Twenty years of research in the Human Nutrition Research Centre, Newcastle University, 1994–2014

Human Nutrition Research Centre, Newcastle University, Newcastle upon Tyne, UK

Abstract
The Human Nutrition Research Centre (HNRC) in Newcastle University was established in 1994 as a multidisciplinary, cross-faculty research centre under the direction of Professors John Mathers and Andrew Rugg-Gunn. The remit of the centre was to undertake research into the links between nutrition and health and, in particular, on interventions that could reduce the risk of common non-communicable diseases and so improve public health. Although that remains the central goal, we have expanded our research approaches to take advantage of emerging technologies such as those in nutrigenomics and have major interests in interactions between nutrition and the genome. Innovative methodology is central to advances in all sciences and we have undertaken research on new tools for the measurement of dietary intake that are appropriate for different population groups to span all life stages. In 2008, we were re-designated as a University Research Centre. This article has been written to outline the work that the centre has undertaken to celebrate 20 years of nutrition research in the HNRC.

Keywords: Human Nutrition Research Centre, Newcastle University

In the beginning: The early days of the Human Nutrition Research Centre

In 1994, Newcastle University’s Human Nutrition Research Centre (HNRC) was co-founded by John Mathers and Andrew Rugg-Gunn. Mathers held a Chair in Human Nutrition in the Department of Biological and Nutritional Sciences within the Faculty of Agriculture and Biological Sciences, and Rugg-Gunn held a Chair in Preventive Dentistry in the Department of Child Dental Health within the Faculty of Medicine. In the early 1990s, cross-faculty research collaborations were rare but were seen as an essential way forward if the university was to deploy multidisciplinary approaches to address real-world problems such as the links between nutrition and health. This initiative was made possible by Professor (now Sir) George Alberti, Professor of Medicine who, during his tenure as Chair of the Research Committee of the Northern Regional Health Authority, facilitated the award of £300 000 to Mathers and Rugg-Gunn to create the HNRC for an initial period of 3 years. This initiative was strongly supported by Professor Andrew Hamnett, Deputy Vice Chancellor responsible for research. His support, and that of his successors, has been critical in ensuring that the HNRC survived beyond those initial 3 years and continues to thrive. It is therefore instructive to learn a little about the two co-founders of the HNRC.

John Mathers is a Newcastle graduate in Agricultural Biochemistry and Nutrition. As a post-graduate in Cam-
bridge University, Mathers studied for the Diploma in Nutrition which introduced him to nutrition researchers within the Medical Research Council (MRC) Dunn Nutrition Laboratory and across Cambridge University. His PhD and post-doctoral work under the supervision of Dr Eric Miller provided a rigorous training in experimental design and in the conduct of studies on the interactions between food, the rumen microbial population and host metabolism. After a short time as a Research Fellow in the University of Edinburgh, Mathers was appointed to a Lectureship in his former department in Newcastle with the remit to develop research and teaching in human nutrition. This coincided with the start of the long decline in financial support for research on primary food production, which has been reversed only recently following worldwide concerns about food sustainability. UK research focus had shifted to human nutrition and health and Mathers built on his experience of research on rumen fermentation to initiate research on fermentation of dietary fibre and its implications for health of the human large bowel, particularly risk of colorectal cancer. These early studies revealed the intimate links between food components and the gut microflora and showed that the amount and type of dietary fibre had profound effects on the patterns of short-chain fatty acids (SCFA) produced by the microflora (Key & Mathers 1993). In addition, it became clear that these SCFA, and in particular butyrate, had implications for metabolism and function of the intestinal epithelial cells (Key et al. 1996).

With encouragement from Professor Ivan Johnson (Professor of Surgery), Mathers took on supervision of his first doctoral (MD) student, a young surgeon called Mike Bradburn who was interested in patients with the condition familial adenomatous polyposis (FAP). Such patients develop bowel cancer at very young ages and prophylactic colectomy in their late teens was the usual treatment. Bradburn’s MD explored the impact of dietary carbohydrates on fermentation in the large bowel of FAP patients (Bradburn et al. 1993). FAP families in Newcastle were cared for by the genetics service, and Professor (now Sir) John Burn was the newly appointed head of the genetics group. Mathers joined a research discussion group led by Burn that included Alistair Gunn (gastrointestinal surgeon) and Pam Chapman (research nurse). From these discussions evolved the idea of using people with FAP to investigate potential interventions to reduce bowel cancer risk. At the time, the genetic basis for FAP was unknown but, shortly after, the inherited defect in the adenomatous polyposis coli (APC) gene on chromosome 5 was discovered, and the recognition that the FAP protein was a key player in WNT (Wingless-related integration site) signalling paved way for exciting mechanistic studies of how dietary factors could modulate bowel cancer risk. Importantly, somatic mutations in APC are almost universal in ‘ordinary’ bowel cancer so we argued that the study of those with inherited APC mutations could potentially reveal how environmental factors (drugs and nutrition) influence bowel cancer risk. This concept was received sceptically by colleagues who argued that the genetic contribution to cancer in FAP was overwhelming and that environmental factors were unlikely to be important. Burn and Mathers with Professor Tim Bishop (University of Leeds) initiated the CAPP1 (Concerted Action Polyposis Prevention) Study – a 2 × 2 factorial design human intervention study with FAP patients to test the hypothesis that aspirin and/or resistant starch (RS) could modulate large bowel neoplasia (Burn et al. 2011a). This was followed by the CAPP2 (Colorectal Adenoma/ carcinoma Prevention Programme) Study – this time in patients with Lynch syndrome who have an inherited defect in one of the DNA mismatch repair genes (often MLH1 or MSH2) and who, like FAP patients, develop bowel (and other) cancers early (Burn et al. 2008). Results showed that the anti-inflammatory agent aspirin could reduce bowel cancer risk by about 50% (Burn et al. 2011b). However, there was no effect of RS and it was concluded that RS does not emulate the apparently protective effect of diets rich in dietary fibre against colorectal cancer (Mathers et al. 2012).

These studies of individuals with specific genetic defects provided a strong foundation for our ongoing nutrigenomic studies at the HNRC of the interactions between diet and the genome and implications for human health, described below. Another of Mathers’ key early collaborations was with Professor Oliver James, a liver specialist who was also interested in ageing. This collaboration led to investigations of the effects of ageing on microbial metabolism in the large bowel (Mathers et al. 1993) and on digestive and transport mechanisms in the small bowel (Wallis et al. 1993). Our research interests in nutrition and ageing continue to expand and now range from basic studies of the biology of ageing (Nooteboom et al. 2010) to the development of lifestyle-based interventions (see comments on The LiveWell Programme, below) and of measurement of the Healthy Ageing Phenotype – a panel of measures that captures key features of healthy ageing (Lara et al. 2013).

Two people in particular helped to steer Andrew Rugg-Gunn into a research career in nutrition and oral health. Philip J Holloway was Rugg-Gunn’s tutor during his undergraduate dental training at the London
Hospital, and subsequently co-director of the research unit in Manchester University where Rugg-Gunn studied for his PhD. Holloway had worked with May Mellanby in the 1950s, jointly publishing a paper on vitamin A and tooth development (Holloway & Mellanby 1961). May was the wife of Sir Edward Mellanby who besides playing a key role in the discovery of vitamin D was a very significant researcher in her own right, for over 50 years. In 1918 she reported that dogs reared on diets deficient in a ‘fat soluble A accessory food factor’ (which she subsequently recognised as vitamin D) delayed development of teeth, which had poorly calcified enamel (Mellanby 1918). The link between enamel hypoplasia and increased risk of dental caries led May Mellanby to undertake MRC-supported clinical trials of vitamin D’s ability to prevent dental caries development (Rugg-Gunn & Hackett 1993). Today, this remains an unsolved conundrum (Rugg-Gunn 2001). Rugg-Gunn had the privilege of meeting May Mellanby in the early 1970s. As for Holloway, his early career at Manchester led to the publication of a paper (jointly with a dietitian) on dietary counselling in the control of dental disease (Holloway et al. 1969): this paper first described the 3-day food diary which was to be used by Rugg-Gunn in the Ashington dietary survey 10 years later. This 3-day food diary proved to be a very useful tool for quantifying food intake and, equally important, was acceptable to the adolescents participating in this, and later, studies.

The second influential researcher was George Neil Jenkins, Professor of Oral Physiology in Newcastle University, and Rugg-Gunn’s head of department for a number of years. Having obtained a degree in biochemistry at Liverpool University, Jenkins studied for his PhD under Sir Gowland Hopkins in Cambridge, working as part of the Second World War effort on the development of the ‘National Loaf’. To this day, white flour is fortified with calcium and it was Rugg-Gunn’s research carried out in Newcastle that helped to retain this fortification (Hackett et al. 1984a).

In 1979, six years after appointment as Lecturer at Newcastle University, Rugg-Gunn obtained a MRC grant to investigate relationships between the diet of children and dental caries. The study area was Morpeth, Ashington and Newbiggin-by-the-Sea, outside the fluordated Newcastle area, and which provided a good social class mix. The grant allowed employment of a nutritionist – Allan Hackett – who collected dietary data during two school years from over 400 adolescents. Valuable advice on dietary assessment methodologies was provided by Alison Black of the Dunn Nutrition Unit in Cambridge and on study design and data analysis by Newcastle medical statistician David Appleton. To our surprise, there was a dearth of information on the diets of schoolchildren in the UK at that time and analyses of the data from this one study resulted in the publication of 16 full articles. This, in itself, emphasises a principle that if people are generous and volunteer to take part in research, especially if supported by public funds, the researchers have an obligation to maximise the publication of useful information; not doing so would be unethical. Ten years later (1989–1991), Rugg-Gunn obtained a further MRC grant to investigate the diets of schoolchildren, aged 12–13 years, attending the same seven schools. The aim of this research was to quantify any changes in their diets over the 10-year period, which had been a time of considerable activity in the promotion of better diets (NACNE 1983). Again, Rugg-Gunn was very fortunate in his choice of nutritionist for this study – Miss Ashley Burton – who had the temerity to ask for a week off in May during the dietary survey to get married to become Ashley Adamson. There were ten articles from this second study that revealed several signs of improvement in the diets of adolescents.

In 1991, Dr (now Professor) Paula Moynihan was appointed as a Lecturer in Nutrition within the Department of Child Dental Health – the first nutritionist appointed to an academic post within a dental school in Europe. In 1996, the Department of Child Dental Health at Newcastle was designated a World Health Organization (WHO) Collaborating Centre for Nutrition and Oral Health with Rugg-Gunn as the Director; Moynihan succeeded him as Director on Rugg-Gunn’s retirement in 2002.

Thus, when the HNRC was created in 1994, there was a good range of skills in nutritional research, and the strapline for the Centre became From cells to populations. The Northern Regional Health Authority grant allowed the appointment of two lecturers – Drs Ashley Adamson and Chris Seal, plus a technician and a part-time secretary – and office space was provided in an area of the Royal Victoria Infirmary dedicated for clinical research. Obtaining external grants was vital for the long-term survival and prosperity of the Centre and so targeting major funders including the research councils, National Institute for Health Research, Wellcome Trust, government departments and the European Union (EU) was a priority that continues to the present day.

**Research highlights from the Human Nutrition Research Centre**

Currently, research in the HNRC falls under three themes: (1) public health nutrition (led by Professor
Ashley Adamson); (2) molecular nutrition (led by Professor Dianne Ford); and, (3) food quality and health (led by Professor Chris Seal); highlights of each theme are outlined below. Our research ranges from basic molecular and cellular mechanisms to the development of dietary interventions for improved public health and wellbeing, and in recent years, the HNRC has adopted the new strapline From molecules to public health. Much of the HNRC research is multidisciplinary, and there has been a sustained focus on some of the major public health concerns, i.e. obesity and ageing and on common age- and obesity-related chronic diseases including diabetes, cardiovascular disease and colorectal cancer.

Public health nutrition theme

Public health nutrition at Newcastle includes research strands in nutrition epidemiology, intervention studies and methodology. Strong foundations in public health nutrition were laid by Rugg-Gunn in establishing the Ashington surveys in 1980 as important cross-sectional and longitudinal studies, which continue to provide a rich resource to chart temporal changes in food and nutrient intakes and dietary intake patterns (Hackett et al. 1984b). For example, schools in the Ashington survey were revisited in 1990 by Adamson and in 2000 by Emma Fletcher. All three studies found that intakes of non-milk extrinsic sugars (NMES) were high compared with UK intakes and with national recommendations. Over the 20-year period, intakes of NMES remained high but there was a notable change in the dietary sources of NMES with the contribution from soft drinks and breakfast cereals increasing, while that from confectionery and table sugar decreased (Fletcher et al. 2004; Rugg-Gunn et al. 2007).

The value of these cross-sectional studies was further enhanced through Wellcome Trust-funded follow-up of the 1980 cohort at 32–33 years (Craigie et al. 2009) and Food Standards Agency (FSA)-funded follow-up of the 2000 cohort at 17 years (Hossack et al. 2007). Both studies found significant tracking of body mass index (BMI) from adolescence into adulthood, with 94% of those in the highest quartile becoming overweight or obese adults compared with 24% in the lowest quartile (Craigie et al. 2009). Intake of some food groups also tracked and intakes of energy, macronutrients, vitamin C and iron were moderately, but significantly, predictable from adolescent intakes (Hossack et al. 2007). Accordingly, these studies highlighted the importance of childhood lifestyle factors as antecedents of obesity risk in adulthood (Craigie et al. 2011).

The Ashington survey was revisited in 2010 and extended to include primary schoolchildren in Newcastle. These data provided a unique opportunity to measure the impact of introduction of the UK school food policy in 2007–2009 after 20 years of no defined standards for school food. Funded by the Department of Health policy research programme, this showed that children aged 4–7 years who had school lunches post-implementation had higher mean daily intakes of vitamin C and iron and lower mean daily percentage of energy from fat and saturated fat than children who had packed lunches. Although school lunches improved for older children, there was limited evidence of the effect of lunch type post-implementation on the total diet in children aged 11–12 years. Findings showed the impact of nutritional standards and the potential of the provision of school lunches to improve children’s overall diet (Spence et al. 2013) and have since been used as evidence in the development of the School Food Plan (2014) (www.schoolfoodplan.com/). This work in evaluation of implementation of a public health policy sits with other policy evaluation such as that on OfCom regulations for advertising foods to children, led by Dr Jean Adams (Adams et al. 2012) and work on front-of-pack food labels (Draper et al. 2013).

In 2006 a new longitudinal study, the Gateshead Millennium Study (GMS) came under our custodianship. Established by Professor Charlotte Wright (now Glasgow University), the GMS has followed 1029 children born to Gateshead mothers in 1999/2000. Originally set up to examine feeding and growth in infancy, later data sweeps captured key stages in the children’s development with a change in focus to examine the early origins of obesity (Parkinson et al. 2011a; Basterfield et al. 2012a, 2012b; Pearce et al. 2012b). Our GMS data revealed that parents of children aged 6–8 years have limited ability to recognise when their child is overweight (Jones et al. 2011; Parkinson et al. 2011b). These findings led to research funded by MRC–National Prevention Research Initiative examining how parental recognition of their child’s weight status can be improved. Visual tools (body image scales of known BMI) for parents of children aged 4–5 and 10–11 years designed to improve parental ability to recognise overweight in their child were created by the Map Me Study and are being tested in a large cluster randomised trial.

Currently, we undertake mixed methods research that addresses concerns around nutrition and oral health, e.g. evidence synthesis on sugars and dental caries that informed the recent WHO guidelines (Moynihan & Kelly 2014) and research on factors influencing childhood dental erosion. The research
extends to dental and other factors influencing food intake by older people (Bradbury et al. 2008), whilst the links between food intake (measured using an adapted 24-hour multiple pass method) (Adamson et al. 2009) and health-related outcomes in 800 of the oldest old as part of the Newcastle 85+ study are also being investigated. Based on extensive systematic reviews (Heaven et al. 2013; Hobbs et al. 2013; Lara et al. 2014), we have developed and are piloting lifestyle-based interventions, delivered via the Internet, to enhance healthy ageing (The LiveWell Programme: http://research.ncl.ac.uk/livewell/).

At HNRC, there is a strong focus on methodology, including the development of tools to measure food environments and individual behaviours and to improve dietary assessment methods. The Food Assessment in Schools Tool was developed to assess dietary intake of large groups of children aged 3–7 years (Fletcher et al. 2004) and the Young Person’s Food Atlas as an aid to portion size assessment for children aged 18 months to 16 years (Foster & Adamson 2014). This work was the basis for development of an online 24-hour dietary recall tool (based on the multiple pass recall method) called INTAKE24, which is suitable for collection of detailed dietary intake from children aged 11–24 years and which was developed using an iterative cycle of user testing and development (Foster & Adamson 2014). In parallel, in collaboration with Professor John Draper and colleagues in Aberystwyth University, a novel metabolomics-based approach was used to discover metabolites in urine, which are characteristic of the consumption of specific foods such as citrus fruit, salmon and broccoli (Favé et al. 2011; Lloyd et al. 2011). This proof-of-principle work is currently being extended to an MRC-funded project (with Aberystwyth and Imperial College) to discover and validate additional biomarkers of food intake. The overall aim is to integrate the outcomes from these metabolomics- and computer-based approaches to produce novel, objective, acceptable and cost-effective approaches to dietary assessment with wide utility.

**Molecular nutrition theme**

The molecular nutrition theme at HNRC aims to provide mechanistic understanding of the ways in which diets, foods and food components influence molecular and cellular events and how these changes contribute to cell, tissue and whole-body function and, ultimately, health. This research has been revolutionised by developments in genomics and by the application of post-genomic technologies, so-called nutrigenomics. HNRC’s nutrigenomics research is in two areas: (1) identifying genetic factors that influence nutritional requirements; and (2) investigating the mechanisms by which nutritional factors alter gene expression and cell function.

From the outset, researchers at HNRC have investigated the effects of butyrate on molecular changes related to colorectal cancer risk. Butyrate has been a particularly attractive nutrient for these studies because it is a histone deacetylase inhibitor and, therefore, an epigenetic regulator of gene expression. Because epigenetic marks and molecules are modifiable by nutrition, we hypothesised that epigenetics may be an important molecular mechanism through which nutrition modulates gene expression and, therefore, phenotype (Mathers 2008; Mathers et al. 2010). Research to date has attempted to test this hypothesis using maternal inadequate folate supply during reproduction as a nutritional insult in animal models and has shown effects on both the gut and brain of the offspring (McKay et al. 2011a, 2011b; Langie et al. 2013). Recent findings have shown that other early life nutritional insults may also affect DNA repair in the developing brain through epigenetic mechanisms (Langie et al. 2014). In studies of human mothers and their offspring, Professor Caroline Relton and colleagues have investigated interactions between nutritional status, genotype and DNA methylation – a core component of the epigenetic machinery (Groom et al. 2012; McKay et al. 2012; Pearce et al. 2012a; Potter et al. 2013).

The appointments of Professors John Hesketh and Dianne Ford in the late 1990s further strengthened our interests and expertise in molecular nutrition and widened the focus to include other micronutrients, in particular selenium (Hesketh) and zinc (Ford). Accordingly, novel zinc transporters have been identified and characterised and we have demonstrated how their expression is regulated by zinc in both cell models and directly in the human intestine (Cragg et al. 2002, 2005; Jackson et al. 2007; Valentine et al. 2007; Coneyworth et al. 2012). Selenium (Se)-related research has included investigation of the functionality of variants in genes encoding selenoproteins and study of the impact of such variants in response to selenium supplementation in humans (Méplan et al. 2007, 2008; Pagmantidis et al. 2008). More recently, this work has expanded to molecular epidemiological studies of the effect of combinations of low Se intake and genetic factors on susceptibility to diseases such as cancer and heart disease (Bermano et al. 2007; Méplan et al. 2009, 2010; Crosley et al. 2013).
This fundamental work on diet–gene interactions alongside experience in the design and delivery of human intervention studies underpins our research on personalised nutrition. The HRNC is leading the proof-of-principle study within the EU-funded Food4Me project (directed by Professor Mike Gibney, University College Dublin), which is testing the hypothesis that personalisation of dietary advice based on dietary, phenotypic and genotypic information produces bigger, more appropriate and sustained improvements in eating behaviour (http://food4me.org/). This intervention study, which recruited participants in seven European countries, collected biological samples including buccal swabs for genotyping and dried blood spots for metabolite measurements remotely and was delivered via the Internet. The study was completed in March 2014 and results are currently being prepared for publication.

Food quality and health theme

The food quality and health research theme at HNRC aims to understand and optimize how diets, foods and food components affect human health, including how this can be affected by an individual’s genotype. Recent topics include diet composition, functional foods and food supplements, as well as the provision of evidence to support health claims. There is also research to understand and optimize how production methods affect the sensory and nutritional quality of foods and food supplements. This includes primary production (agriculture), processing, storage, quality control/standardization and safety assurance.

The health benefits of wholegrains have been a major focus of research by Professor Chris Seal and colleagues. This included the WHOLEheart study (funded by the FSA) – the largest wholegrain intervention yet completed worldwide – in collaboration with colleagues from the MRC HNR Cambridge (see Brownlee et al. 2010, 2013; Peacock et al. 2010; Kuznesof et al. 2012). This study demonstrated no apparent effect of the intervention on cardiometabolic outcomes and highlighted the need for better-controlled wholegrain intervention studies. Following on from this study, protocols were refined to develop the GrainMark study (also FSA funded) which, in collaboration with Draper and colleagues (Aberystwyth University), identified biomarkers of wholegrain intake in comparison with the established biomarker, alkylresorcinols (Primrose et al. 2011; Ross et al. 2012; Beckmann et al. 2013). Using a metabolomics-based approach, research by HNRC was the first to identify hydroxylated phenylacetamides as biomarkers of consumption of wholegrain sourdough rye bread in humans (Beckmann et al. 2013). Current work is focused on establishing global definitions of ‘wholegrain’ and ‘wholegrain foods’ (Thielecke et al. 2013; Ferruzzi et al. 2014; van der Kamp et al. 2014).

Underlying reasons for the high inter-individual variability in vitamin A metabolism are explored by Dr Georg Lietz and colleagues. Such variability in β (beta)-carotene metabolism can be caused by differences in absorption and metabolism of dietary carotenoids (Leung et al. 2009; Grune et al. 2010; Lietz et al. 2010, 2012a, 2012b) and our research to date has focused on variation in the BCMO1 gene, which encodes β,β-carotene 15, 15’-monooxygenase 1, the enzyme which cleaves β-carotene symmetrically into two molecules of retinal (vitamin A). Variants in this gene can alter the capacity to convert β-carotene to vitamin A by up to 69% (Leung et al. 2009; Lietz et al. 2012b). HNRC research has also shown that genetic variants contribute to inter-individual variation in capacity for DNA repair in humans (Tyson et al. 2009).

Dr Kirsten Brandt and colleagues investigate the significance of bioactive compounds from vegetables, notably carrots, which contain polyacetylenes (i.e. falcarinol and falcarindiol) with potential for cancer-preventive properties. Although polyacetylenes are present in carrots in similar concentrations to the carotenoids, and show much more potent biological activity in some bioassays (Zaini et al. 2012), much less is known about polyacetylenes as they are difficult to detect and study. Brandt hypothesised that the polyacetylenes are responsible for much of the discrepancy between the substantial benefits of carrot intake (seen in observational studies) and the much smaller benefits, or even harmful effects, of β-carotene supplementation (seen in intervention studies). The research carried out to date has shown that feeding freeze-dried carrot to ApcMin mice (which have a mutation at codon 850 in the Apc gene and so develop intestinal tumours spontaneously) substantially and significantly reduced tumour number and tumour volume (Saleh et al. 2013). Research is currently ongoing to determine which compounds are involved and if the effect can be extended to humans. The polyacetylene content of carrots is influenced by external conditions such as storage temperature (Ahmad et al. 2011), so a better understanding of their role may affect how carrots are stored and processed.

New horizons in nutrition research

Overall, it is clear that this is a very exciting time to be engaged in nutrition research, with great opportunities...
not only for advancing basic understanding of nutrition–function–health relationships, but also for developing and implementing nutrition-based interventions to improve human health and wellbeing. In the next few years significant advances in several areas are anticipated to include:

(i) **Measurement:** Measurement is the bedrock of all science and in nutrition there is a continuing challenge to provide better estimates of dietary intake for all population groups and to do this more economically and with less burden for both researchers and participants. Developments in computer-based science, including image analysis and food recognition systems, together with biologically-based approaches such as metabolomics offer great promise in describing and quantifying what is eaten with the potential to escape from the tyranny of conventional food intake measurement tools.

(ii) **Models:** Better models usually mean better science and, increasingly, nutrition researchers are employing a much wider range of better models. These include a wider range of species – from ants to zebrafish – and also better in vitro models. Scientists are no longer constrained to use less-than-ideal cell lines. Now is the time to take advantage of developments in stem cell biology and employ ‘self-organising’ organoids as realistic models for the study of the effects of nutrition on specific organs, e.g. the gut, the eye or the brain.

(iii) **Mechanisms:** The last decade was dominated by genomics-based research that has enabled nutritionists to begin to reveal the exquisite ways in which nutrition interacts with our genome to influence health. Now there is a rapidly expanding molecular toolkit available to researchers, including, for example, the CRISPR–Cas9 system for genome editing, which heralds a step change in the ability of nutrition researchers to test specific mechanistic hypotheses.

(iv) **Making a difference (interventions):** The near universal recognition that a better diet can help keep us healthier has created an appetite for effective, acceptable dietary interventions at all levels from the individual to societies. To satisfy this appetite, nutritionists will need to work in multidisciplinary teams with behaviour change psychologists, digital interaction scientists and designers, as well as other disciplines, not only to develop interventions that work but also to deliver them at low cost to large numbers of people. There will also be opportunities to develop/redesign foods with improved nutritional composition.
If nutrition as a discipline is to make good on its promises and to address the major societal challenges of population ageing and obesity in the context of stresses on food security, we will need to attract, train, motivate and retain the best young scientists. The HNRC in Newcastle University is active in all of these areas and we look forward to making our contribution to the next 20 years of exciting discoveries and developments in nutrition research (Fig. 1).

The website of the HNRC can be found at: www.ncl.ac.uk/hnrc/

Conflict of interest
The authors have no conflict of interest to disclose.

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