000 (96%)	2,100 (99%)	0 (0%)	0 (0%)	41 (36,47)	22	78
15-49 F	4.9 (2.8)	4.4	14,000 (94%)	13,900 (94%)	14,600 (99%)	0 (0%)	0 (0%)	41 (36,47)	22	78
50-64 All	7.2 (4.1)	6.3	8,600 (76%)	8,600 (76%)	10,800 (95%)	0 (0%)	0 (0%)	45 (39,52)	24	85
65 + All	7.4 (4.2)	6.3	8,200 (80%)	8,200 (80%)	10,200 (99%)	0 (0%)	0 (0%)	50 (41,61)	24	87
5µg vitamin D per 100g flour & 1µg vitamin D per 100ml milk										
1.5-3 All	7.6 (3.3)	6.9	1,000 (50%)	1,600 (81%)	1,900 (97%)	0 (0%)	0 (0%)	45 (39,53)	24	86
4 to 8 All	8.4 (2.9)	8.1	2,600 (73%)*	2,600 (73%)	3,400 (98%)	0 (0%)	0 (0%)	47 (40,55)	25	89
9-49 M	9.1 (3.9)	8.7	11,700 (68%)*	11,600 (68%)	15,700 (92%)	0 (0%)	0 (0%)	48 (41,56)	25	91
9-14 F	7.8 (3.1)	7.2	1,600 (79%)*	1,600 (79%)	2,000 (97%)	0 (0%)	0 (0%)	46 (39,53)	24	86
15-49 F	7.6 (3.4)	7.0	11,900 (80%)	11,900 (80%)	14,200 (96%)	0 (0%)	0 (0%)	45 (39,53)	24	86
50-64 All	10.3 (4.8)	9.2	6,300 (56%)	6,300 (56%)	9,500 (84%)	0 (0%)	0 (0%)	50 (42,59)	27	95
65 + All	10.9 (4.8)	10.1	5,100 (50%)	5,100 (50%)	9,600 (93%)	0 (0%)	0 (0%)	57 (45,71)	28	96

Pop. grp	Mean (s.d.)	Median	<RNI*	<EAR	<RDA	>UL	>UL	Mean (CIs)	2.5%ile	97.5%ile
10μg vitamin D per 100g flour & 2.5μg vitamin D per 100ml milk										
1.5-3 All	14.2 (6.2)	13.3	100 (5%)	500 (27%)	1,300 (65%)	100 (7%)	0 (0%)	58 (48,70)	31	109
4 to 8 All	15.4 (5.2)	15.2	500 (15%)*	500 (15%)	1,700 (48%)	200 (4%)	0 (0%)	60 (49,74)	32	114
9-49 M	16.1 (6.9)	15.0	2,900 (17%)*	2,900 (17%)	8,400 (49%)	0 (0%)	0 (0%)	62 (50,77)	33	117
9-14 F	13.7 (5.1)	12.8	6,000 (27%)*	600 (27%)	1,300 (64%)	0 (0%)	0 (0%)	57 (47,69)	30	107
15-49 F	12.8 (5.4)	11.7	5,100 (35%)	5,100 (35%)	10,600 (71%)	0 (0%)	0 (0%)	55 (46,66)	29	104
50-64 All	16.4 (6.9)	15.7	2,200 (19%)	2,200 (19%)	5,300 (47%)	0 (0%)	0 (0%)	63 (51,78)	33	119
65 + All	17.9 (6.8)	16.7	1,100 (11%)	1,100 (11%)	6,600 (64%)	0 (0%)	0 (0%)	71 (54,91)	39	114
15μg vitamin D per 100g flour & 3.5μg vitamin D per 100ml milk										
1.5-3 All	19.3 (8.5)	18.2	0 (2%)	200 (9%)	700 (36%)	400 (21%)	0 (0%)	70 (55-88)	37	132
4 to 8 All	21.1 (7.0)	20.8	100 (3%)*	100 (3%)	700 (20%)	1,000 (28%)	0 (0%)	75 (58-96)	39	141
9-49 M	22.2 (9.5)	20.9	1,200 (7%)*	1,200 (7%)	3,800 (22%)	100 (1%)	0 (0%)	78 (60-100)	41	147
9-14 F	18.8 (6.9)	17.8	100 (7%)*	100 (7%)	700 (33%)	0 (0%)	0 (0%)	68 (54-86)	36	129
15-49 F	17.4 (7.3)	16.2	1,800 (12%)	1,800 (12%)	6,500 (44%)	0 (0%)	0 (0%)	65 (52,81)	34	123
50-64 All	21.7 (8.8)	20.4	800 (7%)	800 (7%)	2,800 (25%)	0 (0%)	0 (0%)	76 (59,98)	40	144
65 + All	23.8 (8.7)	22.5	400 (4%)	400 (4%)	3,900 (38%)	100 (1%)	0 (0%)	84 (62,110)	48	130

*The RNI is only applicable to children between 1.5-3 years, pregnant and breast-feeding women (represented by women aged 15-49 years) and adults over 50 years, this analysis assumes an RNI of 10μg per day applies to all adults and older children.

Table 8g: Vitamin D intakes and winter serum 25(OH)D levels for the whole UK population assuming fortification of flour, milk and flour and milk at various levels, for a range of intake thresholds. *RNI only applies to 'at risk' groups

Using updated NDNS data years 1 &2 of the rolling programme									Winter serum 25(OH)D levels estimated using Cashman equations (nmol/l)		
Level and vehicle of fortification	Vitamin D intake (µg/day)		No. with intakes <RNI (3) *thousands*		No. with intakes <EAR (1) *thousands*	No. with intakes <RDA (1) *thousands*	No. with intakes >UL (66) *thousands*	No. with intakes >UL (1) *thousands*	Mean (95% CIs)	2.5%ile	97.5%ile
	Mean (st.dev.)	Median	Only groups for whom an RNI is set*	All (10µg for 4-50yrs)							
Data from years 1&2 of NDNS rolling programme											
No fortification	3.5 (2.8)	2.7	35,800 (93%)	58,300 (95%)	58,300 (96%)	60,700 (99%)	0 (0%)	0 (0%)	39 (34,44)	20	73
Data from years 1&2 of NDNS rolling programme updated for fortified foods and supplements											
No fortification	3.7 (3.0)	2.8	35,700 (93%)	58,000 (95%)	58,100 (95%)	60,500 (99%)	0 (0%)	0 (0%)	39 (35,45)	20	74
Flour fortification											
5µg/100g flour	7.3 (3.6)	6.6	30,200 (79%)	50,100 (82%)	50,300 (82%)	59,000 (97%)	0 (0%)	0 (0%)	45 (38,52)	23	84
10µg/100g flour	10.8 (4.7)	10.1	19,300 (50%)	29,400 (48%)	29,900 (49%)	51,400 (84%)	0 (0%)	0 (0%)	51 (43,71)	27	95
15µg/100g flour	14.5 (6.2)	13.7	10,900 (28%)	15,900 (26%)	16,500 (27%)	38,200 (63%)	0 (0.1%)	0 (0%)	58 (47,71)	31	108
20µg/100g flour	18.0 (7.7)	17.2	6,100 (16%)	8,400 (14%)	9,000 (15%)	27,000 (44%)	500 (0.8%)	0 (0%)	66 (52,82)	35	122
30µg/100g flour	25.2 (10.9)	24.1	2,500 (7%)	3,800 (6%)	4,100 (7%)	13,000 (22%)	3,300 (5%)	0 (0%)	~~**85 (64,111)**~~	~~**45**~~	~~**157**~~
Milk fortification											
0.5µg/100g milk	4.6 (3.1)	3.7	34,300 (89%)	56,200 (92%)	56,300 (92%)	60,300 (99%)	0 (0%)	0 (0%)	41 (36,47)	21	77
1µg/100g milk	5.5 (3.4)	4.7	32,900 (86%)	54,200 (89%)	54,400 (89%)	60,000 (98%)	0 (0%)	0 (0%)	42 (37,49)	22	79
2µg/100g milk	7.4 (4.4)	6.3	28,100 (73%)	46,800 (77%)	47,200 (77%)	57,700 (94%)	0 (0.04%)	0 (0%)	45 (39,53)	24	85
5µg/100g milk	12.9 (8.3)	11.1	16,200 (42%)	27,500 (45%)	27,700 (45%)	43,700 (71%)	900 (1%)	0 (0%)	56 (46,68)	30	104
7µg/100g milk	16.5 (11.2)	14.0	12,000 (31%)	20,600 (34%)	20,800 (34%)	35,300 (58%)	2,000 (5%)	100 (0.1%)	65 (52,81)	35	120
Milk and flour fortification											
2.5µg/100g flour 0.25µg/100g milk	5.9 (3.2)	5.2	32,500 (85%)	54,000 (88%)	54,100 (89%)	60,000 (98%)	0 (0%)	0 (0%)	43 (37, 49)	22	80
5µg/100g flour 1µg/100g milk	9.1 (4.0)	8.5	24,300 (63%)	40,134 (66%)	40,700 (67%)	56,400 (92%)	0 (0%)	0 (0%)	44 (41,57)	25	90
10 µg/100g flour 2.5µg/100g milk	15.5 (6.3)	14.5	8,600 (22%)	12,500 (20%)	12,900 (21%)	35,200 (58%)	300 (0.5%	0 (0%)	61 (49,75)	32	113
15µg/100g flour 3.5µg/100g milk	20.9 (8.5)	19.8	3,000 (8%)	4,500 (7%)	4,600 (7.5%)	19,000 (31%)	1,600 (3%)	0 (0%)	74 (58,94)	39	137

The text highlighted in bold and strike through indicates scenarios where the mean vitamin D intake rises above 25µg per day. As the Cashman *et. al.* relationships (117, 118) are not appropriate above a mean intake of 25µg vitamin D per day, these results are not valid.

Assessment of the effect of socio-economic status (classified by the National Statistics Socio-Economic Classification (NS-SEC 3 class version) (170)

Table 8h: Vitamin D intakes using data from years 1&2 of the NDNS rolling programme with updated vitamin D composition of fortified foods and supplements. No one had intakes above the UL

Age/sex group	Managerial and professional occupations				Intermediate occupations				Routine and manual occupations			
	Vitamin D intake (µg/day)											
	Mean	s.d.	Median	%<RNI	Mean	s.d.	Median	%<RNI	Mean	s.d.	Median	%<RNI
1.5-3 All	2.7	2.6	1.8	92%	[2.8]	[3.1]	[1.7]	[90%]	2.3	2.5	1.6	96%
4 to 8 All	2.9	2.2	2.4	100%*	2.5	1.8	1.9	100%*	2.5	1.8	2.1	100%*
9-49 M	3.1	2.5	2.3	99%*	2.8	1.6	2.3	100%*	3.2	2.6	2.7	100%*
9-14 F	2.8	2.4	2.0	100%*	[2.5]	[1.9]	[1.9]	[98%]*	2.4	1.6	2.0	98%*
15-49 F	3.1	2.6	2.4	96%	3.3	3.0	2.1	95%	2.9	2.4	2.2	97%
50-64 All	5.2	3.8	4.3	87%	[5.4]	[3.8]	[5.0]	87%	4.4	3.1	3.5	97%
65 + All	5.2	4.2	3.9	90%	5.7	4.5	3.7	83%	4.5	3.8	3.2	94%

[ ] bracket values had cell sizes at less than 50
*RNI only applicable to children between 1.5-3 years, women pregnant and breast-feeding women (represented by women aged 15-49 years)and adults over 50 years, this analysis assumes an RNI of 10µg per day applies to all adults and older children.

Table 8i: Vitamin D intakes using data from years 1&2 of the NDNS rolling programme with updated vitamin D composition of fortified foods and supplements assuming fortification of flour at 10µg per 100g flour. No one had intakes above the UL

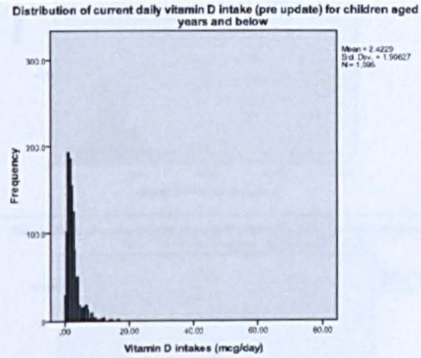
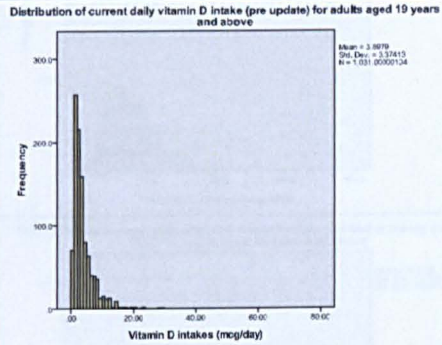
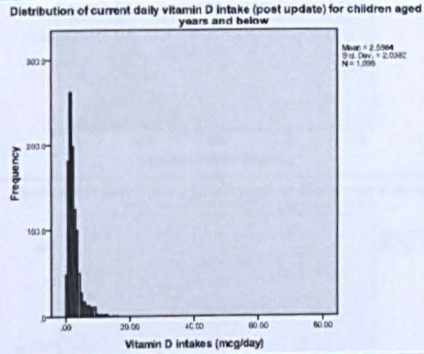
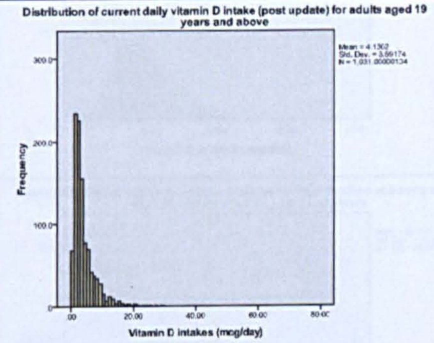
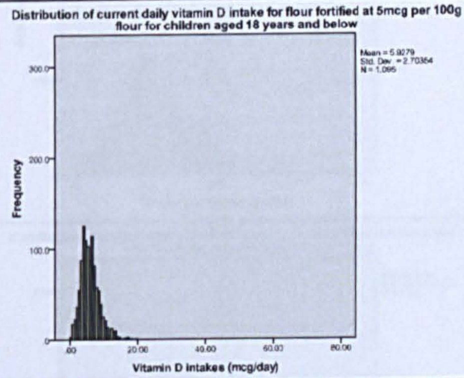
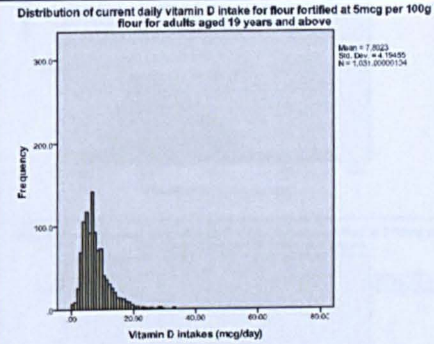
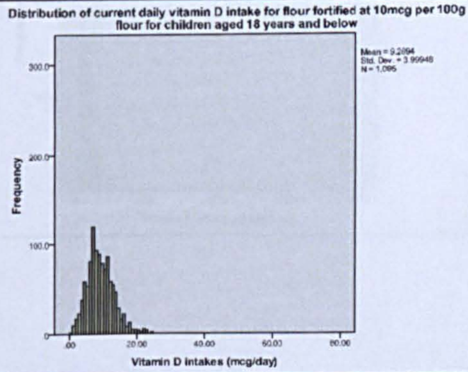
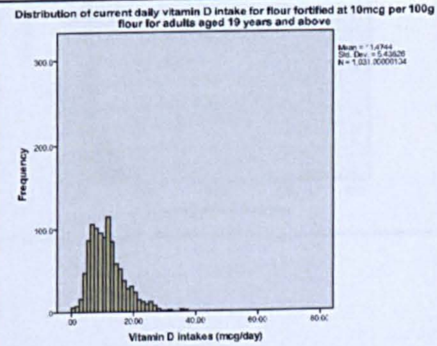
Age/sex group	Managerial and professional occupations				Intermediate occupations				Routine and manual occupations			
	Vitamin D intake (µg/day)											
	Mean	s.d.	Median	%<RNI	Mean	s.d.	Median	%<RNI	Mean	s.d.	Median	%<RNI
1.5-3 All	6.5	3.2	6.1	59%	[6.2]	[3.1]	[5.7]	[63%]	6.4	3.7	5.5	73%
4 to 8 All	9.2	3.4	8.5	63%*	9.3	3.2	8.8	60%*	8.9	3.3	8.6	61%*
9-49 M	11.7	4.7	11.4	51%*	10.9	4.3	10.5	52%*	11.9	5.0	11.9	47%*
9-14 F	9.9	3.8	9.2	54%*	[9.2]	[4.8]	[7.7]	[65%]*	9.5	3.3	9.6	50%*
15-49 F	9.1	4.1	8.4	47%	9.6	4.5	8.3	51%	9.6	4.2	8.9	44%
50-64 All	12.4	5.5	11.5	38%	[12.1]	[5.3]	[10.3]	[49%]	11.6	5.3	10.7	44%
65 + All	12.4	5.3	12.0	37%	12.7	5.6	11.2	37%	11.8	5.3	10.3	42%

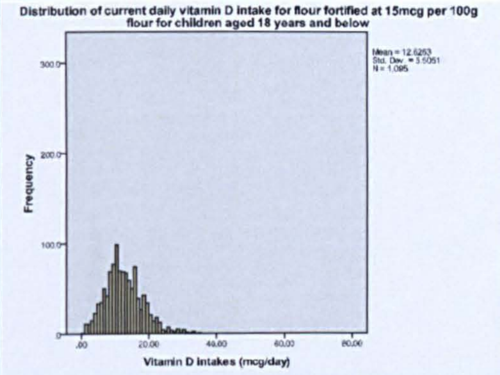
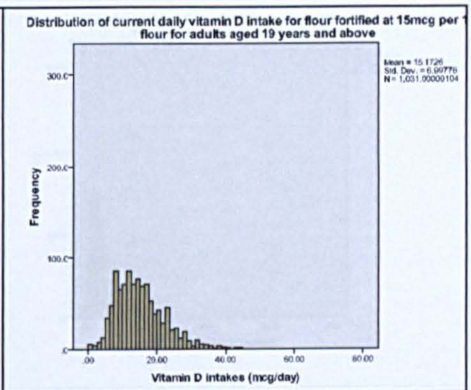
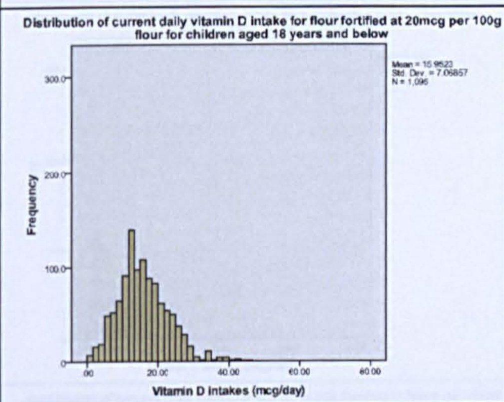
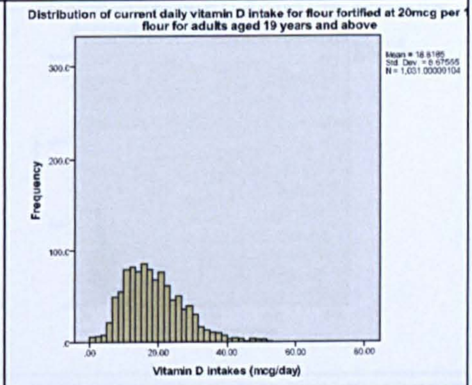
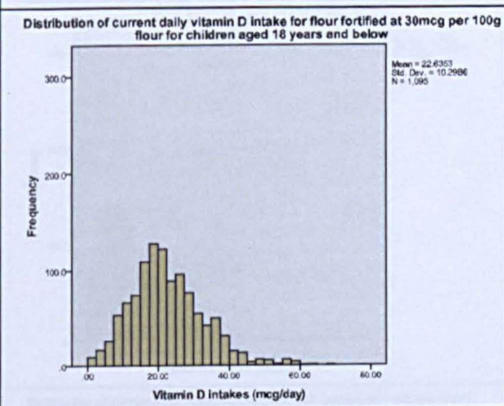
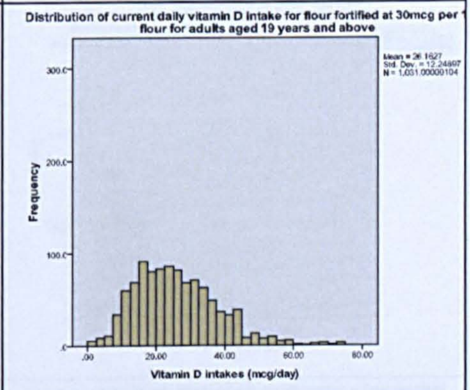
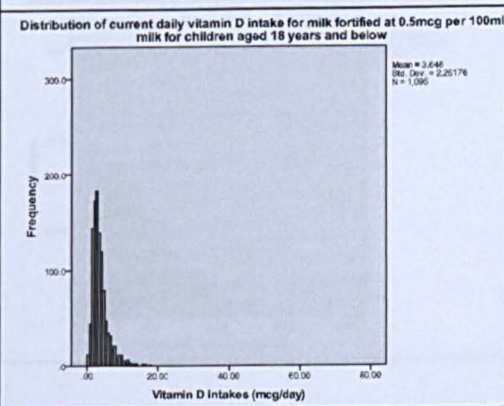
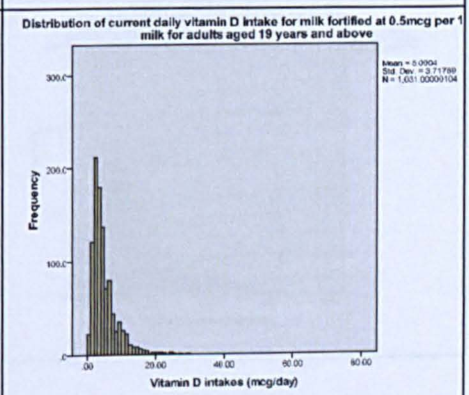
[ ] bracket values represent cell sizes at less than 50
*RNI only applicable to children between 1.5-3 years, pregnant and breast-feeding women (represented by women aged 15-49 years) and adults over 50 years, this analysis assumes an RNI of 10µg per day applies to all adults and older children.

Table 8j: Percentage contribution of dietary sources to vitamin D intake by socio-economic group for children aged 18 months to 18 years and adults aged above 19 years.

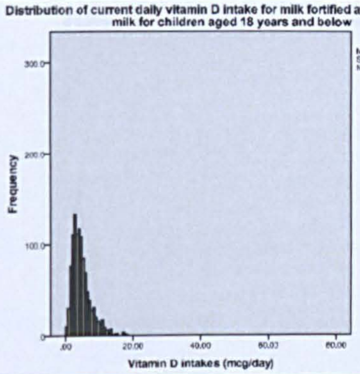
	Percentage contribution of food groups to vitamin D intake (%)							
Group	Meat and meat products	Dairy Products	Fish	Egg and egg products	Fat spreads and oils (not butter)	breakfast cereals	Supple-ments	Other-other cereals, vegetables dishes, desserts
Children: Managerial and professional occupations	18%	8%	12%	6%	15%	9%	22%	8%
Children: Intermediate occupations	20%	13%	9%	7%	18%	10%	14%	9%
Children: Routine and manual occupations	24%	10%	6%	8%	22%	11%	11%	8%
Children: Total	21%	10%	9%	7%	18%	10%	16%	8%
Adults: Managerial and professional occupations	15%	4%	29%	7%	12%	5%	23%	6%
Adults: Intermediate occupations	15%	4%	19%	8%	11%	5%	34%	5%
Adults: Routine and manual occupations	19%	3%	15%	9%	19%	6%	24%	5%
Adults: Total	16%	4%	22%	8%	14%	5%	25%	5%

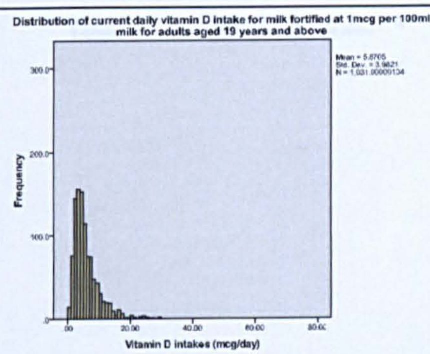
Figure 8a: Distributions of vitamin D intake for children and adults and different scenarios of fortification

	Children	Adults
Current intake pre update of fortified foods and supplements		
Current intake post update of fortified foods and supplements		
Fortification of flour at 5µg (mcg)per 100g flour		
Fortification of flour at10µg (mcg)per 100g flour		

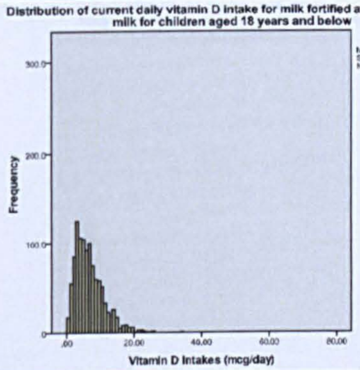
Fortification of flour at 15µg (mcg)per 100g flour		
Fortification of flour at 20µg (mcg)per 100g flour		
Fortification of flour at 30µg (mcg)per 100g flour		
Fortification of milk at 0.5µg (mcg) per 100g milk		

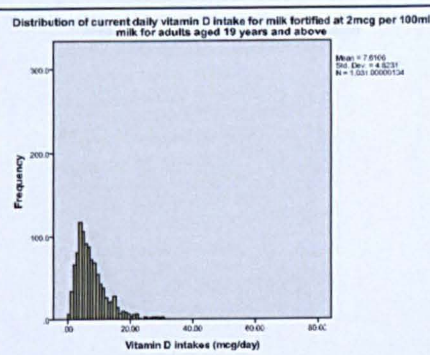
Fortification of milk at 1µg (mcg) per 100g milk



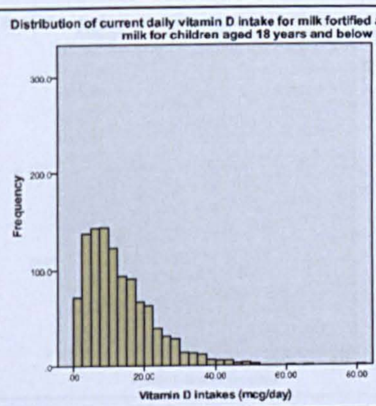


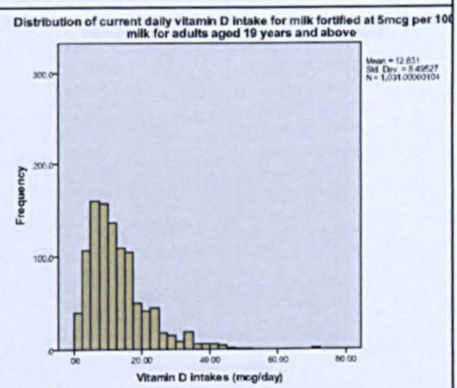
Fortification of milk at 2µg (mcg) per 100g milk



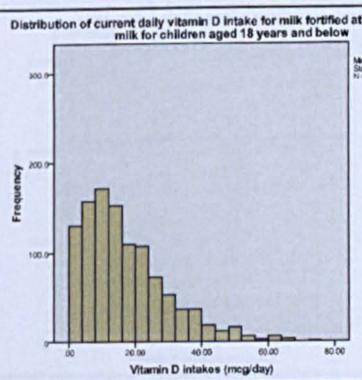


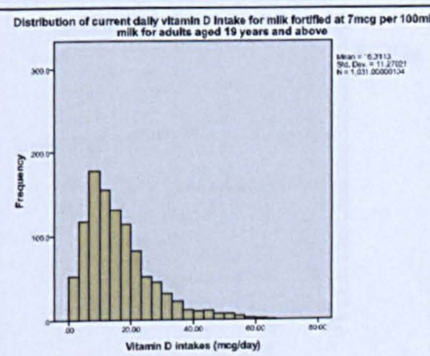
Fortification of milk at 5µg (mcg) per 100g milk



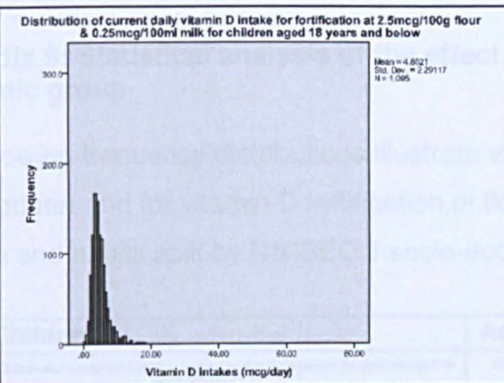


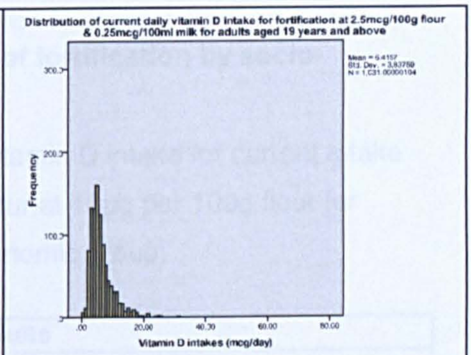
Fortification of milk at 7µg (mcg) per 100g milk



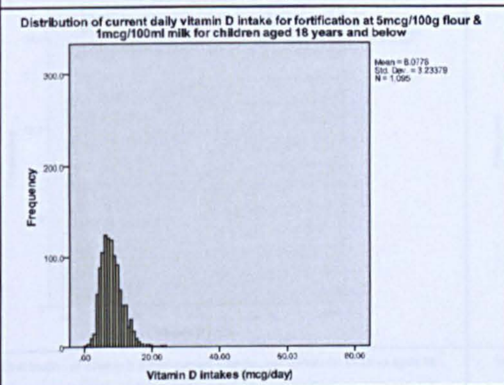


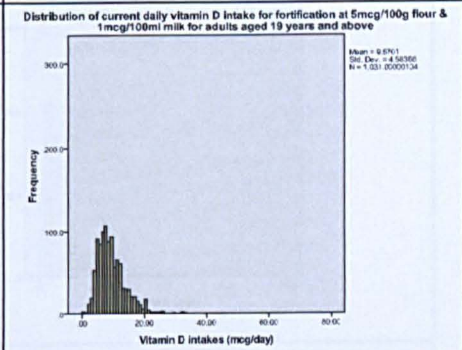
Fortification at 2.5µg (mcg) per 100g flour and 0.25µg per 100ml milk



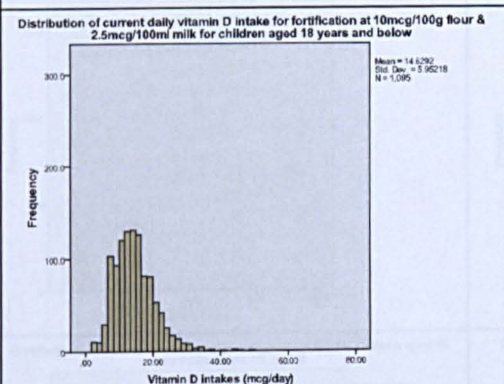


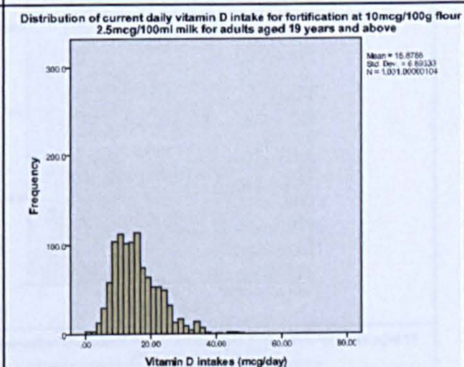
Fortification at 5µg (mcg) per 100g flour and 1µg per 100ml milk



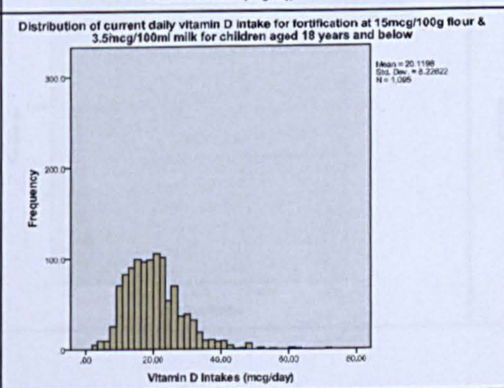


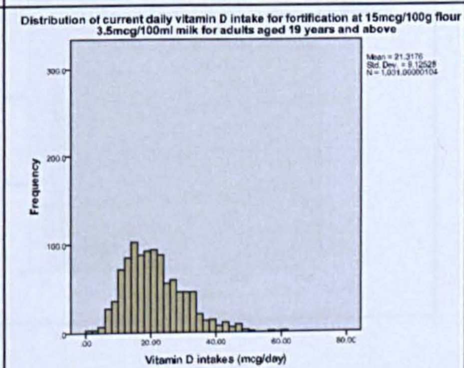
Fortification at 10µg (mcg) per 100g flour and 2.5 µg per 100ml milk





Fortification at 15µg (mcg) per 100g flour and 3.5 µg per 100ml milk





Appendix 9: Statistical analysis of the effect of fortification by socio-economic group

The following frequency distributions illustrate vitamin D intake for current intake (post-update) and for vitamin D fortification of flour at 10µg per 100g flour for children and adults *split* by NS-SEC 3 socio-economic group.

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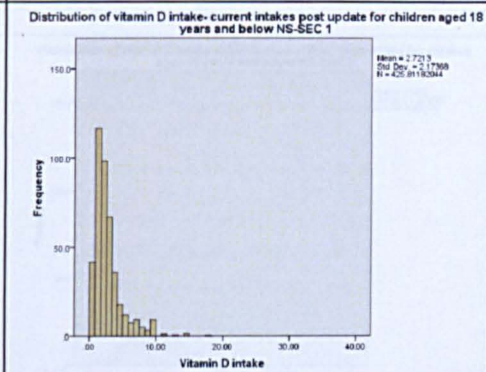
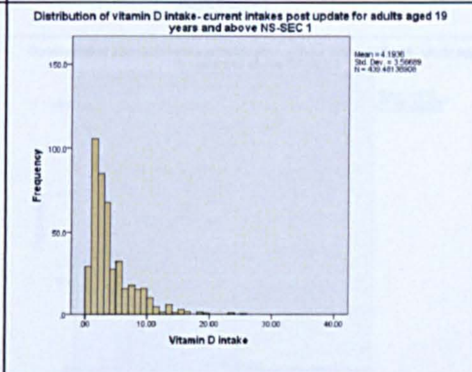
<tr><td>Current intake post update of fortified foods and supplements</td><td>
</td><td>
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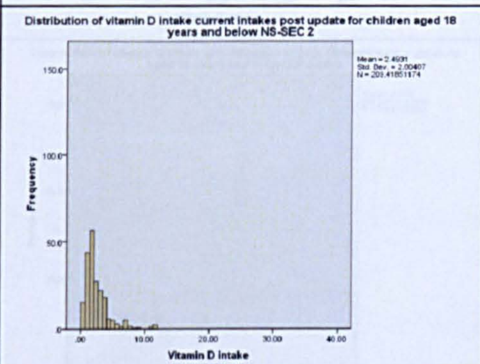
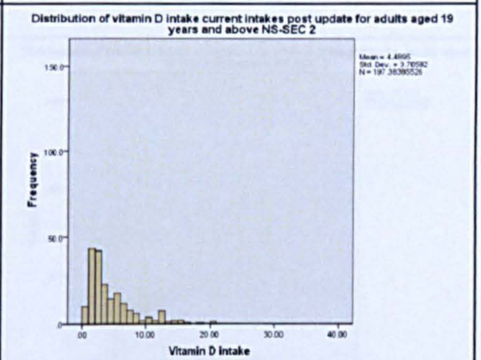
<tr><td>Current intake post update of fortified foods and supplements</td><td>
</td><td>
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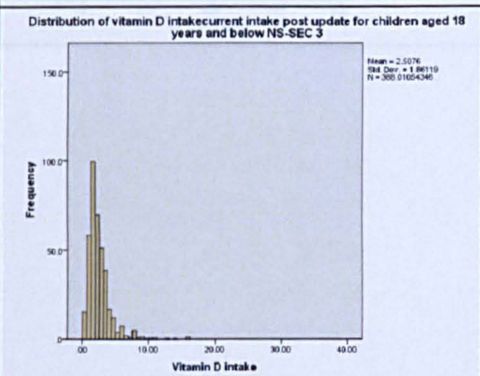
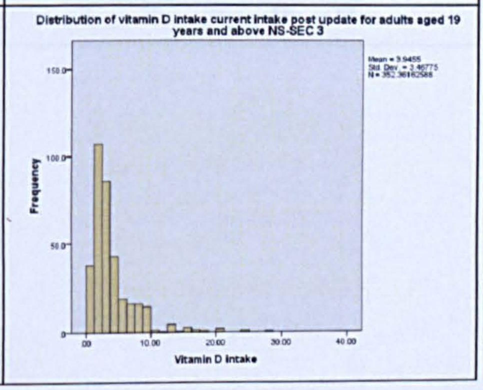
<tr><td>Current intake post update of fortified foods and supplements</td><td>
</td><td>
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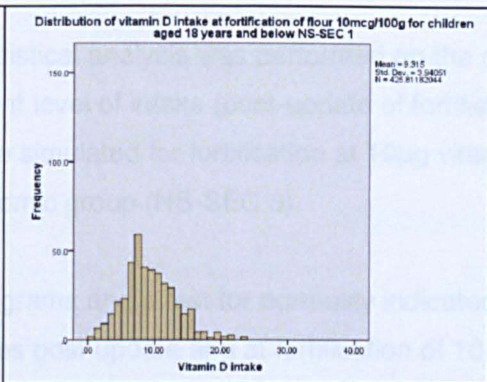
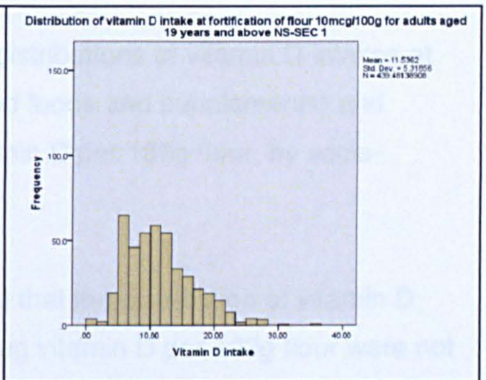
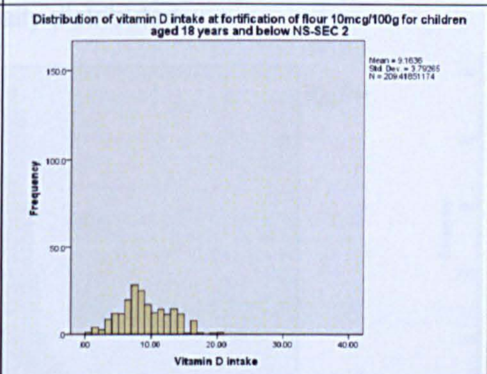
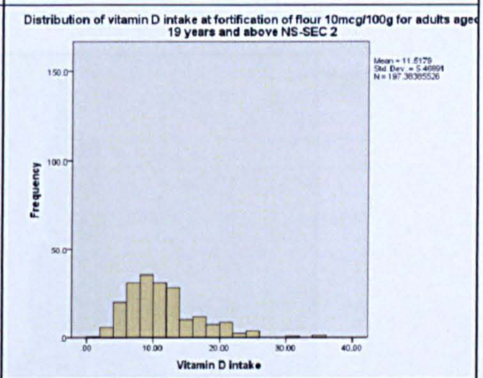
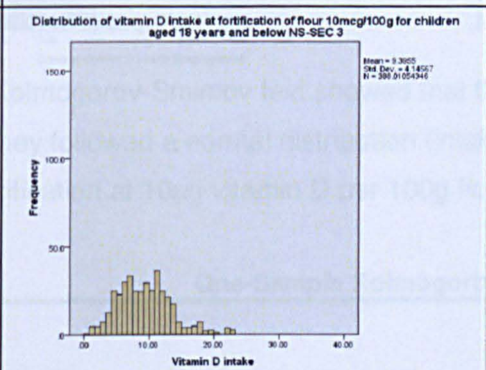
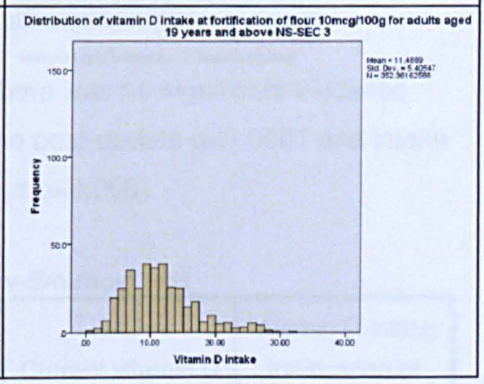
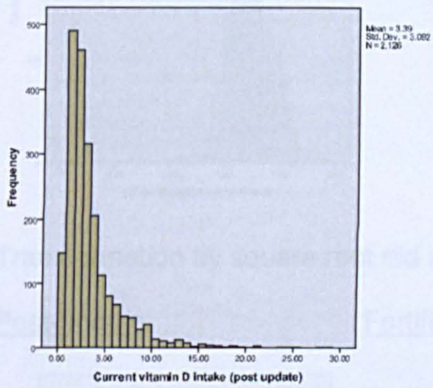
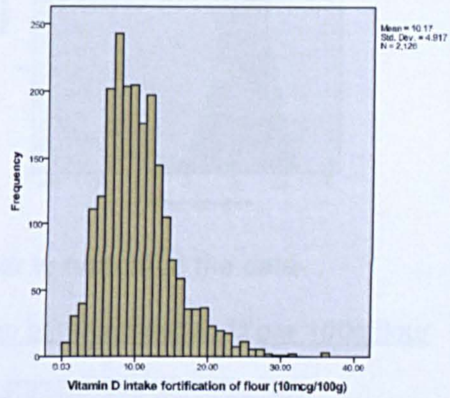
Fortification of flour at 10µg (mcg)per 100g flour		
Fortification of flour at 10µg (mcg)per 100g flour		
Fortification of flour at 10µg (mcg)per 100g flour		

A statistical analysis was performed on the distributions of vitamin D intakes at current level of intake (post-update of fortified foods and supplements) and intake simulated for fortification at 10µg vitamin D per 100g flour, by socio-economic group (NS-SEC 3).

Histograms and a test for normality indicated that the distribution of vitamin D intakes post update and at fortification of 10µg vitamin D per 100g flour were not normally distributed.





The Kolmogorov-Smimov text showed that there was no significant evidence that they followed a normal distribution (intake post-update p=0.0001 and intake at fortification at 10µg vitamin D per 100g flour p=0.005).

One-Sample Kolmogorov-Smirnov Test

		Current vitamin D intake (post update)	Vitamin D intake fortification of flour (10mcg/100g)
N		1122	1122
Normal Parameters[a,b]	Mean	2.5651	9.2866
	Std. Deviation	1.97526	4.00262
Most Extreme Differences	Absolute	.155	.052
	Positive	.155	.052
	Negative	-.121	-.023
Kolmogorov-Smirnov Z		5.178	1.730
Asymp. Sig. (2-tailed)		.000	.005

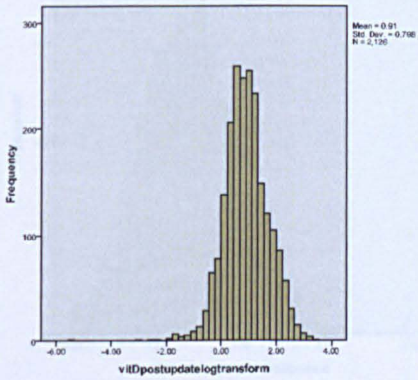
a. Test distribution is Normal.

b. Calculated from data.

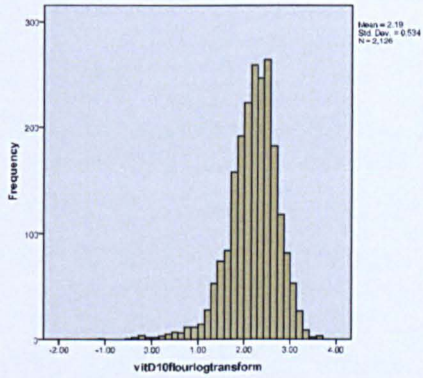
Data were therefore transformed in an attempt to normalise the data so that parametric tests could be performed.

Transformation by natural log (ln) did not normalise the data:

Post-update

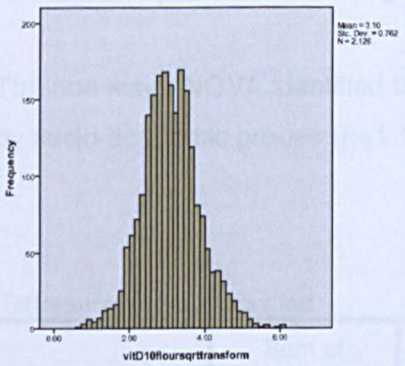


Fortification at 10μg vitamin D per 100g flour

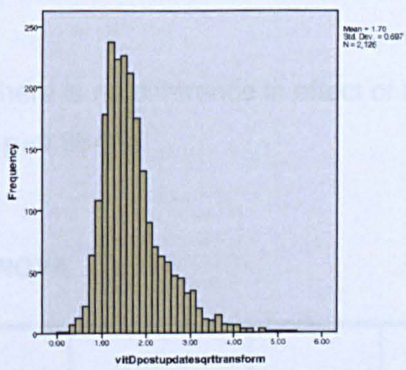


Transformation by square root did appear to normalise the data

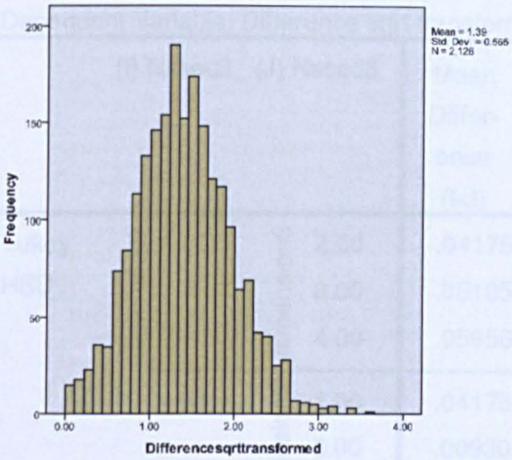
Post-update



Fortification at 10μg vitamin D per 100g flour



The difference of square root intake current post-update and square root intake at fortification 10µg vitamin D per 100g flour was then calculated to test further for normality. The distribution of the difference appeared normal:



A parametric one way ANOVA was therefore performed on the data by socio-economic group (NSSEC3) to assess whether there was any differential effect of fortification by socio-economic group.

The one way ANOVA identified that there is no difference in effect of fortification by socio-economic groups (F=1.107; p=0.354).

ANOVA

Difference sqrt transformed

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.052	3	.351	1.107	.345
Within Groups	343.801	1085	.317		
Total	344.854	1088			

Tukey, LSD and Tunnet tests were also carried out to see if there was variation between groups, no significant differences between groups were found:

Multiple Comparisons

Dependent Variable: Difference sqrt transformed

		(I) Nssec3		(J) Nssec3	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Tukey HSD	dimension2	1.00	dimension3	2.00	-.04175	.04751	.816	-.1640	.0805
				3.00	-.05105	.03951	.568	-.1527	.0506
				4.00	.05956	.07457	.855	-.1323	.2514
		2.00	dimension3	1.00	.04175	.04751	.816	-.0805	.1640
				3.00	-.00930	.04827	.997	-.1335	.1149
				4.00	.10131	.07956	.580	-.1034	.3060
		3.00	dimension3	1.00	.05105	.03951	.568	-.0506	.1527
				2.00	.00930	.04827	.997	-.1149	.1335
				4.00	.11061	.07506	.454	-.0825	.3037
		4.00	dimension3	1.00	-.05956	.07457	.855	-.2514	.1323
				2.00	-.10131	.07956	.580	-.3060	.1034
				3.00	-.11061	.07506	.454	-.3037	.0825
LSD	dimension2	1.00	dimension3	2.00	-.04175	.04751	.380	-.1350	.0515
				3.00	-.05105	.03951	.197	-.1286	.0265
				4.00	.05956	.07457	.425	-.0868	.2059
		2.00	dimension3	1.00	.04175	.04751	.380	-.0515	.1350
				3.00	-.00930	.04827	.847	-.1040	.0854
				4.00	.10131	.07956	.203	-.0548	.2574
		3.00	dimension3	1.00	.05105	.03951	.197	-.0265	.1286
				2.00	.00930	.04827	.847	-.0854	.1040
				4.00	.11061	.07506	.141	-.0367	.2579
		4.00	dimension3	1.00	-.05956	.07457	.425	-.2059	.0868
				2.00	-.10131	.07956	.203	-.2574	.0548
				3.00	-.11061	.07506	.141	-.2579	.0367

Dunnett t (2-sided)[a]	dimension2 1.00	dimension3 4.00	.05956	.07457	.640	-.1076	.2267
	2.00	dimension3 4.00	.10131	.07956	.338	-.0770	.2796
	3.00	dimension3 4.00	.11061	.07506	.243	-.0576	.2788

a. Dunnett t-tests treat one group as a control, and compare all other groups against it.

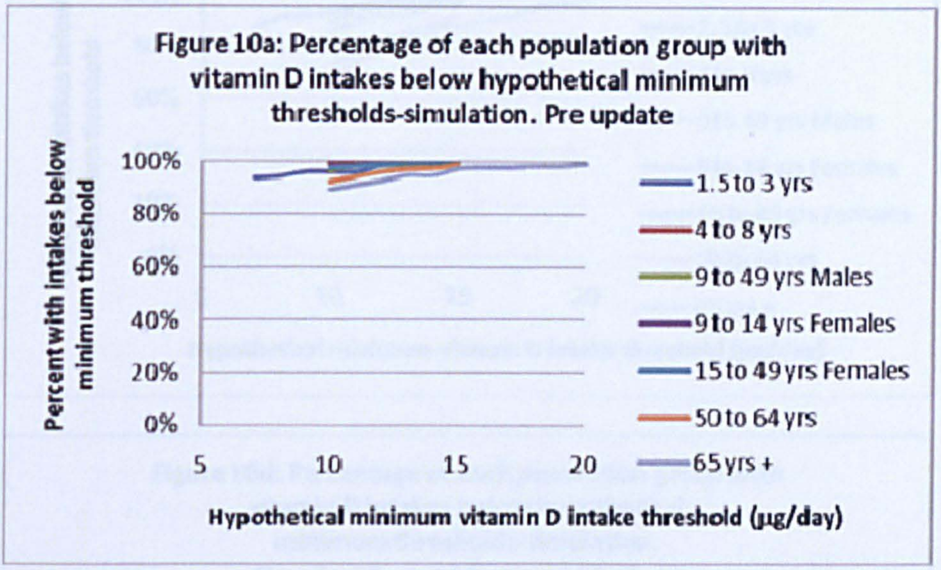
Difference sqrt transformed

	Nssec3	N	Subset for alpha = 0.05
			1
Tukey HSD[a,]	dimension1 4.00	65	1.3721
	1.00	425	1.4317
	2.00	209	1.4735
	3.00	388	1.4828
	Sig.		.293

Means for groups in homogeneous subsets are displayed.
a. The group sizes are unequal. The harmonic mean of the group sizes is used =160.632. Type I error levels are not guaranteed.

Appendix 10: Sensitivity analysis

<u>Minimum thresholds</u>



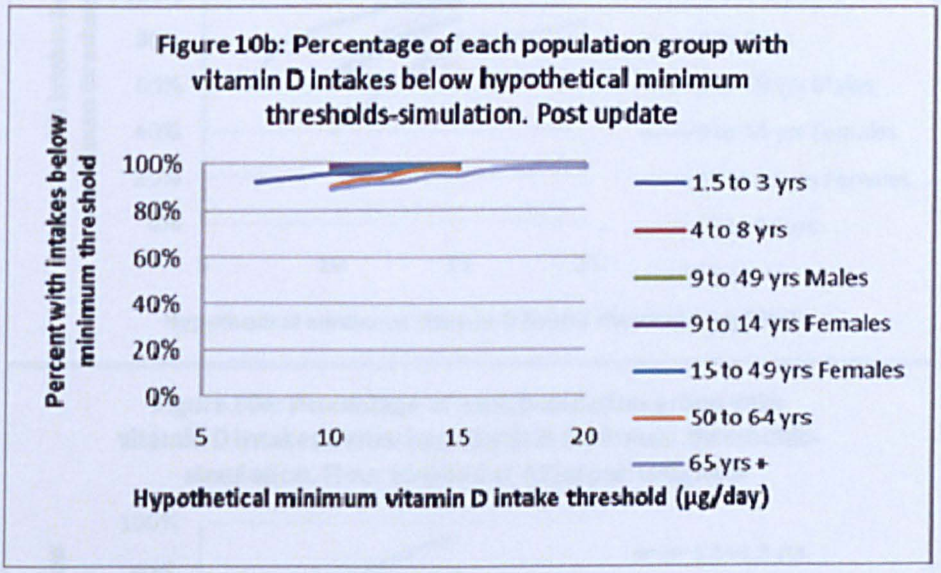


Figure 10c: Percentage of each population group with vitamin D intakes below hypothetical minimum thresholds-simulation. Flour fortified at 5µg per 100g flour

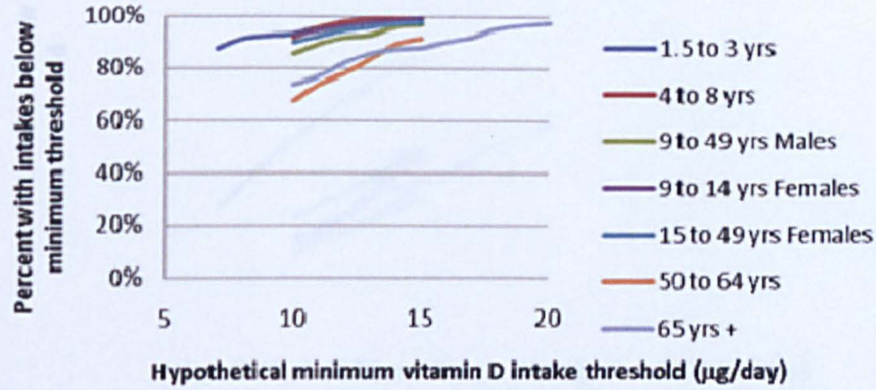


Figure 10d: Percentage of each population group with vitamin D intakes below hypothetical minimum thresholds-simulation. Flour fortified at 10µg per 100g flour

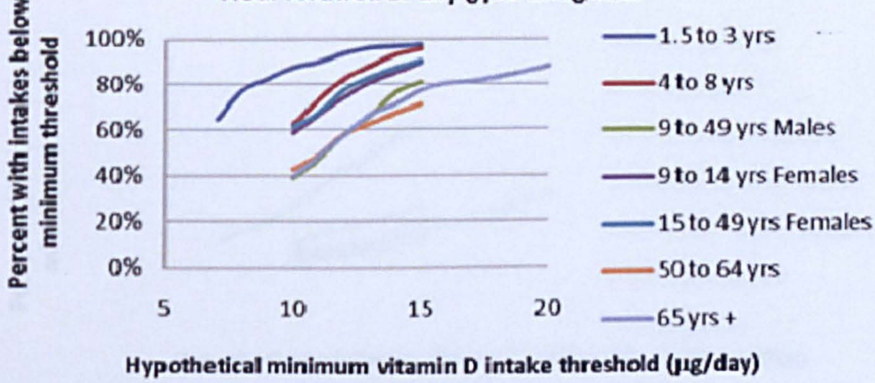


Figure 10e: Percentage of each population group with vitamin D intakes below hypothetical minimum thresholds-simulation. Flour fortified at 15µg per 100g flour

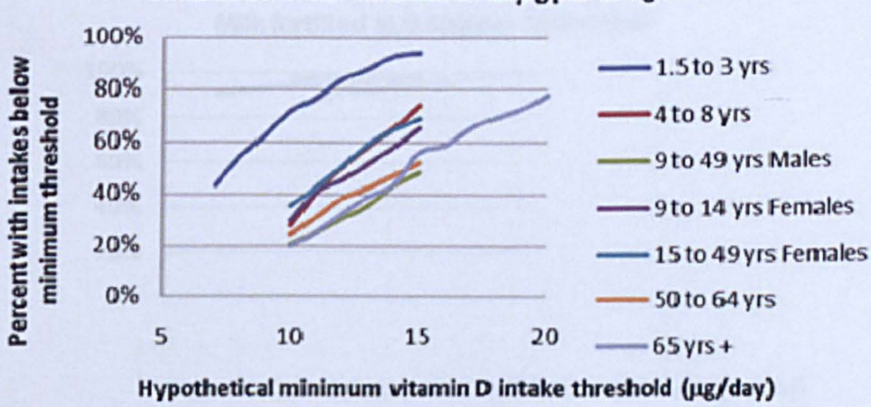


Figure 10f: Percentage of each population group with vitamin D intakes below hypothetical minimum thresholds-simulation. Flour fortified at 20µg per 100g flour

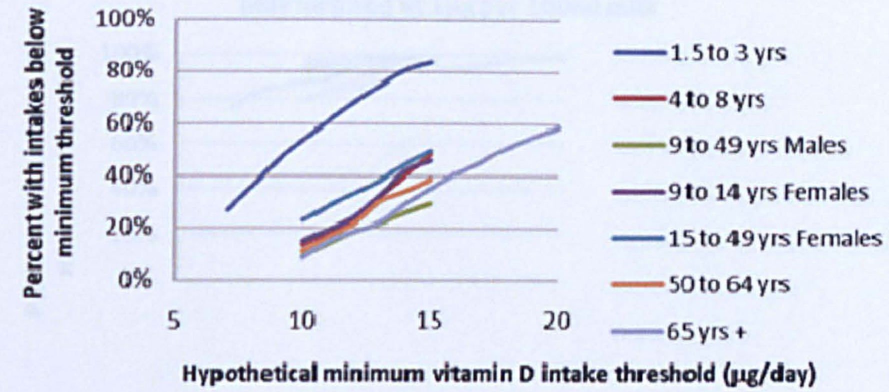


Figure 10g: Percentage of each population group with vitamin D intakes below hypothetical minimum thresholds-simulation.
Flour fortified at 30µg per 100g flour

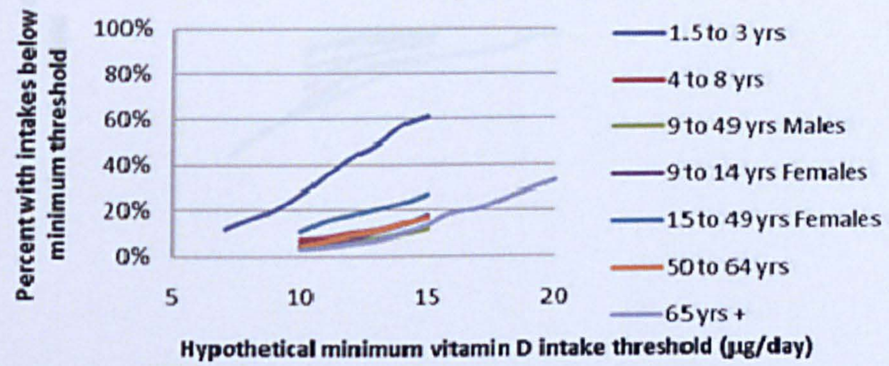


Figure 10h: Percentage of each population group with vitamin D intakes below hypothetical minimum thresholds-simulation.
Milk fortified at 0.5µg per 100ml milk

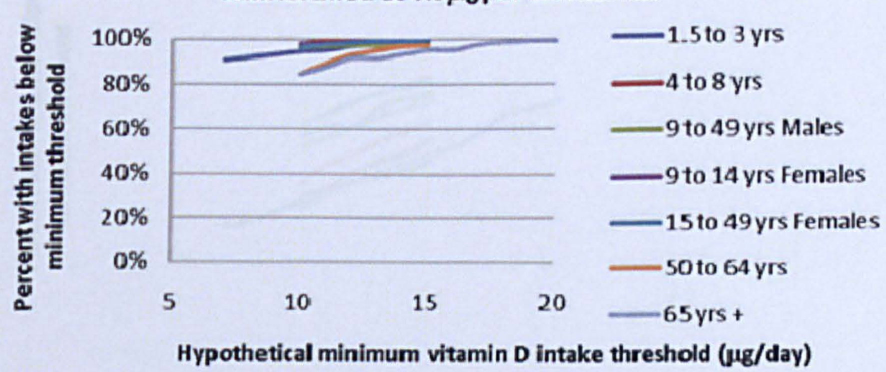


Figure 10i: Percentage of each population group with vitamin D intakes below hypothetical minimum thresholds-simulation. Milk fortified at 1µg per 100ml milk

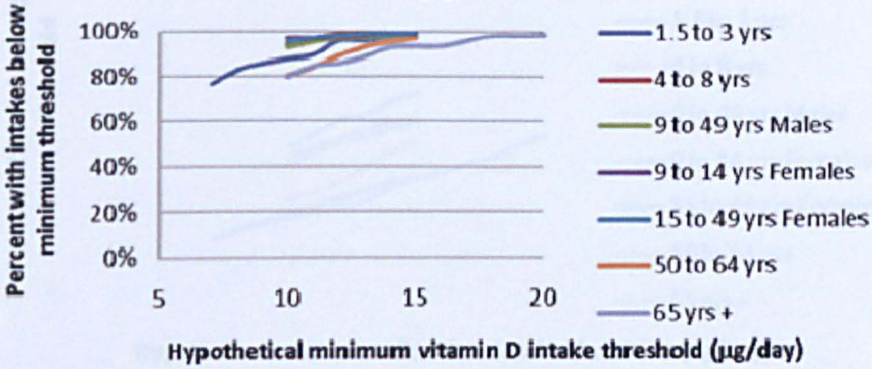


Figure 10j: Percentage of each population group with vitamin D intakes below hypothetical minimum thresholds-simulation. Milk fortified at 2µg per 100ml milk

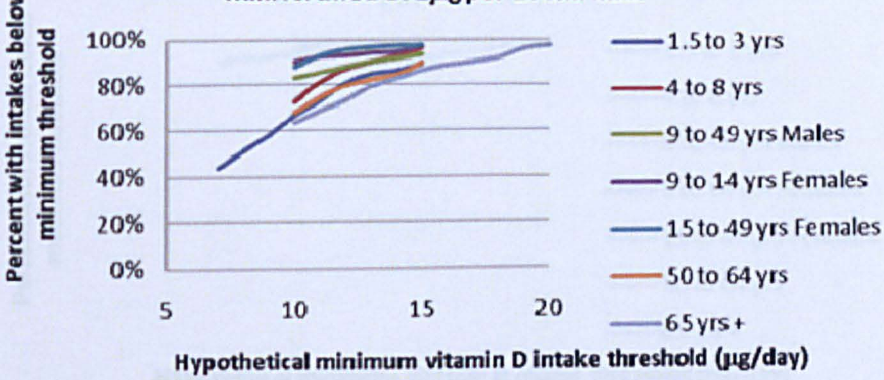


Figure 10k: Percentage of each population group with vitamin D intakes below hypothetical minimum thresholds-simulation. Milk fortified at 5µg per 100ml milk

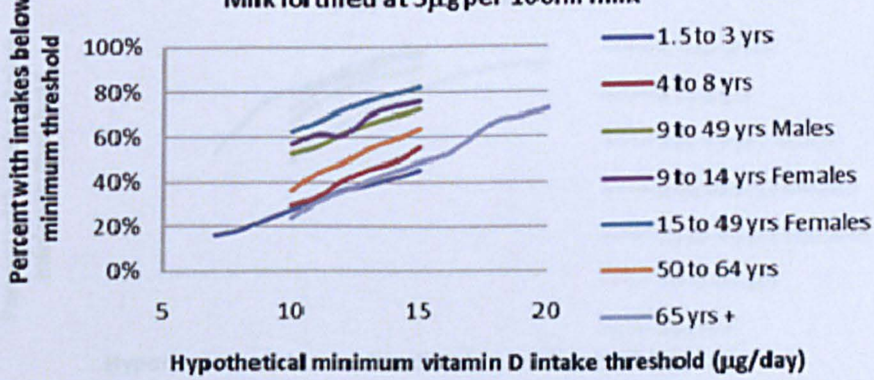


Figure 10l: Percentage of each population group with vitamin D intakes below hypothetical minimum thresholds-simulation. Milk fortified at 7µg per 100ml milk

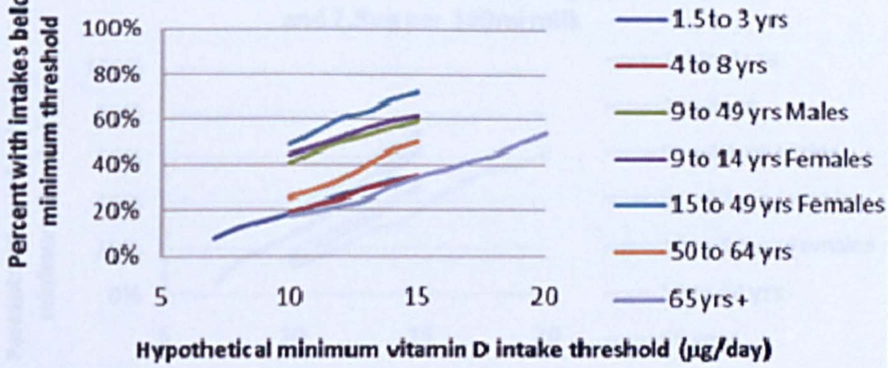


Figure 10m: Percentage of each population group with vitamin D intakes below hypothetical minimum thresholds-simulation. Flour and Milk fortified at 2.5µg per 100mg flour and 0.25µg per 100ml milk

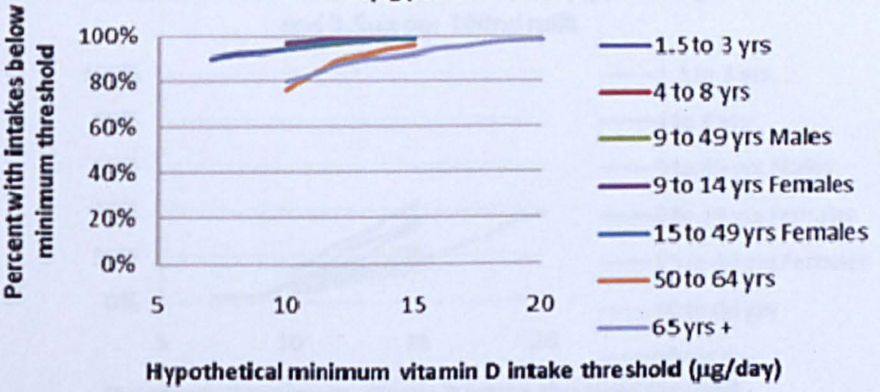


Figure 10n: Percentage of each population group with vitamin D intakes below hypothetical minimum thresholds-simulation. Flour and Milk fortified at 5µg per 100g flour and 1µg per 100ml milk

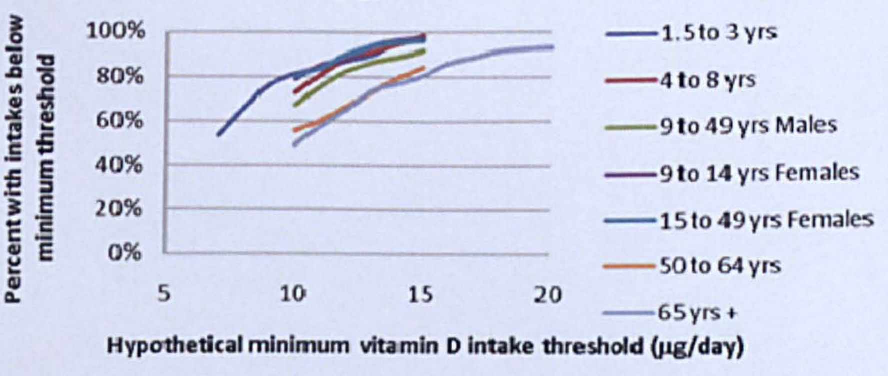


Figure 10o: Percentage of each population group with vitamin D intakes below hypothetical minimum thresholds-simulation. Flour and Milk fortified at 10µg per 100g flour and 2.5µg per 100ml milk

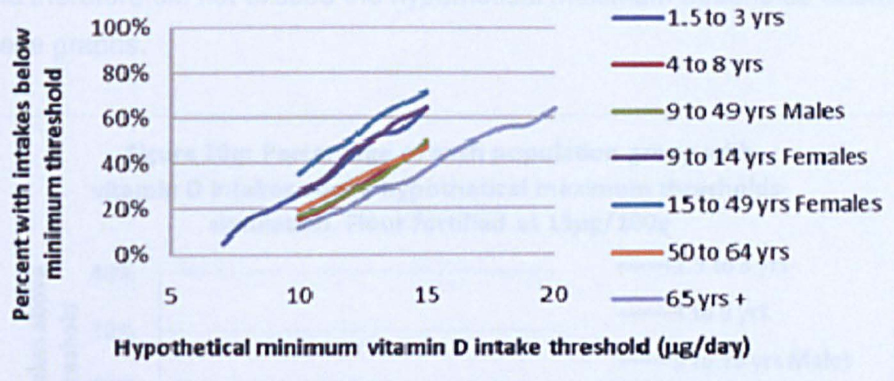
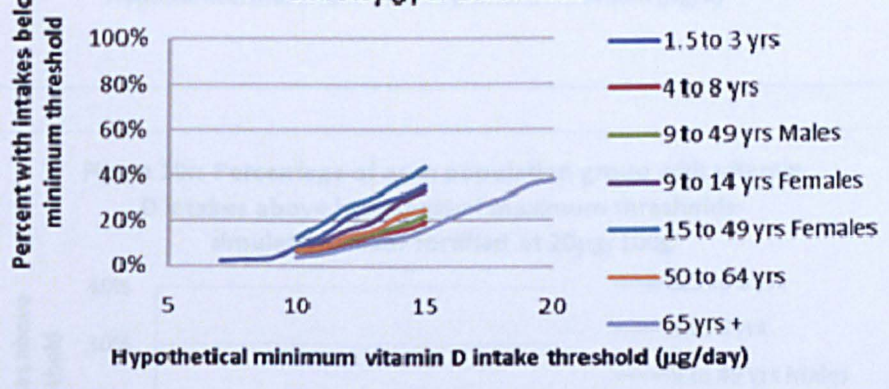


Figure 10p: Percentage of each population group with vitamin D intakes below hypothetical minimum thresholds-simulation. Flour and Milk fortified at 15µg per 100g flour and 3.5µg per 100ml milk



Maximum thresholds

For the fortification scenarios not presented here, no individuals exceeded either the European or US/Canadian tolerable upper intake level (UL) for vitamin D and therefore did not exceed the hypothetical maximum thresholds illustrated in these graphs.

Figure 10q: Percentage of each population group with vitamin D intakes above hypothetical maximum thresholds-simulation. Flour fortified at 15µg/100g

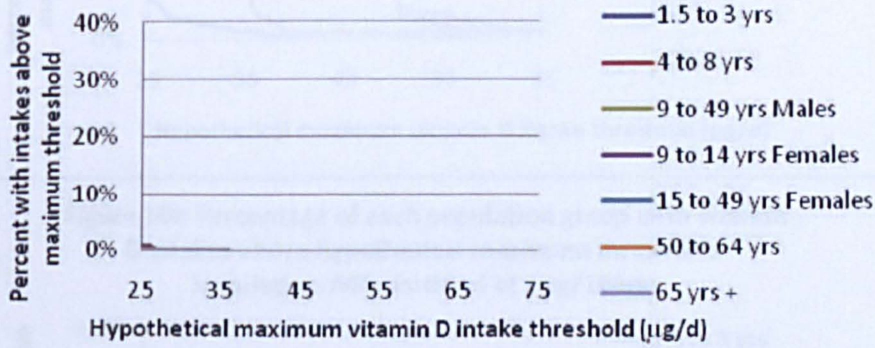


Figure 10r: Percentage of each population group with vitamin D intakes above hypothetical maximum thresholds-simulation. Flour fortified at 20µg/100g

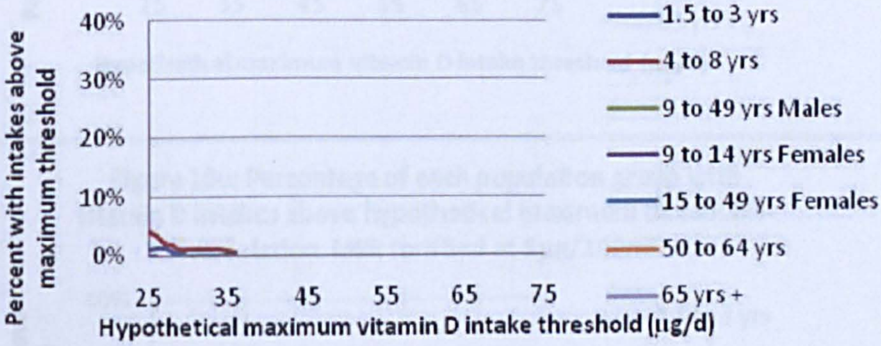


Figure 10s: Percentage of each population group with vitamin D intakes above hypothetical maximum thresholds-simulation. Flour fortified at 30μg/100g

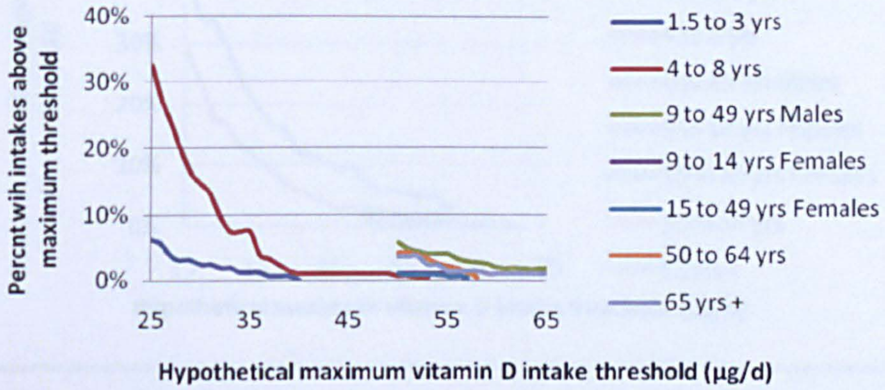


Figure 10t: Percentage of each population group with vitamin D intakes above hypothetical maximum thresholds-simulation. Milk fortified at 2μg/100ml

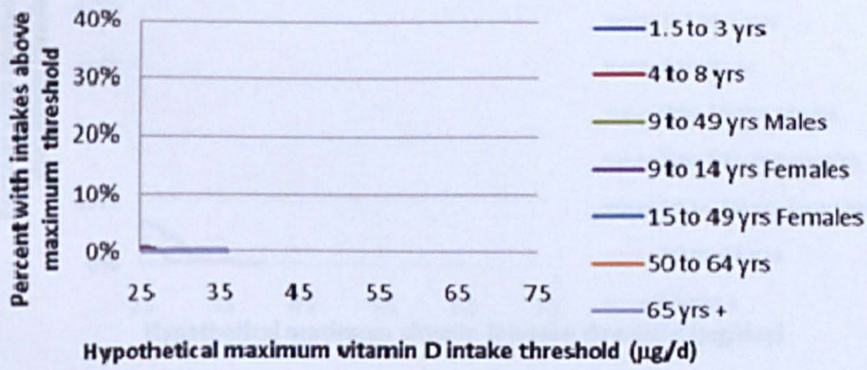
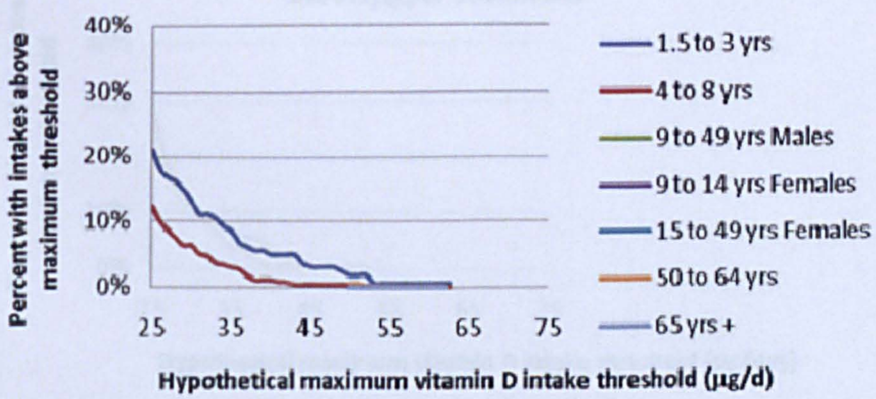


Figure 10u: Percentage of each population group with vitamin D intakes above hypothetical maximum thresholds-simulation. Milk fortified at 5μg/100ml



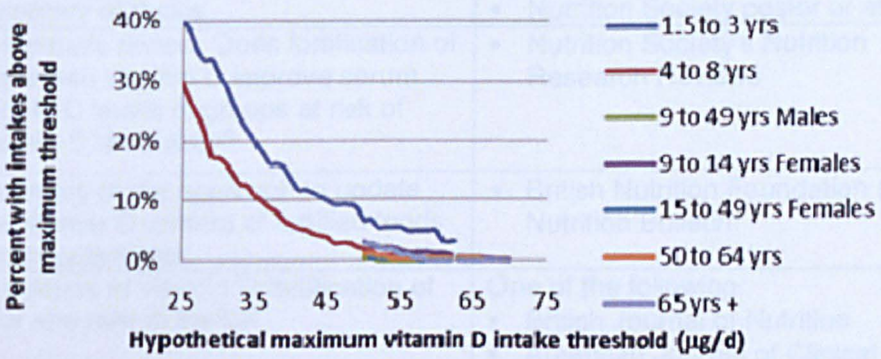


Figure 10v: Percentage of each population group with vitamin D intakes above hypothetical maximum thresholds- simulation. Milk fortified at 7µg/100ml

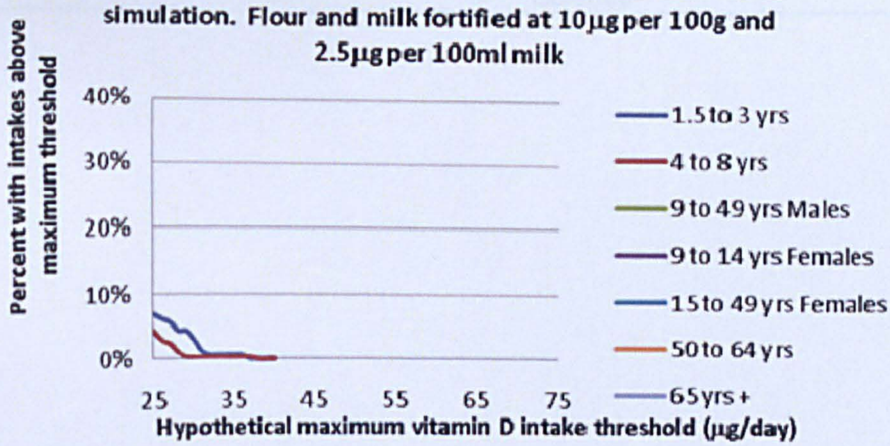


Figure 10w: Percentage of each population group with vitamin D intakes above hypothetical maximum thresholds- simulation. Flour and milk fortified at 10µg per 100g and 2.5µg per 100ml milk

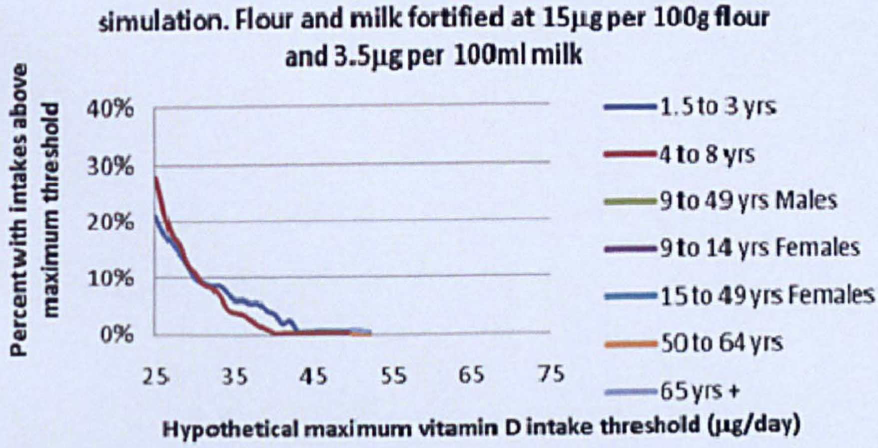


Figure 10x: Percentage of each population group with vitamin D intakes above hypothetical maximum thresholds- simulation. Flour and milk fortified at 15µg per 100g flour and 3.5µg per 100ml milk

Appendix 11

Publication plans

Subject of publication	**Proposed Journal**
Summary of thesis	• Nutrition Society poster or abstract
Systematic review: Does fortification of foods with vitamin D improve serum 25(OH)D levels of groups at risk of vitamin D deficiency?	• Nutrition Society's Nutrition Research Reviews
Summary of the approach to update the vitamin D content of fortified foods and supplements	• British Nutrition Foundation (BNF) Nutrition Bulletin
Simulation of vitamin D fortification of flour and milk in the UK	One of the following: • British Journal of Nutrition • American Journal of Clinical Nutrition (AJCN) • Nutrition Society's Public Health Nutrition or Journal of Nutritional Science