2020

"Role of sodium and potassium in the diet of school-aged children in Ireland: Findings from the National Children's Food Survey II"

Eoin James Morrissey

Role of sodium and potassium in the diet of school-aged children in Ireland: Findings from the National Children's Food Survey II

THESIS

Presented by

Eoin Morrissey, B.Sc.,

for the degree of

MASTER OF SCIENCE

Department of Biological Sciences

Supervisors: Dr Janette Walton, Dr Brendan O'Connell & Professor Albert Flynn

Submitted to Cork Institute of Technology: March 2020

Table of Contents

Acknowledgements

Firstly, I would like to pay a special word of thanks to my primary supervisor Dr Janette Walton for accepting me as a post graduate student in CIT and for all her hard work, patience and guidance in helping me complete my masters and throughout my time in CIT.

To Dr Laura Kehoe, a huge thanks again for all your help and guidance along the way!

I would also like to express my gratitude to my supervisor Professor Albert Flynn for the expertise and guidance he provided me, as well as Dr Brendan O’Connell for acting as my secondary supervisor in CIT.

To all my fellow members of the IUNA team and all those in the Create building I met along the way, thank you for your friendship and support which made my time studying in CIT so enjoyable.

And finally, to all friends and family, particularly my parents James and Geraldine, thank you so much for all the support and encouragement I received over the years which allowed me to get to this point.

Written Declaration

This thesis is based on data from the National Children's Food Survey II (NCFS II) which was carried out in the Republic of Ireland between 2017 and 2018 by the Irish Universities Nutrition Alliance (IUNA) units at University College Cork (UCC), University College Dublin (UCD), Cork Institute of Technology (CIT) and Technological University Dublin (TUD).

I was involved in the processing of urine samples for the estimation of sodium and potassium intakes and updating the food composition database for sodium. All data manipulation and analyses presented in this thesis were performed by me. The thesis is entirely my own work except where otherwise accredited and has not been submitted for an award at any other institution.

Signed: Date:

Signed: Date:

Abstract

Role of sodium and potassium in the diet of school-aged children in Ireland: Findings from the National Children's Food Survey II

Eoin Morrissey

A high sodium to potassium intake ratio (Na:K) resulting from a diet high in sodium and low in potassium can increase the risk of elevated blood pressure or hypertension in children, potentially leading to increased CVD in adulthood. The objective of this thesis was to estimate sodium and potassium intakes and Na:K in school-aged children (5-12y) in Ireland using data from the nationally representative National Children's Food Survey II (NCFS II) (2017-18). The thesis study collected detailed dietary intake data for 600 children using 4-d food records and also collected spot urine samples from 95% of these participants. Sodium and potassium intakes and Na:K were estimated from the spot urines based on urinary excretion of sodium and potassium measured with a Randox RX Daytona. Dietary intakes and key sources of sodium and potassium were also estimated and compared with previous data collected in the NCFS (2003-04). Foods which determined a lower Na:K were identified. The key findings of this study were that the mean sodium intake of Irish children generally exceeded recommendations, while mean potassium intakes below recommendations were found for older children aged 11-12 years. The key sources of sodium were processed meats and breads, while the key sources of potassium were meats, milks, potatoes and fruit & fruit juices. Children with a lower Na:K had higher intakes of breakfast cereals, milk & yogurt, potatoes, vegetables & vegetable dishes, fruit & fruit juices and fresh meat and lower intakes of savoury foods, breads, cheese, processed meats and soft drinks. Compliance with the WHO optimal target urinary Na:K ≤1.0mmol/mmol was very low at 19%. Strategies to lower Na:K amongst Irish children may reduce the proportion of children at risk of developing hypertension and indirectly reduce the prevalence of hypertension related diseases amongst Irish adults.

Abbreviations

AI = Adequate Intake

CHD = Coronary Heart Disease

CVD = Cardiovascular Disease

EFSA = European Food Safety Authority

FSAI = Food Safety Authority of Ireland

Hypertension = High Blood Pressure

K = Potassium

Na = Sodium

Na:K = Sodium to Potassium Intake Ratio

NCD = Non-communicable Disease

NCFS = National Children's Food Survey

NCFS II = National Children's Food Survey II

RNI = Reference Nutrient Intake

UL = Tolerable Upper Intake Level

WHO = World Health Organisation

Chapter 1

Literature Review

Introduction

Cardiovascular disease (CVD) is one of the leading causes of morbidity and mortality amongst adults accounting for approximately one-third of deaths both in Ireland and globally (WHO, 2017). High blood pressure (hypertension) is a major risk factor for CVD and is associated with other adverse health effects such as kidney disease and impaired cognitive function (Mennuni et al., 2014, Iadecola et al., 2016); therefore, efforts to reduce the proportion of the population with hypertension are of great public health importance. Although the morbidities associated with hypertension may not occur until adulthood, elevated blood pressure or hypertension can develop in children under poor dietary practices (Rosner et al., 2013, Ellis and Miyashita, 2011). Evidence suggests that hypertension amongst children is common (Safefood, 2014, Rosner et al., 2013) and that the prevalence of elevated blood pressure in children is increasing (Sharma et al., 2018). Blood pressure as a child has a significant association with blood pressure as an adult, meaning children with elevated blood pressure or hypertension are more likely to be affected by hypertension and its related health outcomes in later life (Chen and Wang, 2008).

A diet low in sodium and high in potassium is widely recommended as a strategy to lower blood pressure and reduce the risk of hypertension (Perez and Chang, 2014). While the independent effects of sodium and potassium on blood pressure have long been established, there is now a consensus that an individual's sodium to potassium intake ratio (Na:K) is a more important predictor of hypertension than either sodium or potassium intake alone (Perez and Chang, 2014, Tzoulaki et al., 2012). A lower Na:K during childhood is thought to protect against rises in blood pressure (Geleijnse et al., 1990); therefore, estimation of sodium and potassium intake and Na:K in children may provide one indicator of their risk of developing elevated blood pressure or hypertension.

This review aimed to examine the available literature on sodium and potassium in children with regards to impact on health, available recommendations, measurement of intakes, current intakes and sources, and Na:K. The data included in this review were sourced from databases, primarily PubMed using relevant search terms such as sodium, salt, potassium, sodium to potassium ratio, Na:K and children. The bibliography sections of the studies generated from the PubMed searches were examined for other relevant papers. Internet searches were also carried out to source relevant grey literature such as published recommendations for sodium and potassium intakes and the reports of national dietary surveys in children. Data which estimated sodium and potassium intakes were included from nationally representative dietary surveys in Europe or key studies in cohorts of children globally, published as reports, online web pages or peer-reviewed journal articles. For inclusion in this review, the studies must have been published in English, collected dietary intake data via food records or 24hr recalls and urinary estimates of sodium/potassium via 24-hour urine or spot urine samples.

Sodium and Potassium in Health

Blood pressure raising mechanism of sodium and potassium

Sodium is positively associated with hypertension, however it is also an essential nutrient needed in the body, acting as the principal cation of the extracellular fluid and functions as the osmotic determinant in the regulation of extracellular fluid and plasma volumes (IOM, 2005). It is thought that about 95% of total body sodium is found in the extracellular fluid acting as an important determinant of the membrane potential of cells and the active transport of molecules across cell membranes, enabling processes such as the uptake of nutrients by cells (IOM, 2005). All of the functions of sodium have been shown to be interdependent of potassium which is known to be negatively associated with hypertension (SACN, 2003). Potassium is the major intracellular cation in the body, playing an important role in neural transmission, muscle contraction and vascular tone (IOM, 2005).

It is thought that a diet high in sodium and low in potassium produces a biological reaction in the kidneys that results in excessive sodium and insufficient potassium concentrations throughout the body. This can lead to vascular smooth cell contraction, followed by an increase in peripheral resistance and higher blood pressure, accumulating in hypertension (Perez and Chang, 2014). The effects of high sodium and low potassium concentrations on the renin-angiotensin system, arterial stiffness and endothelial dysfunction remain under study but are all thought to play a part in hypertension (Perez and Chang, 2014). Potassium is known to counteract the blood pressure raising effect of sodium by increasing urinary excretion of sodium through the distal tube of the kidney (Tian et al., 2013), while additional mechanisms that may potentially explain the blood pressure lowering effect of potassium include its role in limiting plasma renin activity and improving endothelial dysfunction (Kanbay et al., 2013).

In addition to the role sodium plays in the development of hypertension, high sodium intakes have also been linked to osteoporosis, diabetes and cancer, emphasizing the importance of efforts to ensure population sodium intakes are within recommendations (Rios-Leyvraz et al., 2018).

Epidemiology of diseases associated with sodium and potassium intakes

Although the morbidities associated with hypertension may not occur until adulthood, children can develop elevated blood pressure or hypertension under poor dietary practices such as with a diet high in sodium and low in potassium (Rosner et al., 2013, Ellis and Miyashita, 2011). The World Health Organisation (WHO) reviewed the evidence on the relationship between sodium and potassium intakes and blood pressure in children. From a meta-analysis of relevant controlled trials that tested the effect of reduced sodium intake in children, the evidence suggested that a reduced sodium intake resulted in a decrease in resting systolic blood pressure of 0.84mmHg and a decrease in resting diastolic blood pressure of 0.87mmHg (WHO, 2012b). From a meta-analysis of controlled trials that investigated the relationship between potassium intake and blood pressure in children, the evidence suggested that an increased potassium intake (3705mg/d vs 2223mg/d) affected a non-significant decrease of 0.28mmHg in systolic blood pressure and 0.92mmHg in diastolic blood pressure (WHO, 2012a). Both of the WHO reviews highlight that due to renal function being fully developed in early childhood, evidence from studies that show the effects of both sodium and potassium intakes on blood pressure in adults can be added to the evidence found on their effects in children. However, the quality of evidence would be downgraded from high to moderate when referencing these studies with respect to children due to indirectness (WHO, 2012b, WHO, 2012a).

Blood pressure during childhood has been shown to be a significant predictor of blood pressure in adulthood meaning that children with elevated blood pressure or hypertension are more likely to encounter hypertension as adults (Chen and Wang, 2008, Lane and Gill, 2004). Many of the eating habits that begin in childhood such as a preference for a high salt diet are carried forward into adulthood (Movassagh et al., 2017, Stein et al., 2012) which may contribute to the association between blood pressure as a child and as an adult. Additionally, hypertension as a child can also cause physiological changes such as left ventricular hypertrophy during childhood, which is a significant risk factor for CVD and therefore makes those affected more susceptible to hypertension related diseases as an adult (Daniels et al., 1998). It is thought that the correlation between blood pressure as a child and as an adult grows stronger as children grow older, meaning that the older a child is with elevated blood pressure or hypertension the more likely they are to have hypertension as an adult (Chen and Wang, 2008). This association emphasizes the importance of early intervention to reduce the risk of children developing elevated blood pressure or hypertension in order to combat the hypertension related diseases seen in adulthood.

Previous estimations of hypertension levels and salt intakes in Irish children were provided by the Cork Children's Lifestyle Study, which collected dietary data and other lifestyle data in primary school-aged children in Cork between 2012 and 2013 (Safefood, 2014). The study found that 8% of children were considered to be hypertensive with over 50% of children surveyed also far exceeding their daily target salt intake (Safefood, 2014). Twice as many children who were overweight or obese had high blood pressure in comparison to children who were normal weight, with overweight or obese children also having significantly higher salt intakes than normal weight children (Safefood, 2014). Additionally, despite many fruits and vegetables being rich sources of potassium, an estimated 12% of parents reported that their child did not eat any fruit, while 13% reported that their child did not eat any vegetables (Safefood, 2014).

Similar findings were found in the USA, where data from the National Health and Nutrition Examination Survey (NHANES) (2011-2012) found that 90% of school-aged children in the USA consume sodium in excess of recommendations (Cogswell et al., 2014). It was also estimated that 1 in 6 children in the USA have either pre-high blood pressure or high blood pressure and are therefore at a higher risk of becoming hypertensive adults (Rosner et al., 2013). Additionally, a review of the causes of hypertension in children and adolescents in the USA found that elevated blood pressure and hypertension during childhood are becoming more common and that children may soon comprise 20% of the American population affected by hypertension (Ellis and Miyashita, 2011).

The results of these studies highlight that although hypertension related diseases may not occur until adulthood, hypertension can develop at an early age under poor dietary practices. Action appears necessary to improve the dietary and lifestyle habits of children in order to lower the proportion of children who develop hypertension. Implementation of effective strategies to prevent the development of hypertension in children may be a cost-effective means of reducing the burden of hypertension related diseases on public health (Perez and Chang, 2014).

Relationship of sodium intake and disease rates

While sodium has long been positively associated with hypertension, many studies have presented findings which suggest that a j-shaped relationship exists between sodium intake and health outcomes such as mortality and CVD. In other words, mortality or CVD risk may also increase at low sodium intakes (O'Donnell et al., 2014, Kalogeropoulos et al., 2015, Graudal et al., 2014, Pfister et al., 2014, Cook et al., 2016). While the exact relationship between sodium intake and disease risk is still widely debated, the inconsistent findings may possibly be explained by measurement bias or inaccuracies in methodologies across studies (Cobb et al., 2014, Cogswell et al., 2016). The use of sub-optimal methods to estimate sodium intakes (e.g. using food frequency questionnaires), in addition to reverse causation caused by recruiting participants with prior CVD or other diseases who may have been advised to reduce sodium intake may explain the findings of the studies which found a j-shaped relationship between sodium intake and disease outcomes (Cook et al., 2016, Cobb et al., 2014).

The Trials of Hypertension study (TOHP) used multiple 24-hour urine collections to estimate sodium intake (gold standard method) in adults aged 30-54 years and measured mortality rates over 23-26 years of post-trial follow up (Cook et al., 2016). All participants were healthy, pre-hypertensive adults and therefore the findings of the study should not have been affected by reverse causation (Cook et al., 2016). The study found there to be a direct linear relationship between sodium intake and mortality rates of participants, with no evidence of a j-shaped relationship even at the lowest sodium intake levels (Cook et al., 2016). Therefore, potential adverse health effects as a result of insufficient sodium appear unlikely considering the intake levels generally seen amongst most population groups and should not prevent efforts to lower population sodium intakes (Cook et al., 2016, Brown et al., 2009).

Recommended sodium and potassium intakes in children

Many countries have set target salt intakes for children, such as Ireland where the Food Safety Authority of Ireland (FSAI) has set maximum target population salt intakes for children of 3g/d for 4-6 year olds, 5g/d g/d for 7-10 year olds and 6g/d for 11-14 year olds (FSAI, 2016a), having endorsed the same targets recommended for children in the UK by the Scientific Advisory Committee on Nutrition which were derived from the sodium Reference Nutrient Intakes (RNIs) for children (SACN, 2003) **(Table 1)**. It must be noted that these targets are believed to be achievable reductions based on current intakes, as opposed to levels which are optimal for health (FSAI, 2016a).

While salt intakes exceeding such target intakes are common amongst children (Brown et al., 2009), sodium is still an essential nutrient with a certain level of sodium required in the diet. The European Food Safety Authority (EFSA) has set Adequate Intake (AI) levels for sodium (EFSA, 2019), which is the average level consumed daily by a typical healthy population considered adequate for the population’s needs. The AIs set by EFSA for sodium are 1.3g/d for 4-6 year olds, 1.7g/d for 7-10 year olds and 2.0g/d for 11-17 year olds **(Table 1)**.

The Institute of Medicine (IOM) set Tolerable Upper Intake Levels (UL) for sodium, which are the maximum levels of daily consumption likely to pose no risk of adverse health effects (IOM, 2005) **(Table 1)**. These ULs for sodium are 1900mg/d for 4-8 year olds and 2200mg/d for 9-18 year olds.

With regard to potassium intakes, EFSA has set AIs for potassium for children of 1100mg/d for 4-6 year olds, 1800mg/d for 7-10 year olds and 2700mg/d for 11-14 year olds (EFSA, 2017) **(Table 1)**. Due to insufficient data EFSA has not set ULs for potassium (EFSA, 2016), while the IOM decided not to set ULs for potassium as excess potassium is readily excreted in the urine (IOM, 2005).

Measurement of sodium and potassium intakes

It is estimated that approximately 80-95% of dietary sodium and 63-77% of dietary potassium is excreted in urine and that accurate measurement of sodium and potassium urinary excretion levels provide good estimates of dietary intakes (Willett, 2012, Pietinen et al., 1976). The gold standard method of measuring an individual’s sodium intake is by using multiple high quality 24-hour urine collections to measure urinary excretion of sodium (Iwahori et al., 2017a), while measuring urinary excretion of potassium from 24-hour urine collections is also widely regarded as the gold standard method of assessing potassium intakes (Xu et al., 2019, Willett, 2012). However, for population level studies, collecting 24-hour urine samples is not always feasible as they can be costly and time-consuming, and ensuring completeness of 24-hour collections has its own challenges (Iwahori et al., 2017b). As a result, sodium and potassium intakes in many studies are measured by collecting spot/casual urine samples or via dietary assessment methods (e.g. food diaries, food frequency questionnaires, 24-hour recalls).

While 24-hour urine samples are the gold standard for estimating daily sodium and potassium intakes, predictive equations have been developed to estimate 24-hour sodium and potassium excretion from spot urine samples (Kawasaki, 1993, Tanaka et al., 2002). Such equations have been developed to predict 24-hour sodium and potassium excretion based on their concentrations relative to creatine in spot urine while also adjusting for factors such as age, gender, weight and height (Rios-Leyvraz et al., 2018). The use of predictive equations for estimate 24-hour urinary sodium and potassium excretion from spot urine may result in both random and systematic errors and hence are more suitable for population estimates than individual estimates of sodium and potassium intake (Iwahori et al., 2019). Additionally, equations have primarily been developed using studies in adults and may not be ideally suited for children. However, a recent study which collected both spot and 24-hour urine samples in children found that some of the commonly used equations to predict sodium intake from spot urine in adults also provided adequate estimations of sodium intake in children (Rios-Leyvraz et al., 2018). The equation that most accurately estimated sodium intake varied depending on the timing of the collection of the spot urine samples (Rios-Leyvraz et al., 2018). This can possibly be explained by the diurnal variation seen in sodium and potassium excretion which occurs primarily due to the hormone aldosterone (Iwahori et al., 2017d). Plasma aldosterone promotes sodium reabsorption, however aldosterone is subject to circadian rhythms and is inactive during sleeping meaning that sodium excretion measured in spot urines will be overestimated in morning spot samples and underestimated in spot samples collected later in the day (Iwahori et al., 2017d).

Fewer equations exist to predict 24-hour urinary potassium excretion from spot urine samples and they are less commonly used than those to predict 24-hour sodium excretion (Iwahori et al., 2017b). However, a study which evaluated the use of equations to predict 24-hour potassium excretion in over 1000 adults across 11 different countries by collecting both 24-hour and spot urine samples found that a formula developed in Japanese adults provided the most accurate estimations of potassium intake when compared to the measured potassium intakes from the 24-hour urine samples (Mente et al., 2014, Kawasaki, 1993). While this may be the most accurate formula available to predict potassium excretion from spot urine in adults, a relatively poor correlation exists between potassium excretions predicted using such equations and measured 24-hour excretions (Mercado et al., 2018). Therefore, the use of such equations to predict potassium intakes from spot urine, especially when used in children, should be interpreted with caution.

Another method of estimating population 24-hour urinary excretion of sodium and potassium is by correcting sodium and potassium excretion values from spot urines for gender and age-specific population urine output volumes. The effect of a salt substitute on sodium and potassium intakes in 3270 Chinese adults was investigated by measuring sodium and potassium excretion from both spot urine and 24-hour urine collections from each participant at the start and end of the study (Huang et al., 2018). When compared to the changes in sodium and potassium intakes measured from the 24-hour urine collections, the study found that correcting the sodium and potassium excretion values from the spot urine collections using mean population output urine volumes predicted changes in sodium and potassium intakes more accurately than the use of commonly used predictive equations which were found to be ineffective in detecting these changes (Huang et al., 2018). Although this method may be subject to some random error, it can still be useful for providing population level intake estimates and warrants further investigation as a low cost, easily implemented alternative to 24-hour urine collections to estimate population level intakes (Huang et al., 2018).

Collecting dietary data on sodium and potassium intakes is advantageous as it allows for the food sources of these nutrients to be determined. Additionally, dietary assessment methods are thought to provide good estimates of potassium intake (Willett, 2012, Dennis et al., 2003). For sodium however, discretionary salt added at the table or in cooking cannot be measured from dietary data alone and therefore dietary data generally underestimates sodium intake. It has been estimated that on average, self-reporters of dietary intake underestimate sodium intake by 0-15% and over-estimate potassium intake by 8-15% when compared with 24-hour urinary excretion analysis (Huang et al., 2014).

Intakes of sodium in children

A recent review documented the most current national dietary survey for each European country and has provided information on surveys that included data for children and adolescents (Rippin et al., 2018). For the purposes of this review, the methodology of each of the studies listed was examined to determine which studies measured sodium intakes and had data which include the 5-12-year-old age group.

Sodium intake data were available (accessible in English) from 6 nationally representative studies, for children in Cyprus, France, Ireland, the Netherlands, Turkey and the UK (**Table 2**).

In Cyprus, based on estimates from a 3-day food diary, average sodium intakes for boys and girls aged 6-9 years were 2331mg/d and 2283mg/d respectively (Tornaritis et al., 2014). For boys and girls aged 9-14 years, average sodium intakes were 2515mg/d and 2289mg/d respectively. The study used the IOM Dietary Reference Intakes to assess compliance with dietary guidance (IOM, 2006). The IOM ULs for sodium of 1.9g/d for 4-8 year olds and 2.2g/d for 9-12 year olds were exceeded by approximately 75% of those aged 6-9 years and by over 50% of those aged 9-14 years (IOM, 2005).

In France, estimates of sodium intake were provided based on data from a previous national dietary survey, the INCA 1 study (1998-1999) (Meneton et al., 2009). This study estimated intakes via a 7-day food diary and validated the estimates by comparing the data with 24-hour urinary excretion measurements in a subgroup of the population. For 2-14 year olds, the average sodium intake was estimated to be 2369mg/d (Meneton et al., 2009).

In Ireland, sodium intakes were estimated as part of the National Children's Food Survey (2003-04), which collected food and beverage consumption data using 7-day food diaries. Boys and girls aged 5-12 years had average sodium intakes from food sources of 2181mg/d and 1985mg/d respectively (Moloney et al., 2006).

In the Netherlands, based on two non-consecutive 24-hour recalls, for those aged 7-8 years the average sodium intake was 2065mg/d (RIVM, 2012a). For 9-13 year olds, the average sodium intake was 2544mg/d for boys and 2257mg/d for girls (RIVM, 2012a).

In Turkey, based on the Turkey Dietary Guidelines (TUBER), the percentage of boys exceeding the UL for sodium (1900mg/d for 5-8 year olds, 2200mg/d for 9-12 year olds) ranged from 69-85% across age groups, while the percentage of girls exceeding the UL ranged from 76-92% across age groups (Turkey Dietary Guidelines, 2016, Turkey Nutrition and Health Survey, 2010).

In the UK, the National Diet and Nutrition Survey (NDNS) (2008-2012) estimated sodium intakes in children based on 24-hour urine collections. Average sodium intake was 1518mg/d in 4-6 year olds, 2070mg/d in 7-10 year olds and 2737mg/d in 11-18 year olds (Bates et al., 2014).

Regional cross-sectional studies from around the world have also estimated sodium intakes from urinary sodium excretion values in children (**Table 3)**. An Italian study estimated sodium intakes in children aged 6-18 years from 24-hour urine collections (Campanozzi et al., 2015). Based on the most recent national Italian dietary recommendations, it found that 93% of boys and 89% of girls had a higher sodium consumption than recommended (Campanozzi et al., 2015). In Portugal, a cross-sectional study collected 24-hour urine samples in 163 children aged 8-10 years (Oliveira et al., 2015). It found that 57% exceeded the IOM UL for sodium (IOM, 2005). A cross-sectional study in Australia on 666 schoolchildren aged 4-12 years estimated sodium intakes based on 24-hour urine collections and found that 72% of children exceeded the age-specific UL for sodium intake (Grimes et al., 2017). A study in New Zealand on a relatively small group (n=27) of 8-11 year old school children measured sodium intakes from a spot urine sample and found the mean daily sodium intake was 2191mg/d (Eyles et al., 2018). A study in Japan estimated sodium intakes from 24-hour urine collections in 331 children aged 9-11 years (Seko et al., 2018). It found that 30% of participants exceeded their age-specific dietary goal for salt intake recommended by the Dietary Reference Intakes for Japanese 2015 (Seko et al., 2018). A national cross-sectional study in Lebanon estimated sodium intakes from morning spot urines in Lebanese elementary school children aged 6-10 years (El Mallah et al., 2017). It found that the sodium intake of half the children exceeded the UL based on the IOM recommendations (IOM, 2005).

From the studies examined, despite variations in cut-offs used to assess compliance with sodium recommendations, it is clear that intakes exceeding recommendations are prevalent amongst children hence efforts to reduce sodium intakes are necessary.

Sources of sodium intake in children

From the studies examined which collected dietary data and reported the key sources of sodium, most studies found similar foods as key sources of sodium in children. In Ireland, the main sources of sodium in 5-12 year olds were ‘meat & meat products’ (24%) and ‘bread & rolls’ (21%) (Moloney et al., 2006). In the Netherlands, the main dietary sources of sodium in 7-18 year olds were ‘cereals and cereal products’ (34%), ‘meat and meat products’ (19%) and ‘dairy products’ (15%) (RIVM, 2012b). In the UK, the largest contributors to sodium intake in people of all ages were ‘cereals & cereal products’ (31-37%) (of which 16-19% came from bread), ‘meat & meat products’ (19-28%), and ‘milk & milk products’ (8-11%). In Australia, the main sources of sodium in 4-12 year olds were ‘cereals and cereal-based products’ (50%), ‘meat, poultry and game products and dishes’ (18%) and ‘milk products and dishes’ (10%), with approximately 75% of salt intake coming from processed foods and discretionary salt accounting for approximately 15% of total salt intake (Grimes et al., 2017). In New Zealand, data from a cross-sectional study on 8-11 year olds found the main sources of sodium were ‘bread’ (15%), ‘pies and pastries’ (13%), ‘bread and pasta based dishes’ (12%), ‘sauces and condiments’ (9%), ‘meat and poultry’ (9%) and ‘savoury snack foods’ (9%) (Eyles et al., 2018). While the studies examined are from various regions and do not always classify foods according to the same food groups, it is still clear that the main contributors to sodium intakes amongst children are similar across studies. The key sources of sodium were generally processed foods such as cereal and cereal products and meat and meat products, while dairy products were also commonly found as a key source of sodium in children.

Intakes of potassium in children

With regards to data on potassium intakes in children, a recent review which documented the latest national dietary survey for each European country was used to determine which studies measured potassium intakes and had data which include the 5-12-year-old age group (Rippin et al., 2018). Based on this study, there was potassium intake data for children (accessible in English) that included 5-12 year olds from 7 of these nationally representative studies including Cyprus, France, Ireland, Italy, the Netherlands, Turkey and the UK (Rippin et al., 2018) (**Table 2**).

In Cyprus, the average potassium intakes in those aged 6-9 years estimated using 3-day food diaries were 2337mg/d and 2311mg/d in boys and girls respectively (Tornaritis et al., 2014). For boys and girls aged 9-14 years, average potassium intakes were 2364mg/d and 2166mg/d respectively. These average potassium intakes were lower than the IOM AI in both age groups (3.8g/d for 4-8 year olds and 4.5g/d for 9-13 year olds) (Tornaritis et al., 2014).

In France, estimated from the 7-day food diaries collected in the INCA 1 study (1998-1999), the average potassium intake in 2-14 year olds was 2496mg/d (Meneton et al., 2009).

In Ireland, the average potassium intakes of boys and girls aged 5-12 years estimated as part of the National Children's Food Survey (2003-04) were 2298mg/d and 2086mg/d respectively (Hannon, 2006).

In Italy, the average dietary potassium intake of 3-10 year olds was 2441mg/d based on analysis of intakes of 193 children in this age group using 3-day food records (Sette et al., 2011).

In the Netherlands, based on two non-consecutive 24-hour recalls, for those aged 7-8 years the average potassium intake was 2367mg/d (RIVM, 2012a). For 9-13 year olds, while the average potassium intake was 2758mg/d for boys and 2501mg/d for girls (RIVM, 2012a).

In Turkey, based on the Turkey Dietary Guidelines 2015 (TUBER) developed based on EFSA scientific opinion reports as well as IOM reports, 98-99% of boys did not meet the potassium AI (3.8g/d for 5-8 year olds, 4.5g/d for 9-12 year olds), while 97-99% of girls did not meet the AI (Turkey Dietary Guidelines, 2016).

In the UK, the National Diet and Nutrition Survey (NDNS) (2008-2012) estimated potassium intakes in children based on 24-hour urine collections. Average potassium intake was 1248mg/d in 4-6 year olds, 1677mg/d in 7-10 year olds and 2028mg/d in 11-18 year olds (Bates et al., 2014).

Regional cross-sectional studies from around the world also estimated potassium intakes from urinary potassium excretion values in children (**Table 3)**. An Italian study estimated potassium intakes in children aged 6-18 years from 24-hour urine collections and based on the most recent national Italian dietary recommendations, 96% of boys and 98% of girls had potassium intakes lower than the recommended potassium AI (Campanozzi et al., 2015). A study in New Zealand on a relatively small group (n=27) of 8-11 year old school children measured potassium intakes by a spot urine sample and found the mean daily potassium intake was 1776mg/d (Eyles et al., 2018). A national cross-sectional study in Lebanon estimated potassium intakes from morning spot urines in Lebanese elementary school children aged 6-10 years and found that almost all children failed to meet the IOM potassium AI (El Mallah et al., 2017, IOM, 2005).

Based on the studies reviewed, potassium intakes below recommendations appear common amongst children regardless of whether they were estimated by urinary excretion of potassium or by dietary assessment methods. For studies which did not assess compliance with recommended potassium intakes, when compared to the EFSA potassium AIs of 1100mg/d for 4-6 year olds, 1800mg/d for 7-10 year olds and 2700mg/d for 11-18 year olds (EFSA, 2017), intakes below these levels appear common and action appears necessary to increase potassium intakes amongst children to meet recommendations.

Sources of potassium intake in children

From the studies examined which collected dietary data and estimated the key sources of potassium intakes in children, most studies found similar foods as main contributors to potassium intake. In Ireland, the main sources of potassium in 5-12 year olds were ‘milk’ (19%), ‘potatoes & potato products’ (19%), ‘meat & meat products’ (14%) and ‘fruits & fruit juices’ (11%) (Hannon, 2006). In Italy, the main sources of potassium in 3-10 year olds were ‘vegetables, fresh and processed’ (19%), ‘cereals and cereal products’ (14%) and ‘fruit, fresh and processed’ (14%)

(Sette et al., 2013). In the Netherlands, the main sources of potassium for 7-18 year olds were 'dairy products' (21%), 'cereals and cereal products' (15%), 'potatoes and other tubers' (13%) and 'meat and meat products' (13%) (RIVM, 2012b). In the UK, the largest contributors to potassium intakes for 4-10-year-olds were 'vegetables and potatoes', 'milk & milk products' and 'cereals and cereal products' which all provided similar proportions (18-21%) (Bates et al., 2014). In Australia, the main sources of potassium in 4-12 year olds were 'milk products and dishes' (18%), 'vegetable products and dishes' (14%), 'meat, poultry and game products and dishes' (13%), 'fruit products and dishes' (11%) and 'cereal based products and dishes' (11%) (Grimes et al., 2017). In New Zealand, data from a cross-sectional study on 8-11 year olds found the main sources of potassium were 'dairy products' (24%), 'meat and poultry dishes' (10%) and 'fruit' (8%) (Eyles et al., 2018). In general, the main contributors to potassium intake amongst children were found to be similar across studies with dairy products, fruit and vegetables, cereal and cereal products and meat and meat products commonly found as key sources of potassium in children.

Na:K hypothesis

An individual's sodium to potassium intake ratio (Na:K) refers to the ratio of their sodium intake to their potassium intake. The importance of the Na:K for the management of hypertension first began to gain momentum in the 1970s (Dahl et al., 1972). Since then there has been many studies to support the hypothesis that an individual's Na:K is a more important predictor of hypertension than either sodium or potassium intake alone (Grobbee et al., 1987, Nowson and Morgan, 1988, Suppa et al., 1988, Sacks et al., 2001). Numerous studies have shown Na:K from 24-hour urine samples to be a predictor of hypertension (Perez and Chang, 2014, Tzoulaki et al., 2012, Stamler et al., 1989, Iwahori et al., 2017c), highlighting that measurement of an individual's Na:K can be used as an indicator of the level of risk of developing hypertension.

INTERSALT was a large world-wide epidemiological study consisting of over 10,000 adults aged 20-59 years across 32 countries which investigated factors that impact blood pressure (Stamler et al., 1989). Findings from this study suggested that a reduction in mean population urinary molar Na:K from 3.09 to 1.0 would enable a mean reduction in population systolic blood pressure of 3.36mmHg (Stamler et al., 1989). The estimated reductions in blood pressure were larger in line with reductions in Na:K rather than when sodium or potassium intakes were analysed separately. The study also estimated that reductions in population blood pressure between 3-5mmHg would reduce stroke morality by 8-14%, coronary heart disease (CHD) mortality by 5-9% and all-cause mortality by 4-7%, indicating that reducing Na:K is indirectly effective for prevention of CVD (Stamler et al., 1989).

The TOHP study measured sodium and potassium intakes from numerous 24-hour urine collections in adults aged 30-54 years and analysed CVD occurrence in 10-15 years of post-trial follow-up (Cook et al., 2009). The results of the study found there to be a direct association between Na:K and CVD risk as well as all-cause mortality (Cook et al., 2016). The increased CVD risk found with a higher Na:K was greater than the increase in CVD risk associated with either sodium or potassium intake alone. A recent study has also found Na:K measured from spot urine to be a predictor of stroke, with molar ratios below 1.0 found to exhibit lower stroke risk (Averill et al., 2019).

Although the studies mentioned demonstrate the relationship of Na:K with blood pressure and CVD risk in adults, the importance of Na:K in predicting hypertension is evident. Research has also shown that a lower Na:K during childhood is thought to protect against rises in blood pressure (Geleijnse et al., 1990) and that reducing Na:K amongst children populations can mitigate the development of hypertension (Perez and Chang, 2014). Therefore, it can be assumed that measurement of Na:K in children may serve as a good indicator of the potential risk of developing hypertension in later life.

Na:K Recommendations

The WHO recommend a sodium intake of <2000mg/d and a potassium intake of >3510mg/d for adults (WHO, 2012b, WHO, 2012a), which if both were simultaneously met would yield a Na:K of less than 1.0mmol/mmol (equivalent to

0.6mg/mg). When the guidelines for individual sodium and potassium intakes are adjusted downward for children based on their energy needs relative to adults, the target ratio would remain ≤1.0mmol/mmol for children of all ages (WHO, 2012a). Achieving a Na:K ≤1.0 is considered beneficial for health and to prevent hypertension (WHO, 2012a), however the ease at which it can be achieved is questionable considering many populations have a mean Na:K of 3.0mmol/mmol or more (Ware et al., 2017). A molar Na:K of between 1.0 and 2.0 has also been shown to exhibit lower CVD risk in adults (Cook et al., 2009) and as compliance for a molar intake ratio ≤1.0 is generally low (Ware et al., 2017), a molar intake ratio ≤2.0 can be seen as an interim suboptimal target ratio for people to lower blood pressure (Cook et al., 2009).

Measurement of Na:K

The gold standard method of measuring an individual's sodium intake is by using multiple high quality 24-hour urine collections to measure urinary excretion of sodium (Iwahori et al., 2017a), while measuring urinary excretion of potassium from 24-hour urine collections is also widely regarded as the gold standard method of assessing potassium intakes (Xu et al., 2019, Willett, 2012). Therefore, estimating an individual's Na:K based on urinary excretion of sodium and potassium from 24-hour urinary collections should provide good estimates of Na:K (Iwahori et al., 2017c).

To estimate 24-hour Na:K from spot urine samples, timing bias corrections should be applied. (Iwahori et al., 2017c). Based on a study which measured Na:K in individuals from both 24-hour urine samples and spot urine samples (Iwahori et al., 2017c), it is recommended that values of 0.6 should be subtracted from molar Na:K estimated from morning spot urine samples while a value of 0.4 should be added to molar ratios estimated from daytime spot urine samples (Iwahori et al., 2017d).

Estimates of Na:K can also be derived from dietary data; however, dietary data generally underestimates sodium intake and overestimates potassium intake when compared to urinary measures of sodium and potassium (Huang et al., 2014). Therefore, Na:K estimated from dietary data will be generally lower than that estimated from urinary data by approximately 20% when compared to measurement of Na:K in 24-hour urines (Huang et al., 2014).

Na:K in children

In France, the INCA 1 study (1998-1999) reported the mean molar Na:K of 2-14 year olds to be 1.64 (Meneton et al., 2009) **(Table 2)** and is seemingly the only European national dietary survey to report Na:K in children. In the UK, the National Diet and Nutrition Survey (NDNS) (2008-2012) measured sodium and potassium excretion in 24-hour urine collections in children (Bates et al., 2014) and from these measured excretions it was possible to estimate mean urinary molar Na:K by dividing the mean urinary sodium excretion by the mean urinary potassium excretion of each age group. The estimated mean molar ratios calculated from this method were 2.06 in 4-6 year olds, 2.09 in 7-10 year olds and 2.27 in 11-18 year olds **(Table 2)**.

Regional cross-sectional studies from around the world were found which estimated Na:K in children (**Table 3)**. An Italian study estimated Na:K in children aged 6-18 years from 24-hour urine collections and found the mean molar Na:K to be 3.5 in boys and 3.4 in girls (Campanozzi et al., 2015). In Portugal, a cross-sectional study collected 24-hour urine samples in 163 children aged 8-10 years and found a mean molar Na:K of 3.2 for boys and 2.5 for girls. (Oliveira et al., 2015) A cross-sectional study in Australia on 666 schoolchildren aged 4-12 years estimated Na:K based on 24-hour urine collections with the estimated mean molar Na:K of Australian schoolchildren found to be 2.4. (Grimes et al., 2017). A study in New Zealand on a relatively small group (n=27) of 8-11 year old school children measured Na:K from spot urine samples and estimated the average molar Na:K to be 2.0 (Eyles et al., 2018). A study in Japan estimated Na:K from 24-hour urine collections in 331 children aged 9-11 years and found a median molar Na:K of 4.5 (Seko et al., 2018). A national cross-sectional study in Lebanon estimated Na:K from morning spot urines in Lebanese elementary school children aged 6-10 years and found an average molar Na:K of 2.36 (El Mallah et al., 2017).

From the studies reviewed, target molar Na:K of ≤1.0 (WHO, 2012a) and ≤2.0 (Cook et al., 2009) were typically exceeded in most studies. These findings indicate that many children from the respective population groups may be at increased risk of developing elevated blood pressure or hypertension and action to lower Na:K should be considered.

Dietary determinants of Na:K

In France, the foods associated with a higher Na:K in 2-14 year olds were 'cheeses', 'cooked pork meats', 'pastries and sugary products', 'breakfast cereals', 'breads', 'soups' and 'fast foods', while the foods associated with a lower Na:K were 'fruits', 'hot beverages', 'meats', 'vegetables' and 'dairy products' (Meneton et al., 2009). Additionally, in both the Japan and Lebanon based studies, there was found to be a negative correlation between fruit and vegetable consumption and Na:K (Seko et al., 2018, El Mallah et al., 2017). Both studies highlighted increasing fruit and vegetable consumption as a potential means to lower Na:K (Seko et al., 2018, El Mallah et al., 2017).

Current challenges in reducing Na:K and potential solutions

To reduce the high Na:K found commonly in the studies reviewed, implementation of effective strategies to lower sodium and increase potassium intakes appears warranted. Many studies identify the importance of targeting children in interventions to prevent the development of hypertension (such as lowering Na:K), as the pathology of diseases such as CVD starts in childhood (Chen and Wang, 2008). However, the implementation of effective strategies has been shown to be challenging.

In 2013 The WHO released a report 'Global Action Plan for the Prevention and Control of NCDs 2013-2020'. As part of the report The WHO have set a target of reducing population salt consumption to less than 5g/d by 2025. The report offered a list of guidelines and policy options for member states to work as a road map to achieve this target and contribute to a larger goal of a 25% reduction in premature mortality from non-communicable diseases (NCDs) such as CVD by 2025 (WHO, 2013). The report notes that although deaths from NCDs occur in adulthood, exposure to risk factors begins in childhood as is the case with CVD. It notes the need for legislative and regulatory measures as well as health promotion interventions that engage state and non-state bodies in order to create an environment that promotes healthy behaviors (WHO, 2013). Potential methods to create a health promoting environment include changes in policies for member states such as incentives, disincentives, regulatory and fiscal measures, stricter laws and health education. Examples of such methods include placing a higher tax rate on unhealthy foods, promotion of uniform nutrition labelling according to International Codex standards, evidence informed public campaigns and social marketing initiatives as well as creating health-promoting environments by education in schools, workplaces and hospitals (WHO, 2013).

While the guidelines and policy options listed in the WHO report provide potential methods of lowering population sodium intakes (WHO, 2013), lowering population sodium intakes is not a straightforward process as it requires cooperation between numerous bodies and organizations. Additionally, reformulation to reduce the salt content of products is a difficult process due to the role salt plays in taste, preservation and processing (Dötsch et al., 2009). While initiatives and action plans have had some relative success in lowering population salt intakes (FSAI, 2016b), stricter laws and policies with regards the salt content of foods appear necessary to enforce further reformulation of products and ensure the food and beverage industry take further responsibility for public health.

Educating children on their salt intake to enable them to make healthy choices is another potential solution which may help to lower population salt intakes (He et al., 2015, WHO, 2013). A study in China by *He et al* split a total of 279 children into two groups. One group received educational training on the harmful effects of salt and recommended salt consumption levels and reduction targets. The other group did not receive this training and instead attended a class not related to the study. Following 24-hour urine collections at the start and end of the study, it found that over a 3.5 month period the group who received the healthy eating education classes had an average reduction in salt consumption of 27%, while the group who did not receive the healthy eating classes had an increased salt intake (He et al., 2015). The study demonstrates the potential for educational healthy eating classes to alter the eating habits of children and is an example of a potential means of creating a health promoting environment that warrants further investigation. Such education if introduced on a large-scale could potentially reduce the amount of discretionary salt added at the table for meals and would aid in decreasing population sodium intakes.

From the studies reviewed, potassium intakes below recommendations appear common amongst children of all ages (Tornaritis et al., 2014, Bates et al., 2014, Campanozzi et al., 2015, Eyles et al., 2018, El Mallah et al., 2017). Therefore, strategies to increase potassium intakes appear necessary to significantly lower Na:K amongst children. As highlighted by some of the papers reviewed, targeting an increased fruit and vegetable consumption amongst children could potentially be an effective strategy to increase potassium intakes (Oliveira et al., 2015, Seko et al., 2018, El Mallah et al., 2017). However, effectively promoting fruit and vegetable consumption and making fruit and vegetables widely available to children requires cooperation between numerous bodies and organisations related to public health. Therefore, although such initiatives appear necessary, implementation of strategies to increase potassium intakes in children is also challenging.

While large-scale reductions in population Na:K are likely to take time, there is the possibility that future technological advancements and breakthroughs may have profound effects in aiding to reduce population Na:K. For example, the development of devices which offer prompt, on-site feedback for estimations of an individual's Na:K from a urine sample now means that it is possible for an individual to monitor their Na:K. Although initial findings suggest that the use of these devices were ineffective in aiding individuals to meet target Na:K intake ratios (Iwahori et al., 2018), it is possible the use of such devices going forward if improved upon and made widely accessible could help individuals to achieve target Na:K. Similarly, the use of salt substitutes which would enable the food industry to reduce the salt content of products without compromising quality is another concept that has been considered (FSAI, 2016a). However, it has been found that the currently available salt substitutes have an undesirable flavor profile hence widescale use of salt substitutes appears unlikely at present. Technological advances in the future may address this challenge and could contribute to the availability of lower salt products on the market.

Conclusions

The main findings of this review were that sodium intakes exceeding recommendations and potassium intakes below recommendations were commonly found amongst children from the studies examined. Adherence to target molar Na:K of $\leq$1.0 and $\leq$2.0 was very low amongst children, with the mean ratios from most of the studies examined exceeding these targets. Based on these findings, many children may be at increased risk of developing elevated blood pressure or hypertension. A significant relationship exists between blood pressure as a child and blood pressure as an adult, meaning that for interventions to combat the hypertension related diseases seen in later life to be effective they should target children. From the studies which looked at dietary sources of sodium and potassium, the high consumption of processed foods and the low consumption of fruit and vegetables appeared to be factors in the high sodium and low potassium intakes found. Further cooperation between all bodies and organizations related to public health appears necessary to reduce sodium intakes and increase potassium intakes amongst children to aid in lowering population Na:K which may reduce the burden of CVD on public health.

Table 1. Dietary guidance on salt/sodium and potassium intakes

Recommended by	Age (years)	Recommendation
FSAI[a] and SACN[b]		Target maximum population salt intakes (g/d)
	4-6	3
	7-10	5
	11-14	6
EFSA[c]		Sodium Adequate Intake (AI) (g/d)
	4-6	1.3
	7-10	1.7
	11-17	2.0
Institute of Medicine[d]		Sodium Tolerable Upper Intake Level (UL) (mg/d)
	4-8	1900
	9-18	2200
EFSA[e]		Potassium Adequate Intake (AI) (mg/d)
	4-6	1100
	7-10	1800
	11-14	2700

[a](FSAI, 2016a), [b](SACN, 2003), [c](EFSA, 2019), [d](IOM, 2005), [e](EFSA, 2017)

Table 2. Dietary and urinary intakes of sodium (Na) and potassium (K) and Na:K in children from European national dietary surveys

Country	Age (Years)	Dietary Na (mg/d)	Dietary K (mg/d)	Urinary Na (mmol/d)	Urinary K (mmol/d	Na:K (mmol:mmol)
Cyprus[a]	6-9	Boys 2331	Boys 2337	-	-	-
		Girls 2283	Girls 2311	-	-	-
	9-14	Boys 2515	Boys 2364	-	-	-
		Girls 2289	Girls 2166	-	-	-
France[b]	2-14	2369*	2496*	-	-	-
Ireland[c,d]	5-12	Boys 2182	Boys 2298	-	-	-
		Girls 2289	Girls 2086	-	-	-
Italy[e]	3-10	n/a	2441	-	-	-
Netherlands[f]	7-8	2065	2367	-	-	-
	9-13	Boys 2544	Boys 2758	-	-	-
		Girls 2257	Girls 2502	-	-	-
UK[g]	4-6	-	-	66	32	2.06*
	7-10	-	-	90	43	2.09*
	11-18	-	-	119	52	2.27*

- no data available
*self-calculated from data
[a](Tornaritis, 2014), [b](Meneton, 2009), [c](Moloney, 2006), [d](Hannon, 2006), [e](Sette, 2011), [f](RIVM, 2012), [g](Bates, 2014)

Table 3. Urinary sodium intakes (Na), potassium intakes (K) and Na:K from cross-sectional studies in children

Region	n	Age (years)	Urinary Na (mmol/d)	Urinary K (mmol/d)	Urinary Na:K (mmol:mmol)
Italy[a]	1424	6-18	Boys 129 Girls 117	Boys 39 Girls 36	Boys 3.5 Girls 3.4
Portugal[b]	163	8-10	Boys 128* Girls 104*	Boys 44* Girls 43 *	Boys 3.2 Girls 2.5
Australia[c]	666	4-12	103	47	2.4
New Zealand[d]	30	8-11	95*	46*	2
Japan[e]	331	9-11	129	29	4.5
Lebanon[f]	1403	6-10	97	47	2.4

*self-calculated from data

[a](Campanozzi, 2015), [b](Oliveria, 2015), [c](Grimes, 2017), [d](Eyles, 2018), [e](Seko, 2018), [f](El Mallah, 2017)

Bibliography

Averill, M. M., Young, R. L., Wood, A. C., Kurlak, E. O., Kramer, H., Steffen, L., McClelland, R. L., Delaney, J. A. & Drewnowski, A. 2019. Spot Urine Sodium-to-Potassium Ratio Is a Predictor of Stroke. *Stroke,* 50**,** 321-327.

Bates, B., Lennox, A., Prentice, A., Bates, C., Page, P., Nicholson, S. & Swan, G. 2014. National Diet and Nutrition Survey. Results from Years 1,2,3 and 4 (combined) of the Rolling Programme (2008/2009-2011/2012) *In:* Public Health England, W. H., 133-155 Waterloo Road, London SE1 8UG (ed.).

Brown, I. J., Tzoulaki, I., Candeias, V. & Elliott, P. 2009. Salt intakes around the world: implications for public health. *International Journal of Epidemiology,* 38**,** 791-813.

Campanozzi, A., Avallone, S., Barbato, A., Iacone, R., Russo, O., De Filippo, G., D'Angelo, G., Pensabene, L., Malamisura, B., Cecere, G., Micillo, M., Francavilla, R., Tetro, A., Lombardi, G., Tonelli, L., Castellucci, G., Ferraro, L., Di Biase, R., Lezo, A., Salvatore, S., Paoletti, S., Siani, A., Galeone, D., Strazzullo, P. & Group, M.-G. P. S. 2015. High sodium and low potassium intake among Italian children: relationship with age, body mass and blood pressure. *PloS one,* 10**,** e0121183-e0121183.

Chen, X. & Wang, Y. 2008. Tracking of blood pressure from childhood to adulthood: a systematic review and meta-regression analysis. *Circulation,* 117**,** 3171-3180.

Cobb, L. K., Anderson, C. A., Elliott, P., Hu, F. B., Liu, K., Neaton, J. D., Whelton, P. K., Woodward, M. & Appel, L. J. 2014. Methodological issues in cohort studies that relate sodium intake to cardiovascular disease outcomes: a science advisory from the American Heart Association. *Circulation,* 129**,** 1173-86.

Cogswell, M. E., Mugavero, K., Bowman, B. A. & Frieden, T. R. 2016. Dietary Sodium and Cardiovascular Disease Risk--Measurement Matters. *The New England journal of medicine,* 375**,** 580-586.

Cogswell, M. E., Yuan, K., Gunn, J. P., Gillespie, C., Sliwa, S., Galuska, D. A., Barrett, J., Hirschman, J., Moshfegh, A. J., Rhodes, D., Ahuja, J., Pehrsson, P., Merritt, R. & Bowman, B. A. 2014. Vital signs: sodium intake among U.S. school-aged children - 2009-2010. *MMWR Morb Mortal Wkly Rep,* 63**,** 789-97.

Cook, N. R., Appel, L. J. & Whelton, P. K. 2016. Sodium Intake and All-Cause Mortality Over 20 Years in the Trials of Hypertension Prevention. *Journal of the American College of Cardiology,* 68**,** 1609-1617.

Cook, N. R., Obarzanek, E., Cutler, J. A., Buring, J. E., Rexrode, K. M., Kumanyika, S. K., Appel, L. J., Whelton, P. K. & Trials of Hypertension Prevention Collaborative Research, G. 2009. Joint effects of sodium and potassium intake on subsequent cardiovascular disease: the Trials of Hypertension Prevention follow-up study. *Archives of internal medicine,* 169**,** 32-40.

Dahl, L. K., Leitl, G. & Heine, M. 1972. Influence of dietary potassium and sodium/potassium molar ratios on the development of salt hypertension. *J Exp Med 136, 318-330.*

Daniels, S. R., Loggie, J. M., Khoury, P. & Kimball, T. R. 1998. Left ventricular geometry and severe left ventricular hypertrophy in children and adolescents with essential hypertension. *Circulation,* 97**,** 1907-11.

Dennis, B., Stamler, J., Buzzard, M., Conway, R., Elliott, P., Moag-Stahlberg, A., Okayama, A., Okuda, N., Robertson, C., Robinson, F., Schakel, S., Stevens, M., Van Heel, N., Zhao, L. & Zhou, B. F. 2003. INTERMAP: the dietary data--process and quality control. *J Hum Hypertens,* 17**,** 609-22.

Dötsch, M., Busch, J., Batenburg, M., Liem, G., Tareilus, E., Mueller, R. & Meijer, G. 2009. Strategies to Reduce Sodium Consumption: A Food Industry Perspective. *Critical Reviews in Food Science and Nutrition,* 49**,** 841-851.

EFSA 2016. EFSA NDA Panel (EFSA Panel on Dietetic Products, Nutrition and Allergies),Turck D, Bresson J-L, Burlingame B, Dean T, Fairweather-Tait S, Heinonen M, Hirsch-Ernst KI,Mangelsdorf I, McArdle H, Neuh€auser-Berthold M, Nowicka G, Pentieva K, Sanz Y, Siani A, Sj€odin A,Stern M, Tome D, Van Loveren H, Vinceti M, Willatts P, Aggett P, Martin A, Przyrembel H, Br€onstrup A,Ciok J, Gomez Ruiz JA, de Sesmaisons-Lecarre A and Naska A, 2016. Scientific opinion on dietaryreference values for potassium. EFSA Journal 2016;14(10):4592, 56 pp. doi:10.2903/j.efsa.2016.4592.

EFSA 2017. Dietary Reference Values for nutrients Summary report. *EFSA Supporting Publications,* 14.

EFSA 2019. EFSA NDA Panel (EFSA Panel on Nutrition, Novel Foods and Food Allergens),Turck D, Castenmiller J, de Henauw S, Hirsch-Ernst K-I, Kearney J, Maciuk A, Mangelsdorf I, McArdle HJ,Pelaez C, Pentieva K, Siani A, Thies F, Tsabouri S, Vinceti M, Aggett P, Fairweather-Tait S, Martin A,Przyrembel H, Ciccolallo L, de Sesmaisons-Lecarre A, Martinez SV, Martino L and Naska A, 2019. ScientificOpinion on the dietary reference values for sodium. EFSA Journal 2019;17(9):5778, 191 pp.

El Mallah, C., Merhi, K., Ghattas, H., Shatila, D., Francis, S., Hlais, S., Toufeili, I. & Obeid, O. 2017. Elevated urinary Na/K ratio among Lebanese elementary school children is attributable to low K intake. *Eur J Nutr,* 56**,** 1149-1156.

Ellis, D. & Miyashita, Y. 2011. Primary hypertension and special aspects of hypertension in older children and adolescents. *Adolescent health, medicine and therapeutics,* 2**,** 45-62.

Eyles, H., Bhana, N., Lee, S. E., Grimes, C., McLean, R., Nowson, C. & Wall, C. 2018. Measuring Children's Sodium and Potassium Intakes in NZ: A Pilot Study. *Nutrients,* 10**,** 1198.

FSAI 2016a. Salt and Health. Review of the Scientific Evidence and Recommendations for Public Policy in Ireland. Food Safety Authority of Ireland, Dublin.

FSAI 2016b. Salt Reducing in Processed Foods - Salt in Diet Still High. . *https://www.fsai.ie/news_centre/press_releases/salt_reduction_programme_031116.html (Accessed online May 2019).*

Geleijnse, J. M., Grobbee, D. E. & Hofman, A. 1990. Sodium and potassium intake and blood pressure change in childhood. *British Medical Journal,* 300**,** 899.

Graudal, N., Jurgens, G., Baslund, B. & Alderman, M. H. 2014. Compared with usual sodium intake, low- and excessive-sodium diets are associated with increased mortality: a meta-analysis. *Am J Hypertens,* 27**,** 1129-37.

Grimes, C. A., Riddell, L. J., Campbell, K. J., Beckford, K., Baxter, J. R., He, F. J. & Nowson, C. A. 2017. Dietary intake and sources of sodium and potassium among Australian schoolchildren: results from the cross-sectional Salt and Other Nutrients in Children (SONIC) study. *BMJ open,* 7**,** e016639-e016639.

Grobbee, D. E., Hofman, A., Roelandt, J. T., Boomsma, F., Schalekamp, M. A. & Valkenburg, H. A. 1987. Sodium restriction and potassium supplementation in young people with mildly elevated blood pressure. *J Hypertens,* 5**,** 115-9.

Hannon, E. M. 2006. The National Children's Food Survey: Micronutrient intakes and risk-benefit analysis of micronutrient fortificiation of foods in Irish children. PhD, University College Cork.

He, F. J., Wu, Y., Feng, X.-X., Ma, J., Ma, Y., Wang, H., Zhang, J., Yuan, J., Lin, C.-P., Nowson, C. & MacGregor, G. A. 2015. School based education programme to reduce salt intake in children and their families (School-EduSalt): cluster randomised controlled trial. *BMJ (Clinical research ed.),* 350**,** h770-h770.

Huang, L., Woodward, M., Stepien, S., Tian, M., Yin, X., Hao, Z., Li, Z., Sun, J., Yu, Y., Zhou, B., Zhao, Y., Wu, Y. & Neal, B. 2018. Spot urine samples compared with 24-h urine samples for estimating changes in urinary sodium and potassium excretion in the China Salt Substitute and Stroke Study. *International Journal of Epidemiology,* 47**,** 1811-1820.

Huang, Y., Van Horn, L., Tinker, L. F., Neuhouser, M. L., Carbone, L., Mossavar-Rahmani, Y., Thomas, F. & Prentice, R. L. 2014. Measurement error corrected sodium and potassium intake estimation using 24-hour urinary excretion. *Hypertension (Dallas, Tex. : 1979),* 63**,** 238-244.

Iadecola, C., Yaffe, K., Biller, J., Bratzke, L. C., Faraci, F. M., Gorelick, P. B., Gulati, M., Kamel, H., Knopman, D. S., Launer, L. J., Saczynski, J. S., Seshadri, S., Zeki Al Hazzouri, A., American Heart Association Council on, H., Council on Clinical, C., Council on Cardiovascular Disease in the, Y., Council on, C., Stroke, N., Council on Quality of, C., Outcomes, R. & Stroke, C. 2016. Impact of Hypertension on Cognitive Function: A Scientific Statement From the American Heart Association. *Hypertension (Dallas, Tex. : 1979),* 68**,** e67-e94.

IOM 2005. Institute of Medicine, *Dietary Reference Intakes for Water, Potassium, Sodium, Chloride and Sulfate. Washington, DC: The National Academies Press,* doi:10.17226/10925.

IOM 2006. Institute of Medicine: Dietary Reference Intakes. The Essential Guide to Nutrient Requirements. 2006, Washington: The National Academies Press.

Iwahori, T., Miura, K. & Ueshima, H. 2017a. Time to Consider Use of the Sodium-to-Potassium Ratio for Practical Sodium Reduction and Potassium Increase. *Nutrients,* 9.

Iwahori, T., Miura, K. & Ueshima, H. 2017b. Time to Consider Use of the Sodium-to-Potassium Ratio for Practical Sodium Reduction and Potassium Increase. *Nutrients,* 9**,** 700.

Iwahori, T., Miura, K., Ueshima, H., Chan, Q., Dyer, A. R., Elliott, P. & Stamler, J. 2017c. Estimating 24-h urinary sodium/potassium ratio from casual ('spot') urinary sodium/potassium ratio: the INTERSALT Study. *Int J Epidemiol,* 46**,** 1564-1572.

Iwahori, T., Miura, K., Ueshima, H., Tanaka-Mizuno, S., Chan, Q., Arima, H., Dyer, A. R., Elliott, P., Stamler, J. & for the, I. R. G. 2019. Urinary sodium-to-potassium ratio and intake of sodium and potassium among men and women from multiethnic general populations: the INTERSALT Study. *Hypertension Research*.

Iwahori, T., Ueshima, H., Ohgami, N., Yamashita, H., Miyagawa, N., Kondo, K., Torii, S., Yoshita, K., Shiga, T., Ohkubo, T., Arima, H. & Miura, K. 2018. Effectiveness of a Self-monitoring Device for Urinary Sodium-to-Potassium Ratio on Dietary Improvement in Free-Living Adults: a Randomized Controlled Trial. *J Epidemiol,* 28**,** 41-47.

Iwahori, T., Ueshima, H., Torii, S., Saito, Y., Kondo, K., Tanaka-Mizuno, S., Arima, H. & Miura, K. 2017d. Diurnal variation of urinary sodium-to-potassium ratio in free-living Japanese individuals. *Hypertension research : official journal of the Japanese Society of Hypertension,* 40**,** 658-664.

Kalogeropoulos, A. P., Georgiopoulou, V. V., Murphy, R. A., Newman, A. B., Bauer, D. C., Harris, T. B., Yang, Z., Applegate, W. B. & Kritchevsky, S. B. 2015. Dietary sodium content, mortality, and risk for cardiovascular events in older adults: the Health, Aging, and Body Composition (Health ABC) Study. *JAMA Intern Med,* 175**,** 410-9.

Kanbay, M., Bayram, Y., Solak, Y. & Sanders, P. W. 2013. Dietary potassium: a key mediator of the cardiovascular response to dietary sodium chloride. *Journal of the American Society of Hypertension : JASH,* 7**,** 395-400.

Kawasaki, T., Itoh, K., Uezono, K., & Sasaki, H. 1993. A SIMPLE METHOD FOR ESTIMATING 24 H URINARY SODIUM AND POTASSIUM EXCRETION FROM SECOND MORNING VOIDING URINE SPECIMEN IN ADULTS. Clinical and Experimental Pharmacology and Physiology, 20(1), 7–14. doi:10.1111/j.1440-1681.1993.tb01496.x.

Lane, D. A. & Gill, P. 2004. Ethnicity and tracking blood pressure in children. *J Hum Hypertens,* 18**,** 223-8.

Meneton, P., Lafay, L., Tard, A., Dufour, A., Ireland, J., Ménard, J. & Volatier, J. L. 2009. Dietary sources and correlates of sodium and potassium intakes in the French general population. *European Journal Of Clinical Nutrition,* 63**,** 1169.

Mennuni, S., Rubattu, S., Pierelli, G., Tocci, G., Fofi, C. & Volpe, M. 2014. Hypertension and kidneys: unraveling complex molecular mechanisms underlying hypertensive renal damage. *J Hum Hypertens,* 28**,** 74-9.

Mente, A., O'Donnell, M. J., Dagenais, G., Wielgosz, A., Lear, S. A., McQueen, M. J., Jiang, Y., Xingyu, W., Jian, B., Calik, K. B., Akalin, A. A., Mony, P., Devanath, A., Yusufali, A. H., Lopez-Jaramillo, P., Avezum, A., Jr., Yusoff, K., Rosengren, A., Kruger, L., Orlandini, A., Rangarajan, S., Teo, K. & Yusuf, S. 2014. Validation and comparison of three formulae to estimate sodium and potassium excretion from a single morning fasting urine compared to 24-h measures in 11 countries. *J Hypertens,* 32**,** 1005-14; discussion 1015.

Mercado, C. I., Cogswell, M. E., Loria, C. M., Liu, K., Allen, N., Gillespie, C., Wang, C.-Y., de Boer, I. H. & Wright, J. 2018. Validity of predictive equations for 24-h urinary potassium excretion based on timing of spot urine collection among adults: the MESA and CARDIA Urinary Sodium Study and NHANES Urinary Sodium Calibration Study. *The American Journal of Clinical Nutrition,* 108**,** 532-547.

Moloney, R., Hannon, E. & Flynn, A. 2006. Sodiumintakes from food sources in Irish adults aged 18-64 and Irish children aged 5-12 years. *Proceedings of The Nutrition Society*

Movassagh, E. Z., Baxter-Jones, A. D. G., Kontulainen, S., Whiting, S. J. & Vatanparast, H. 2017. Tracking Dietary Patterns over 20 Years from Childhood through Adolescence into Young Adulthood: The Saskatchewan Pediatric Bone Mineral Accrual Study. *Nutrients,* 9**,** 990.

Nowson, C. A. & Morgan, T. O. 1988. Change in blood pressure in relation to change in nutrients effected by manipulation of dietary sodium and potassium. *Clin Exp Pharmacol Physiol,* 15**,** 225-42.

O'Donnell, M., Mente, A., Rangarajan, S., McQueen, M. J., Wang, X., Liu, L., Yan, H., Lee, S. F., Mony, P., Devanath, A., Rosengren, A., Lopez-Jaramillo, P., Diaz, R., Avezum, A., Lanas, F., Yusoff, K., Iqbal, R., Ilow, R., Mohammadifard, N., Gulec, S., Yusufali, A. H., Kruger, L., Yusuf, R., Chifamba, J., Kabali, C., Dagenais, G., Lear, S. A., Teo, K. & Yusuf, S. 2014. Urinary sodium and potassium excretion, mortality, and cardiovascular events. *N Engl J Med,* 371**,** 612-23.

Oliveira, A. C., Padrão, P., Moreira, A., Pinto, M., Neto, M., Santos, T., Madureira, J., Fernandes, E. d. O., Graça, P., Breda, J. & Moreira, P. 2015. Potassium urinary excretion and dietary intake: a cross-sectional analysis in 8-10 year-old children. *BMC pediatrics,* 15**,** 60-60.

Perez, V. & Chang, E. T. 2014. Sodium-to-potassium ratio and blood pressure, hypertension, and related factors. *Advances in nutrition (Bethesda, Md.),* 5**,** 712-741.

Pfister, R., Michels, G., Sharp, S. J., Luben, R., Wareham, N. J. & Khaw, K. T. 2014. Estimated urinary sodium excretion and risk of heart failure in men and women in the EPIC-Norfolk study. *Eur J Heart Fail,* 16**,** 394-402.

Pietinen, P., Findley, T., Clausen, J., Finnerty Jr, F. & Altschul, A. 1976. Studies in community nutrition: estimation of sodium output. *Preventive medicine,* 5**,** 400-407.

Rios-Leyvraz, M., Bovet, P., Tabin, R., Genin, B., Russo, M., Rossier, M. F., Bochud, M. & Chiolero, A. 2018. Urine Spot Samples Can Be Used to Estimate 24-Hour Urinary Sodium Excretion in Children. *J Nutr,* 148**,** 1946-1953.

Rippin, H. L., Hutchinson, J., Jewell, J., Breda, J. J. & Cade, J. E. 2018. Child and adolescent nutrient intakes from current national dietary surveys of European populations. *Nutrition Research Reviews***,** 1-32.

RIVM 2012a. DNFCS Core survey - Part 6, Micronutrients. https://www.rivm.nl/en/dnfcs-core-survey-part-6-micronutrients (Accessd online 24/01/2019).

RIVM 2012b. Dutch National Food Consumption Survey 2007-2010 Part 8-A Sources of micronutrients, Version 2, based on dataset. DFC_2010_core_20120822.

Rosner, B., Cook, N. R., Daniels, S. & Falkner, B. 2013. Childhood blood pressure trends and risk factors for high blood pressure: the NHANES experience 1988-2008. *Hypertension,* 62**,** 247-54.
Sacks, F. M., Svetkey, L. P., Vollmer, W. M., Appel, L. J., Bray, G. A., Harsha, D., Obarzanek, E., Conlin, P. R., Miller, E. R., 3rd, Simons-Morton, D. G., Karanja, N. & Lin, P. H. 2001. Effects on blood pressure of reduced dietary sodium and the Dietary Approaches to Stop Hypertension (DASH) diet. DASH-Sodium Collaborative Research Group. *N Engl J Med,* 344**,** 3-10.
SACN 2003. Scientific Advisory Committee on Nutrition, Salt and Health. *Crown Copyright 2003. Published for the Food Standards Agency and the Department of Health under licence from the Controller of Her Majesty's Stationery Office*.
Safefood 2014. Safefood Ireland Report; Results from the Cork Children's Lifestyle Study (CCLaS). *(Accessed online on 27/08/2019) https://www.safefood.eu/Professional/Nutrition/Nutrition-News-en/Nutrition-News/March-2014/Cork-Children%E2%80%99s-Lifestyle-Study.aspx*.
Seko, C., Taguchi, Y., Segawa, H., Odani, K., Aoi, W., Wada, S., Kitaoka, K., Masumoto, T. & Higashi, A. 2018. Estimation of salt intake and sodium-to-potassium ratios assessed by urinary excretion among Japanese elementary school children. *Clin Exp Hypertens,* 40**,** 481-486.
Sette, S., Le Donne, C., Piccinelli, R., Arcella, D., Turrini, A. & Leclercq, C. 2011. The third Italian National Food Consumption Survey, INRAN-SCAI 2005–06 – Part 1: Nutrient intakes in Italy. *Nutrition, Metabolism and Cardiovascular Diseases,* 21**,** 922-932.
Sette, S., Le Donne, C., Piccinelli, R., Mistura, L., Ferrari, M. & Leclercq, C. 2013. The third National Food Consumption Survey, INRAN-SCAI 2005-06: major dietary sources of nutrients in Italy. *Int J Food Sci Nutr,* 64**,** 1014-21.
Sharma, A. K., Metzger, D. L. & Rodd, C. J. 2018. Prevalence and Severity of High Blood Pressure Among Children Based on the 2017 American Academy of Pediatrics Guidelines. *JAMA pediatrics,* 172**,** 557-565.
Stamler, J., Rose, G., Stamler, R., Elliott, P., Dyer, A. & Marmot, M. 1989. INTERSALT study findings. Public health and medical care implications. *Hypertension,* 14**,** 570-7.
Stein, L., Cowart, B. & Beauchamp, G. 2012. The development of salty taste acceptance is related to dietary experience in human infants: A prospective study. *The American journal of clinical nutrition,* 95**,** 123-9.
Suppa, G., Pollavini, G., Alberti, D. & Savonitto, S. 1988. Effects of a low-sodium high-potassium salt in hypertensive patients treated with metoprolol: a multicentre study. *J Hypertens,* 6**,** 787-90.
Tanaka, T., Okamura, T., Miura, K., Kadowaki, T., Ueshima, H., Nakagawa, H. & Hashimoto, T. 2002. A simple method to estimate populational 24-h urinary sodium and potassium excretion using a casual urine specimen. *J Hum Hypertens,* 16**,** 97-103.
Tian, N., Zhang, Z., Loustalot, F., Yang, Q. & Cogswell, M. E. 2013. Sodium and potassium intakes among US infants and preschool children, 2003-2010. *The American journal of clinical nutrition,* 98**,** 1113-1122.

Tornaritis, M. J., Philippou, E., Hadjigeorgiou, C., Kourides, Y. A., Panayi, A. & Savva, S. C. 2014. A study of the dietary intake of Cypriot children and adolescents aged 6-18 years and the association of mother's educational status and children's weight status on adherence to nutritional recommendations. *BMC public health*, 14**,** 13-13.

Turkey Dietary Guidelines 2016. Turkey Dietary Guidelines, Ministry of Health of Turkey Publication No: 1046, Ankara 2016.

Turkey Nutrition and Health Survey 2010. Hacettepe University, Ministry of Health (Turkey), Ankhara Numune Research and Training Hospital (Turkey). Turkey Nutrition and Health Survey 2010.

Tzoulaki, I., Patel, C. J., Okamura, T., Chan, Q., Brown, I. J., Miura, K., Ueshima, H., Zhao, L., Van Horn, L., Daviglus, M. L., Stamler, J., Butte, A. J., Ioannidis, J. P. A. & Elliott, P. 2012. A nutrient-wide association study on blood pressure. *Circulation*, 126**,** 2456-2464.

Ware, L. J., Swanepoel, B. & Schutte, A. E. 2017. Urinary sodium-to-potassium ratio: it may be SMART, but is it easy? *Public Health Nutrition*, 20**,** 758-760.

WHO 2012a. Guideline: Potassium intake for adults and children. Geneva, World Health Organization (WHO), 2012.

WHO 2012b. Guideline: Sodium intake for adults and children. Geneva, World Health Organization (WHO), 2012.

WHO 2013. *Global Action Plan for the Prevention and Control of NCDs 2013-2020*.

WHO 2017. Cardiovascular Disease Fact Sheet. https://www.who.int/cardiovascular_diseases/en/ (Accessed September 2018). Geneva, World Health Organization (WHO), 2017.

Willett, W. 2012. *Nutritional epidemiology*, Oxford University Press. 3rd edition.

Xu, J., Du, X., Bai, Y., Fang, L., Liu, M., Ji, N., Zhong, J., Yu, M. & Wu, J. 2019. Assessment and validation of spot urine in estimating the 24-h urinary sodium, potassium, and sodium/potassium ratio in Chinese adults. *Journal of Human Hypertension*.

Aims and objectives

The overall aim of this research was to examine the role of sodium and potassium in the diets of school-aged children in Ireland, specifically to estimate the intakes and dietary sources of sodium and potassium and Na:K in this population group. Analyses were based on data from the National Children's Food Survey II (NCFS II), which collected both urinary and dietary data in a nationally representative sample of children aged 5-12 years in the Republic of Ireland between April 2017 and May 2018 (*n* 600).

Objectives:

- To estimate sodium intake from both urinary and dietary data and to determine the key dietary sources of sodium in Irish children

- To estimate potassium intake from both urinary and dietary data and to determine the key dietary sources of potassium in Irish children

- To estimate the Na:K and the foods associated with a lower Na:K. in Irish children

- To examine the changes in sodium and potassium intakes, sources and Na:K since the previous NCFS (2003-04)

Chapter 2

Methodology

Overview of study

Analyses for this study were based on data from the National Children's Food Survey (NCFS) II (2017-18) which was a nationally representative cross-sectional study that collected food and beverage consumption data from 600 Irish children aged 5-12 years in the Republic of Ireland between 2017 and 2018. The NCFS II (2017-18) was carried out by the Irish Universities Nutrition Alliance (IUNA) units at University College Cork (UCC), University College Dublin (UCD), Cork Institute of Technology (CIT) and Technological University Dublin (TUD). A detailed outline of the survey methodology and the methods relevant to this study are provided below, while the methods specific to each chapter will be discussed accordingly. Further information and a detailed methodology relating to additional data collected in the NCFS II such as lifestyle data and anthropometric measurements is available at www.iuna.net. Findings from the NCFS II can be compared to the previous NCFS (2003-04), which used a similar methodology with the exception of the 7-day weighed food diary used in the NCFS compared to a 4-day weighed food diary used in the NCFS II. The methodology for the NCFS has been described previously (www.iuna.net) and is described in brief at the end of this chapter.

Ethical approval

The study was conducted according to the guidelines laid down in the Declaration of Helsinki. Ethical approval was obtained from the Clinical Research Ethics Committee of the Cork Teaching Hospitals, University College Cork and the Human Ethics Research Committee of University College Dublin. Written informed consent was obtained from both the parent/guardians and participants prior to participation in the survey.

Research team training

All data collection for the NCFS II (2017-18) was completed by trained researchers from the nutrition units at UCC and UCD. Prior to commencement of the fieldwork phase of the study, each member of the research team was trained in how to follow the Standard Operating Procedures (SOPs) that had been established for each component of the study. Additionally, training was provided to each researcher involving role-play workshops which promoted a natural and friendly approach to interactions with the children taking part in the study and their parents/guardians. The aim of the training provided to the researchers was to ensure that the data collected was as accurate as possible and that participants felt at ease so that they could complete the components of the study to accurately reflect their habitual diet and lifestyle.

Sampling and recruitment methodology

A list of primary schools in Ireland provided by the Department of Education and Skills was used to select schools to participate in the survey. This database contained a total of 3124 schools from which schools were categorised according to:

a) size of the school ('large' >500 pupils, 'medium' 200-499 pupils or 'small' <200 pupils)
b) gender(s) attending the school ('all boys', 'all girls' or 'mixed')
c) whether disadvantaged or not disadvantaged
d) location (urban or rural)

Schools were randomly selected to participate so that so that the final sample of children surveyed was representative of Irish children with respect to the proportion of children attending these categories of schools according to the database.

Eligible participants were schoolchildren aged 5-12 years living in the Republic of Ireland. The sample size of 600 children was based on the previous National Dietary Survey of Irish children, the National Children's Food Survey (NCFS) (2003-04) (www.iuna.net), and also follows the EFSA guidance of a minimum of 160 children per sub-group (EFSA, 2014). This sample size was deemed enough to describe frequency distribution of outcomes and to compare means for subgroups (e.g. based on age, gender etc).

An introductory letter with information about the survey was sent to the principal of schools selected to participate, followed by a phone call from a member of the research team with 80% of schools contacted agreeing to participate. If the principal agreed to the participation of their school, a suitable date and time was arranged for a researcher to visit the school. Upon the researcher school visit, information packs about the survey were provided to the school principal as well as instructions on how to randomly select children from the school role to receive the information packs. Children selected by the school principal from these instructions were given an envelope consisting of an introductory letter, information brochure and a reply slip to be brought home to their parent/guardian. If the parents who received this envelope were interested in their child participating in the survey, they were instructed to fill out the reply slip with their details and return it to the school principal who would pass on the details to the researcher. Those who returned reply slips were contacted by a member of the research team about dates for home visits of a researcher which covered all seasons and included school holidays. The demographic features of the final sample of children surveyed were found to be representative of Irish children with respect to age, gender and geographical location when compared to 2016 census data (Central Statistics Office, 2017). However, the sample contained a higher proportion of children of professional workers and a lower proportion of children of semi-skilled or unskilled workers than the national population therefore all data presented in this thesis were weighted to account for these differences. The overall response rate of the survey was 65%.

Data collection

Overview

Data were collected for the study over a 1-year period (to account for seasonality) and data collection took place between April 2017 and May 2018. A researcher visited each child and their parent/guardian(s) three times over the study period. At the first visit, the study was explained in detail to the parent/guardian(s) and informed consent obtained. A food diary and food scales were provided for the survey period to aid in the collection of a 4-day weighed food diary which included at least one weekend day. The researcher trained the parent/guardian(s) and child (for older children) how to correctly complete the food diary and use the weighing scales to quantify all foods/beverages consumed. A packaging bag was also provided to each family to collect any packaging from the foods and beverages consumed. The second researcher visit occurred 24-36 hours into the recording period and was to ensure that the food diary was completed correctly and to clarify any details regarding specific food descriptors and quantities. The final visit occurred 1 or 2 days after the recording period. At this visit the food diary was reviewed for completeness and collected along with the food scales provided. All retained food/beverage packaging was also checked and collected.

Urinary data

Urine collection

Participants were asked to provide a morning first void urine sample (first urination in morning) from which excretion levels relating to nutrient intake such as sodium and potassium intakes could be measured. For those who agreed to provide a sample (572 children, 95% of total children), a sterile labelled container for obtaining the urine sample (about 30ml) along with detailed instructions for obtaining the sample was left with each participant and their parent/guardian during the first researcher home visit. Each container was labelled with a participant ID number as opposed to any personal information to allow for anonymity of data.

With the aid of a parent/guardian where necessary, a morning first void urine sample was obtained from each child typically on the morning of the second recording day of the survey period. Once obtained, an ice pack was wrapped around the sealed container containing the sample and it was then placed in a seal lock bag. The seal lock bag was then placed in a thermal cooler bag and stored in cool conditions out of sunlight prior to same day collection by the researcher. Once collected, the urine sample was stored appropriately on dry ice by the researcher and transported to UCC or UCD for storage at -80℃.

Urine sample processing and analysis

All urine samples were stored in UCC/UCD in designated storage freezers at -80℃ until processing. Processing took place in biofluid laboratories in UCC/UCD. Samples were thawed and centrifuged and then the appropriate amounts needed for each analysis were aliquoted to sterile tubes using a micropipette. These aliquots were then stored at -20℃ until batch analysis. Urinary creatinine was measured in UCD by a standard spectrophotometric assay using a Randox RX Daytona Clinical Chemistry Analyser, while urinary sodium and potassium were measured by Randox Laboratories using a Randox Rx Daytona with an ion selective electrode. All samples were analysed in duplicate and the average of the two readings calculated. Results for the measured sodium and potassium in mmol/L for each participant were returned from Randox Laboratories via an excel-file and added to the results for measured creatinine (µmol/L). Inter-assay coefficient for sodium was <2.2%, for potassium was <3.8% and for creatinine was <4.3%. Randox quality control urine with assigned values for sodium, potassium and creatinine was used as a quality control method to calibrate the Randox RX Daytonas prior to analysis of the samples. The quality assurance used was Randox International Quality Assessment Scheme.

Dietary data

Food and beverage consumption data

Food and beverage consumption data were collected using a 4-day weighed food diary. Upon the first researcher home visit, a food diary and a digital food scales (Tanita© KD-400, 5000 x 1g) were provided and the researcher trained participants on how to complete the food diary to record all foods, beverages and nutritional supplements consumed during the survey period. Parents/guardians/participants were asked to weigh as many foods and beverages as possible and also to weigh and record any leftovers. For any foods that were not weighed directly a hierarchy as outlined below was used to quantify the amount of food or beverage the child consumed. Participants were instructed to keep any packaging and labelling information of any foods, beverages or nutritional supplements consumed using the packaging bag provided to facilitate the updating of the Irish food composition databases. Recipes of composite dishes were also recorded to facilitate updating the existing recipe databases. Additional information was collected such as brand of food, beverage or nutritional supplement consumed, preparation method, the participant's definition of the eating or drinking occasion (e.g. lunch, snack etc.), time and location the food/beverage was prepared and eaten/drank and with whom the food/beverage was eaten/drank. Each researcher was responsible for ensuring that all details recorded in the food diaries they collected were as accurate as possible.

Quantification

Foods and beverages were quantified using a hierarchal method of quantification established by the IUNA and used for previous surveys (www.iuna.net). The methods used to quantify the foods and beverages consumed during the NCFS II (2017-18) included:

1) Direct weighing – a portable digital weighing scale was given to each parent/guardian and they were asked to weigh any foods/beverages consumed as well as any leftovers. Each parent/guardian received a demonstration as well as detailed instructions on how to use the scales. This method was used to quantify 76% of foods/beverages consumed.

2) Manufacturer's information – each parent/guardian was provided with a bag to keep hold of all packaging of foods, beverages and nutritional supplements consumed so that the information on the packaging could be used to help quantify the amount consumed. This method was used to quantify 11% of foods/beverages (and all nutritional supplements) consumed.

3) Use of a photographic food atlas (Foster and Adamson, 2012) – a photographic atlas consisting of pictures of meals and foods of various portion sizes was used to quantify the amount of 7% of foods/beverages consumed.

4) Food Portion Sizes – A reference book of typical food portion sizes (Food Standards Agency, 2002a) was used to quantify 2% of foods/beverages consumed.

5) IUNA weights – an online database of typical food/beverage portion sizes in Irish population groups that had been ascertained for certain foods/beverages based on past surveys (Lyons et al., 2013) was used to quantify 1% of foods/beverages consumed.

6) Household measures (Harrington et al., 2001) – use of measures such as teaspoon, tablespoon, pint etc to quantify intake; this method was used to quantify 1% of food/beverage intake.

7) Estimated – Some quantities of foods were estimated by the researcher based on their knowledge of the child's average portion size and general eating habits. This method was used to quantify 2% of foods/beverages consumed.

Nutrient composition of foods

The quantified food/beverage consumption data was then coded, with each food, beverage and nutritional supplement consumed being assigned an individual brand code and corresponding food code. The coded data were then entered into Nutritics© software along with all other details of the eating/drinking occasion following established SOPs and protocols. Nutritics© is linked to the nutrient database, the UK Composition of Foods Integrated Dataset (COFID), which is updated with McCance and Widdowson 7th edition (Food Standards Agency, 2015, Food Standards Agency, 2002c). During the survey, modifications were made to the food composition database to reflect any new foods or beverages on the Irish market, recipes of composite dishes, fortified foods or nutritional supplements.

To ensure consistency, each researcher was responsible for the coding and data entry of the data from the food diaries they collected. Additionally, all data entry was rechecked after completion and a certain amount of completed diary entries were rechecked by a different researcher. From the data entered into Nutritics©, a food/beverage consumption database was generated where each individual food, beverage and nutritional supplement as consumed by each child during the 4-day survey period was listed along with the nutrient composition (including sodium and potassium composition), the quantity of each food/beverage/nutritional supplement consumed and all other details of the eating/drinking occasion recorded.

Updating sodium composition values

All packaging collected throughout the survey was photographed to capture information from the ingredient list and nutritional labels. Where packaging was not available in the participant's home, the researchers located the item in the supermarket and photographed it using the same SOP. As the sodium composition of products differs across brands all nutritional labels were checked at brand level for sodium content using the databank of photographs. In cases where sodium composition values in the Nutritics database differed from the information on the packaging collected, the sodium composition value was updated accordingly to ensure the most up to date and accurate sodium composition values were used.

Estimation of dietary sodium and potassium intakes

Mean daily sodium and potassium intakes were determined for each individual. Usual distribution of sodium and potassium intakes were then calculated using the validated National Cancer Institute (NCI)-Method using SAS Enterprise Guide© Version 6.1 (SAS Institute Inc., Cary, NC, USA) (Tooze et al., 2010).

Under-reporting

Sodium and potassium intakes were estimated both including and excluding under-reporters to investigate the effect of under-reporting on intakes. Under-reporting was determined using Goldberg's cut-off2 criterion updated by Black (Black, 2000). This method evaluates the reported energy intake against the presumed energy requirements. Mean energy intake to basal metabolic rate (BMR) ratio was determined for each child and age specific cut offs were calculated based on different categories of physical activity. Age specific physical activity level (PAL) values for low, moderate, active, very active and highly active physical activity levels adopted by the European Food Safety Authority (EFSA) (EFSA, 2013) were applied to the equations to establish misreporting of energy intake for individuals. BMR was predicted for each participant from the Schöfield equations using body weight and height measurements (Schofield et al., 1985). Physical activity was self-reported with the international physical activity questionnaire (CPAQ/YPAQ) (Corder et al., 2009) (19.5% of the total sample were identified as under-reporters).

The National Children's Food Survey (NCFS) (2003-04)

To examine any changes in sodium and potassium intake amongst Irish children over the last 15 years, dietary data from the NCFS (2003-04) were also examined. The NCFS was a cross-sectional study of 594 Irish children aged 5-12 years carried out between 2003 and 2004. Food and beverage intake data were collected from each participant using a 7-day weighed food diary and quantified using a hierarchal method of food quantification established by the IUNA. Sodium and potassium intakes were estimated using WISP©, which contained data from McCance and Widdowson's Composition of Foods 6th (Food Standards Agency, 2002b) and 5th (Holland et al., 1995) editions plus supplemental volumes (Holland et al., 1988, Holland et al., 1989, Holland et al., 1991, Holland et al., 1992, Holland et al., 1996, Holland et al., 1993, Chan et al., 1994, Chan et al., 1995, Chan et al., 1996). Modifications were also made to the database to include any recipes, composite dishes, nutritional supplements or foods common to the Irish market and the database was updated to reflect sodium content in retail products.

Estimates of sodium and potassium intakes from the NCFS (2003-04) have been previously published (Moloney et al., 2006, Hannon, 2006) and the sodium and potassium intakes in the current study were compared to these reported intakes, while appropriate statistical tests were carried out using the datasets of both studies to identify any significant differences in intakes between studies.

Bibliography

Black, A. E. 2000. Critical evaluation of energy intake using the Goldberg cut-off for energy intake:basal metabolic rate. A practical guide to its calculation, use and limitations. *Int J Obes Relat Metab Disord,* 24**,** 1119-30.

Central Statistics Office 2017. Census 2016 Summary Results - Part 1. Dublin: The Stationery Office.

Chan, W., Brown, J. & Buss, D. 1994. Miscellaneous Foods. Fourth Supplement to McCance & Widdowson’s The Composition of Foods, 5th ed. London: HMSO.

Chan, W., Brown, J., Church, S. & Buss, D. 1996. Meat Products and Dishes. Sixth Supplement to McCance & Widdowson’s The Composition of Foods, 5th ed. London: HMSO.

Chan, W., Brown, J., Lee, S. & Buss, D. 1995. Meat, Poultry and Game. Fifth Supplement to McCance & Widdowson’s The Composition of Foods, 5th ed. London: HMSO.

Corder, K., van Sluijs, E. M., Wright, A., Whincup, P., Wareham, N. J. & Ekelund, U. 2009. Is it possible to assess free-living physical activity and energy expenditure in young people by self-report? *Am J Clin Nutr,* 89**,** 862-70.

EFSA 2013. Scientific Opinion on Dietary Reference Values for energy. *DOI: 10.2903/j.efsa.2013.3005 EFSA Journal 2013;11(1):3005*.

EFSA 2014. European Food Safety Authority Guidance on the EU Menu methodology. *EFSA Journal,* .12(12):3944.

Food Standards Agency 2002a. Food Portion Sizes (Maff handbook). Edited by Mills, A., Patel S. & Crawley, H. *TSO; 3rd Revised edition edition (1 Feb. 2002),* 0112429610.

Food Standards Agency 2002b. Food Standards Agency, McCance and Widdowson's The Composition of Foods, Sixth Summary Edition. Cambridge: Royal Society of Chemistry.

Food Standards Agency 2002c. McCance and Widdowson's The Composition of Foods, 6th ed. Cambridge: Royal Society of Chemistry.

Food Standards Agency 2015. McCance and Widdowson's The Composition of Foods, 7th ed. Cambridge: Royal Society of Chemistry.

Foster, E. & Adamson, A. J. 2012. Development and validation of the Young Person's Food Atlas. *Proceedings of the Nutrition Society,* 71**,** E195.

Hannon, E. M. 2006. The National Children's Food Survey: Micronutrient intakes and risk-benefit analysis of micronutrient fortificiation of foods in Irish children. PhD, University College Cork.

Harrington, K. E., Robson, P. J., Kiely, M., Livingstone, M. B., Lambe, J. & Gibney, M. J. 2001. The North/South Ireland Food Consumption Survey: survey design and methodology. *Public Health Nutr,* 4**,** 1037-42.

Holland, B., Brown, J. & Buss, D. 1993. Fish and Fish Products. Third Supplement to McCance & Widdowson’s The Composition of Foods, 5th ed. London: HMSO.

Holland, B., Unwin, I. & Buss, D. 1988. Cereal and Cereal Products. Third Supplement to McCance & Widdowson’s The Composition of Foods, 4th ed. London: HMSO.

Holland, B., Unwin, I. & Buss, D. 1991. Vegetables, Herbs and Spices. Fifth Supplement to McCance & Widdowson's The Composition of Foods, 4 ed. London: HMSO.

Holland, B., Unwin, I. & Buss, D. 1992. Fruits and Nuts. First Supplement to McCance & Widdowson's The Composition of Foods, 5th ed. London: HMSO.

Holland, B., Unwin, I. & DH, B. 1989. Milk Products and Eggs. Fourth Supplement to McCance & Widdowson's The Composition of Foods, 4th ed. London: HMSO.

Holland, B., Welch, A. & Buss, D. 1996. Vegetable Dishes. Second Supplement to McCance and Widdowson's The Composition of Foods, 5th ed. London: HMSO.

Holland, B., Welch, A. A., Unwin, I. D., Buss, D. H., Paul, A. A. & Southgate, D. A. T. 1995. McCance and Widdowson's The Composition of Foods Fifth Edition. Royal Society of Chemistry and Ministry of Agriculture, Fisheries and Food. London: HMSO.

Lyons, J., Walton, J. & Flynn, A. 2013. Development of an online database of typical food portion sizes in Irish population groups. *Journal of nutritional science,* 2**,** e25-e25.

Moloney, R., Hannon, E. & Flynn, A. 2006. Sodiumintakes from food sources in Irish adults aged 18-64 and Irish children aged 5-12 years. *Proceedings of The Nutrition Society*

Schofield, W., Schofield, C. & James, W. 1985. Basal metabolic rate: Review and prediction, together with an annotated bibliography of source material. Human Nutrition. Clinical Nutrition, 39C Suppl 1, 1-96.

Tooze, J. A., Kipnis, V., Buckman, D. W., Carroll, R. J., Freedman, L. S., Guenther, P. M., Krebs-Smith, S. M., Subar, A. F. & Dodd, K. W. 2010. A mixed-effects model approach for estimating the distribution of usual intake of nutrients: the NCI method. *Statistics in medicine,* 29**,** 2857-2868.

Chapter 3

Sodium intake and sources in Irish school-aged children (5-12y) and compliance with recommendations

Introduction

There is a large body of evidence suggesting that dietary intake of sodium (salt) is positively associated with hypertension, a known risk factor for cardiovascular disease (CVD). Although hypertension related diseases may not occur until adulthood, blood pressure as a child is strongly associated with blood pressure as an adult meaning that children with higher blood pressure are more likely to encounter hypertension in later life (Chen and Wang, 2008). The European Food Safety Authority (EFSA) has set Adequate Intakes (AI) for sodium of 1.3g/d, 1.7g/d and 2.0g/d for those aged 4-6 years, 7-10 years and 11-17 years respectively, with these values extrapolated from AI for adults which was set based on evidence that intakes of these levels may provide a reduced risk of CVD while also being sufficient to maintain sodium balance in the body (EFSA, 2019). While meeting the AI for sodium is considered beneficial for health, the Food Safety Authority of Ireland (FSAI) has set target maximum population salt intakes for children in Ireland of 3g/d for 4-6 year olds, 5g/d for 7-10 year olds and 6g/d for 11-14 year olds, derived from the sodium Reference Nutrient Intakes (RNIs) for children (FSAI, 2016a, SACN, 2003). Despite the effect of sodium on blood pressure being well established, sodium intakes exceeding targets are common in childhood and tend to increase with age in many cases (Brown et al., 2009). Evidence suggests that modest reductions in sodium intakes during childhood could help to reduce the rate at which blood pressure increases with age and may prevent hypertension related diseases in later life (Brown et al., 2009).

The gold standard method of estimating an individual's daily sodium intake is by collecting multiple 24-hour urine collections to measure excretion of sodium (Iwahori et al., 2017a). However, collecting 24-hour urine samples can be costly and time consuming, while the demands placed on participants may also jeopardise compliance, therefore collecting 24-hour urine samples is not always practical for large studies (Mente et al., 2014). Research has shown that spot urine samples (which are more feasible to collect) can be used to estimate average 24-hour sodium intakes at a population level (but not at an individual level) by using appropriate adjustment equations or by correcting for gender and age-specific population urine output volume estimations (Mente et al., 2014, Rios-Leyvraz et al., 2018, Huang et al., 2018). The UK National Diet and Nutrition Survey (NDNS) (2008-2012) (Bates et al., 2014) is the only nationally representative dietary survey in Europe to use 24-hour urines to estimate sodium intakes in children and found all age groups of boys and girls exceeded target salt intakes for children in the UK (SACN, 2003). Cross-sectional studies in Italy, Portugal, Australia, New Zealand and Japan which estimated sodium intakes in children from 24-hour urine collections have also shown sodium intakes exceeding recommendations to be common (Campanozzi et al., 2015, Oliveira et al., 2015, Grimes et al., 2017, Eyles et al., 2018, Seko et al., 2018).

While dietary intake data cannot account for discretionary salt added at the table or in cooking, it can be used to estimate sodium intakes from food sources and to determine the foods contributing to sodium intakes and is commonly collected either to complement or in the absence of urinary data. Furthermore, dietary data aids in identifying foods/food groups where reformulation or changes in consumption levels may aid in lowering population sodium intakes.

Detailed dietary data collected as part of a previous national dietary survey of Irish children, the National Children's Food Survey (NCFS) (2003-04), found that sodium intakes were generally approaching or exceeding recommendations, while the main sources of sodium were 'meat & meat products' (24%) and 'bread & rolls' (21%). These findings were consistent with other studies which looked at sources of sodium intakes in children with cereal & cereal products, meat & meat products and dairy products commonly found as main contributors across studies (RIVM, 2012b, Bates et al., 2014, Grimes et al., 2017, Eyles et al., 2018).

The National Children's Food Survey II (NCFS II) (2017-18) collected updated dietary data in addition to spot urine samples in a nationally representative sample of Irish children aged 5-12 years. The aim of this study was to utilize the spot urines collected to estimate the mean sodium intakes of Irish children and to determine the main foods contributing to sodium intakes from the dietary data collected. An additional aim was to examine any changes in sodium intakes and sources since NCFS (2003-04) by comparing the dietary data between studies.

Methodology

Overview of study

Analyses for this study are based on data from the NCFS II, which was a nationally representative cross-sectional study that collected food and beverage consumption data in 600 Irish children aged 5-12 years in the Republic of Ireland between 2017 and 2018. A trained researcher visited each child and their parent/guardian(s) three times over the study period to enable the collection of a detailed 4-day weighed food diary from each participant and a morning first void spot urine sample from those willing. A detailed outline of the methodology of the study including the ethical approval and the sampling and recruitment procedure is discussed in chapter 2, while the methods relevant to this chapter are described below.

Urinary data

Urine collection, processing and analysis

Out of the total survey sample of 600 children, 95% (n=572) provided morning first void spot urine samples. The samples were obtained using a sterile container which was then stored appropriately prior to same day collection by the researcher and transport to UCC/UCD for storage at -80°C. Samples were stored until batch processing, where they were thawed, centrifuged and then the appropriate amounts needed for analysis were aliquoted to sterile tubes using a micropipette. These aliquots were then stored at -20°C until batch analysis. Aliquots were sent to Randox Laboratories where sodium and potassium concentration were measured using a Randox RX Daytona with an ion selective electrode, while creatinine concentration was measured in UCD by a standard spectrophotometric assay using a Randox RX Daytona Clinical Chemistry Analyser. Inter-assay coefficient for sodium was <2.2%, for potassium was <3.8% and for creatinine was <4.3%. All samples were analysed in duplicate and the average of the two readings calculated.

Estimating sodium intakes in Irish children from urinary outputs

Mean daily sodium intakes were estimated by predicting 24-hour sodium excretion from the spot urines collected using two methods;

1) Firstly, gender-specific predictive equations as shown below were used to estimate 24-hour sodium excretion. While these equations do not use a correction factor to adjust for the timing of the spot urines collected, they are considered the most accurate equations available to predict 24-hour sodium excretion from morning first void urine samples in children (Rios-Leyvraz et al., 2018). The equations were developed using data from over 5000 adults in North American and European populations participating in the INTERSALT study (Brown et al., 2013) and predict 24-hour sodium excretion based on the concentration of sodium relative to creatinine and potassium in spot urine, while also adjusting for age, gender, weight and height (Brown et al., 2013).

Male: Est24hNa = 23 × (25.46 + 0.46 × SpotNa – 2.75 × SpotCre – 0.13 × SpotK + 4.10 × BMI + 0.26 × age)

Female: Est24hNa = 23 × (5.07 + 0.34 × SpotNa – 2.16 × SpotCre – 0.09 × SpotK + 2.39 × BMI + 2.35 × age – 0.03 × age^2)

- Est24hNa = Estimated 24-hour sodium (mg/d)
- SpotNa = Sodium in spot urine (mmol/l)
- SpotCre = Creatinine in spot urine (mmol/l)
- SpotK = Potassium in spot urine (mmol/l)
- BMI = Body Mass Index (kg/m^2)
- Age (years)

2) The second method used to estimate 24-hour population sodium excretion was by correcting the population mean sodium values from the spot urines for gender and age specific 24-hour urine output volumes as shown below. In the absence of population urine output volume estimations for Irish children, volumes derived from a study on Australian children by *Grimes et al* were used which collected 24-

hour urine samples in a large sample of children of a similar age range to the current study (Grimes et al., 2017).

Est24hNa = 23 x (Population mean SpotNa x Gender and age specific urine output volume)

- Est24hNa = Estimated 24-hour sodium (mg/d)
- SpotNa = Sodium in spot urine (mmol/l)
- Urine output volume (L/day)

Conversion to salt intakes

The estimated sodium intakes from both methods used were converted to salt intakes as shown below

Estimated salt intakes (g/d) = [Estimated sodium intake (mg/d) x 2.5] /1000

Compliance with dietary guidelines

The mean daily sodium and salt intakes estimated from both urinary methods were reported for all children and split by gender and age group and were compared to the EFSA Adequate Intakes for sodium of 1.3g/d for 4-6 year olds, 1.7g/d for 7-10 year olds and 2.0g/d for 11-17 year olds (EFSA, 2016) and to the FSAI maximum target population salt intakes of 3g/d for 5-6 year olds, 5g/d for 7-10 year olds and 6g/d for 11-12 year olds (FSAI, 2016a).

Dietary Data

Food consumption data collection

Dietary intake data were collected using a 4-day weighed food diary, in which all foods, beverages and nutritional supplements consumed during the survey period were recorded. All foods and beverages consumed were quantified using a hierarchal method of food quantification established by the IUNA and used for previous surveys (www.iuna.net). The methods used to quantify the foods and beverages consumed included direct weighing (76%), use of manufacturer's information (11%), use of a photographic atlas (Foster and Adamson, 2012) (7%), use of average portion sizes ascertained for foods based on past surveys (2%), estimated by the researcher based on their knowledge of the child's average portion size (2%), use of household measures (Harrington et al., 2001) (1%) and use of an online database of typical food portion sizes in the Irish population (Lyons et al., 2013) (1%). The quantified food consumption data was then coded and entered into *Nutritics*, an electronic software database linked to the nutrient database, The UK Composition of Foods Integrated Dataset (COFIDS), including McCance and Widdowson 7th edition and 6th edition (for a small number of foods) (Food Standards Agency, 2015, Food Standards Agency, 2002). An updated database of Irish Food Composition with any new foods, recipes or nutritional supplements consumed during the survey and their related composition was added to the *Nutritics* database. These data were used to generate a list of each individual food item as consumed by each child along with the quantity consumed and the nutrient composition of the food. The sodium composition values of each food and beverage consumed were checked and updated where appropriate using packaging labels provided by participants.

Estimation of usual intakes

Usual distribution of sodium intake from food sources was calculated from the dietary data collected using the validated National Cancer Institute (NCI)-Method using SAS Enterprise Guide© Version 6.1 (SAS Institute Inc., Cary, NC, USA) (Tooze et al., 2010). Mean dietary sodium intakes (mg/d and mg/10MJ) and salt intakes (g/d) were reported for all children and by gender and age group.

Sources of sodium intake

The percent contribution of each food group to mean daily intake of sodium was calculated by the mean proportion method (Krebs-Smith et al., 1989) and the key contributors were reported in order of importance for the total population. The mean proportion method provides information about the sources that are contributing to the nutrient intake 'per person' and is the preferred method when determining important food sources of a nutrient for individuals in the population group as opposed to investigating the sources of a nutrient within the food supply.

Statistical Analysis

SPSS© for Windows™ version 25 was used for all statistical analysis. Differences in sodium intakes between boys and girls and between the NCFS (2003-04) and the NCFS II (2017-18) were assessed using independent sample t-tests, while differences between age groups were assessed using a one-way analysis of variance (ANOVA) tests. All statistical tests were carried out regardless of normality (due to the large sample size). As sample size increases so does the robustness of t-tests to identify deviations from normality, thus parametric tests are recommended for large samples (Fagerland, 2012). To minimise type 1 errors (as a result of multiple testing), the Bonferoni adjustment was used by dividing the alpha level (0.05) by the number of comparisons. Therefore, intakes were considered significantly different from each other if $P < 0.01$. Also due to the large sample in this study even a small difference between group means was highly statistically significant. Thus, greater emphasis was placed on a descriptive, rather than a formal statistical analysis of the data.

Results

Urinary data

Predictive equation method

Based on the use of predictive equations to predict sodium intakes (Brown et al., 2013), the mean daily sodium intake of 5-12 year olds was estimated to be 2229mg/d, equivalent to a salt intake of 5.6g/d **(Table 1)**. The mean daily sodium intakes of boys and girls aged 5-12 years were 2661mg/d and 1777mg/d respectively, equivalent to mean salt intakes of 6.7g/d in boys and 4.4g/d in girls **(Table 2)**. When split by age group, mean daily salt intakes were 5.2g/d for 5-6 year olds, 5.6g/d for 7-10 year olds and 5.8g/d for 11-12 year olds **(Table 1)**. When split by gender and age group, mean daily sodium intakes for boys were 2559mg/d for 5-6 year olds, 2706mg/d for 7-10 year olds and 2659mg/d for 11-12 year olds, equivalent to salt intakes of 6.4g/d, 6.8g/d and 6.6g/d respectively **(Table 2)**. Mean daily sodium intakes for girls were 1599mg/d for 5-6 year olds, 1780mg/d for 7-10 year olds and 1950mg/d for 11-12 year olds, equivalent to salt intakes of 4.0g/d, 4.4g/d and 4.9g/d respectively **(Table 2)**. The mean daily sodium intake of all age groups of boys and girls examined were above the EFSA AI except for girls aged 11-12 years. Mean daily salt intakes exceeded the FSAI maximum target salt intakes for all age groups of boys and girls examined except for girls aged 7-10 years and 11-12 years who had mean salt intakes of 4.4g/d and 4.9g/d respectively, which are lower than the respective target maximum population intakes of 5g/d and 6g/d for children of those age groups.

Urine output volume method

When sodium intakes were estimated by correcting the spot urines for 24-hour urine output volumes, the mean daily sodium intake of 5-12 year olds was estimated to be 2092mg/d, equivalent to a salt intake of 5.2g/d **(Table 1)**. The mean daily sodium intakes of boys and girls aged 5-12 years were 2108mg/d and 2062mg/d respectively, equivalent to mean salt intakes of 5.3g/d in boys and 5.2g/d in girls **(Table 2)**. When split by age group, mean daily salt intakes were 4.3g/d for 5-6 year olds, 5.3g/d for 7-10 year olds and 5.6g/d for 11-12 year olds **(Table1)**. When split by gender and age group, mean daily sodium intakes for boys were 1762mg/d in 5-6 year olds, 2156mg/d in 7-10 year olds and 2195mg/d in 11-12 year olds, equivalent to salt excretions of 4.4g/d, 5.4g/d and 5.5g/d respectively **(Table 2)**. Mean daily sodium intakes for girls of the same respective age groups were 1713mg/d, 2077mg/d and 2238mg/d, equivalent to salt excretions of 4.3g/d, 5.2g/d and 5.6g/d respectively **(Table 2)**. Mean daily sodium intakes from this method were above the EFSA AIs for all age groups of boys and girls examined. Mean daily salt intakes exceeded the FSAI targets for all age groups examined except for boys and girls aged 11-12 years.

Dietary data

The mean daily intakes of sodium (from food sources only, excluding discretionary salt) of 5-12 year olds was 1657mg/d, equivalent to a salt intake of 4.1g/d **(Table 3)**. Average sodium intake was 1787mg/d in boys and 1537mg/d in girls, equivalent to salt intakes of 4.5g/d and 3.8g/d respectively **(Table 4)**. When split by age group, mean sodium intakes were 1527mg/d for 5-6 year olds, 1662mg/d for 7-10 year olds and 1799mg/d for 11-12 year olds, equivalent to mean salt intakes of 3.8g/d, 4.2g/d and 4.5g/d respectively **(Table 3)**. Mean sodium intakes for boys were 1621mg/d for 5-6 year olds, 1795mg/d for 7-10 year olds and 1971mg/d for 11-12 year olds, equivalent to salt intakes of 4.1g/d, 4.5/d and 4.9g/d respectively **(Table 4)**. Mean sodium intakes for girls were 1436mg/d for 5-6 year olds, 1541mg/d for 7-10 year olds and 1642mg/d for 11-12 year olds, equivalent to salt intakes of 3.6g/d, 3.9g/d and 4.1g/d respectively **(Table 4)**.

The mean daily sodium intake of boys was significantly higher than that of girls (1787mg/d vs 1537mg/d). When adjusted for energy, boys also had a significantly higher mean sodium intake than girls (2702mg/10MJ vs 2620mg/10MJ), indicating that the higher sodium intakes in boys is due to them consuming more sodium and not just due to an overall greater energy intake (**Table 4**). When adjusted for energy, those aged 7-10 years had a higher mean sodium intake than those aged 5-6 years (2659mg/10MJ vs 2638mg/10MJ), while those aged 11-12 years had a higher mean sodium intakes than those aged 7-10 years (2684mg/10MJ vs 2659mg/10MJ), indicating that the higher sodium intakes seen in older children was due to a greater sodium consumption and not just due to an overall greater energy intake **(Table 3)**.

When under-reporters were excluded from analyses, mean sodium intake was 1707mg/d, equivalent to a salt intake of 4.3g/d (data not shown) which was similar to the intake in the total population (including under-reporters) indicating that under-reporters did not influence estimates of sodium intake.

The main sources of sodium intake in Irish children aged 5-12 years were 'meat & meat products' (24%) ('processed meats' 16%; 'meat dishes' 6%) and 'bread & rolls' (22%) ('white sliced bread & rolls' 14%; 'wholemeal & brown bread & rolls' 6.5%). Other key sources of sodium intake in Irish children were 'grains, rice, pasta and savouries' (7.4%), 'milk & yogurt' (6.7%) and 'biscuits, cakes & pastries' (5.8%) **(Table 5)**.

Changes since NCFS (2003-04)

In the current study, sodium/salt intakes were lower across all age groups of boys and girls compared to mean intakes from NCFS (2003-04) **(Tables 6)**. However, the main sources of sodium were similar across the two surveys with the main sources of sodium in NCFS (2003-04) also being 'meat & meat products' (24%) ('processed meats' 18%; 'meat dishes' 5.4%), and 'breads and rolls'(21%). While 'breakfast cereals' were noted a source of sodium in NCFS (2003-04), they were not found to be a key source of sodium intake in NCFS II (2017-18) mainly due to reformulation of such products (as noted from product labels) **(Table 7)**.

Table 1. Mean 24-hour urinary excretion of sodium and salt equivalents in Irish school-aged children (n=572) by age group using 2 methods

	Mean ± SD			
	Age group (years)			
	All (5-12y) (n=572)	**5-6y (n=144)**	**7-10y (n=285)**	**11-12y (n=143)**
Predictive equation method*				
Sodium (mg/d)	2229 ± 641	2078 ± 636	2248 ± 662	2332 ± 575
Salt (g/d)	5.6 ± 1.6	5.2 ± 1.6	5.6 ± 1.7	5.8 ± 1.4
Urine output volume method†				
Sodium (mg/d)	2092	1737	2121	2221
Salt (g/d)	5.2	4.3	5.3	5.6

*Gender specific equations by Brown et al used for predictive equation method (Brown et al., 2013).
†Urine output method using gender and age specific urine output volumes for Australian children derived from a study by Grimes *et al.* (Grimes et al., 2017).

·SDs not included in urine output volume method intakes as mean intakes were adjusted at population level

Table 2. Mean 24-hour urinary excretion of sodium and salt equivalents by method, split by gender and age group

	Boys Mean ± SD				**Girls** Mean ± SD			
Age group (years)	**All (5-12y) (n=287)**	**5-6y (n=71)**	**7-10y (n=143)**	**11-12y (n=73)**	**All (5-12y) (n=285)**	**5-6y (n=73)**	**7-10y (n=142)**	**11-12y (n=70)**
Predictive equation method*								
Sodium (mg/d)	2661 ± 504	2559 ± 499	2706 ± 544	2659 ± 412	1777 ± 418	1599 ± 311	1780 ± 389	1950 ± 499
Salt (g/d)	6.7 ± 1.3	6.4 ± 1.2	6.8 ± 1.4	6.6 ± 1.0	4.4 ± 1.0	4.0 ± 0.8	4.4 ± 1.0	4.9 ± 1.2
Urine output volume method†								
Sodium (mg/d)	2108	1762	2156	2195	2062	1713	2077	2238
Salt (g/d)	5.3	4.4	5.4	5.5	5.2	4.3	5.2	5.6

*Gender specific equations by Brown et al used for predictive equation method (Brown et al., 2013).

†Urine output method using gender and age specific urine output volumes for Australian children derived from a study by Grimes *et al.* (Grimes et al., 2017).

·SDs not included in urine output volume method intakes as mean intakes were adjusted at population level

Table 3. Mean dietary intakes of sodium, salt and sodium per 10MJ in Irish school-aged children (600) by age group

	Mean ± SD			
	Age group (years)			
	All (5-12y) (n=600)	**5-6y (n=151)**	**7-10y (n=299)**	**11-12y (n=150)**
Sodium (mg/d)	1657 ± 365	1527 ± 310[a]	1662 ± 368[b]	1799 ± 366[c]
Salt (g/d)	4.1 ± 0.9	3.8 ± 0.8[a]	4.2 ± 0.9[b]	4.5 ± 0.9[c]
Sodium (mg/10MJ)	2659 ± 349	2638 ± 347[a]	2659 ± 351[b]	2684 ± 346[c]

Significant (P<0.01) differences between age groups denoted by different superscript lowercase letters

Table 4. Mean dietary intakes of sodium, salt and sodium per 10MJ of energy in Irish children by gender and age group (n=600)

	Mean ± SD				Mean ± SD			
	Boys				**Girls**			
Age group (years)	**All (5-12y) (n=300)**	**5-6y (n=75)**	**7-10y (n=149)**	**11-12y (n=76)**	**All (5-12y) (n=300)**	**5-6y (n=76)**	**7-10y (n=150)**	**11-12y (n=74)**
Sodium (mg/d)	1787 ± 374	1621 ± 307	1795 ± 377	1971 ± 349	1537 ± 313*	1436 ± 285	1541 ± 314	1642 ± 305
Salt (g/d)	4.5 ± 0.9	4.1 ± 0.8	4.5 ± 0.9	4.9 ± 0.9	3.8 ± 0.8*	3.6 ± .07	3.9 ± 0.8	4.1 ± 0.8
Sodium (mg/10mj)	2702 ± 352	2679 ± 347	2701 ± 355	2729 ± 349	2620 ± 342*	2598 ± 342	2621 ± 343	2642 ± 338

* Denotes statistically significant difference (P<0.01) from that of boys within the rows via independent samples t-test adjusted for multiple testing

Table 5. Mean daily intake and % contribution of sodium intake by food group in total population (n=600)

Food Groups	Mean Daily Intake (mg/d)	% Contribution
Meat & meat products	415	23.8
Processed meats	*278*	*15.5*
Meat dishes	*100*	*6.0*
Fresh meat	*36.9*	*2.2*
Bread & rolls	373	22.0
White sliced bread & rolls	*233*	*13.6*
Wholemeal & brown bread & rolls	*108*	*6.5*
Other breads	31.5	1.8
Grains, rice, pasta and savouries.	125	7.1
Savouries e.g pizza	*119*	*6.8*
Rice & pasta, flours. grains & starch	*5.94*	*0.3*
Milk & yogurt	107	6.7
Whole milk	*54.9*	*3.5*
Low fat, skimmed & fortified milks	*22.2*	*1.3*
Other	*29.9*	*1.9*
Biscuits, cakes & pastries	94.4	5.8
Biscuits including crackers	*50.5*	*3.2*
Cakes, pastries & buns	*43.9*	*2.6*
Sugars, confectionary, preserves & savoury snacks	95.8	5.5
Savoury snacks	*75.0*	*4.2*
Other	*20.8*	*1.3*
Soups, sauces & miscellaneous foods	94.3	5.4
Breakfast cereals	82.5	5.3
Ready to eat breakfast cereals	*73.4*	*4.7*
Other breakfast cereals	9.02	0.6
Cheese	77.6	4.5
Butter, spreading fats & oils	44.4	2.7
Vegetables & vegetable dishes	35.0	2.1
Potatoes & potato products	33.4	2.0
Fish & fish dishes	35.1	2.0
Eggs & egg dishes	31.4	1.8
Creams, ice-creams & chilled desserts	24.0	1.5
Beverages	25.1	1.5
Fruit & fruit juices	5.71	0.4
Nuts, seeds, herbs & spices	1.99	0.1
Nutritional supplements	0.04	0.0
Total	1701	100

Table 6. Mean dietary intakes of sodium and salt in Irish children in NCFS (2003-04) and NCFSII (2017-18) by gender

	NCFS (2003-04) Mean±SD			**NCFSII (2017-18)** Mean±SD		
	Total (n=594)	Boys (n=293)	Girls (n=301)	Total (n=600)	Boys (n=300)	Girls (n=300)
Sodium (mg/d)	2081 ± 506	2182 ± 522	1982 ± 472	1657 ± 365*	1787 ± 374*	1537 ± 313*
Salt (g/d)	5.2 ± 1.3	5.5 ± 1.3	5.0 ± 1.2	4.1 ± 0.9*	4.5 ± 0.9*	3.8 ± 0.8*

* Denotes statistically significant difference (P<0.01) from that of NCFS (2003-04) within the rows via independent samples t-test adjusted for multiple testing

Table 7. Mean daily sodium intake and main foods contributing to sodium intake by food group in Irish school-aged children in NCFS (2003-04) (n=594) and NCFSII (2017-18) (n=600)

	NCFSII (2017-18)		**NCFS (2003-04)**	
Food group	**Mean daily intake (mg/d)**	**% contribution**	**Mean daily intake (mg/d)**	**% contribution**
Meat & meat products	415	23.8	512	24.1
Processed meats	*278*	*15.5*	*382*	*17.9*
Meat dishes	*100*	*6.0*	*110*	*5.3*
Fresh meat	*36.9*	*2.2*	*17*	*0.8*
Bread & rolls	373	22.0	438	21.0
White sliced bread & rolls	*233*	*13.6*	*329*	*15.8*
Wholemeal & brown bread & rolls	*108*	*6.5*	*68.0*	*3.2*
Other breads	*31.5*	*1.8*	*41.0*	*2.0*
Grains, rice, pasta and savouries.	125	7.1	123	5.8
Milk & yogurt	107	6.7	139	6.9
Biscuits, cakes & pastries	94.4	5.8	81.3	4.2
Sugars, confectionary, preserves & savoury snacks	95.8	5.5	117	6.0
Soups, sauces & miscellaneous foods	94.3	5.4	128	6.0
Breakfast cereals	82.5	5.3	173	8.4
Other foods	314	18.5	369	17.7
Total	1701	100	2081	100

Discussion

The aim of this study was to estimate the sodium intakes of Irish children based on urinary excretion of sodium from morning spot urine samples and to determine the main foods contributing to these sodium intakes. An additional aim was to compare sodium intakes and sources between NCFS (2003-04) and the current study. The main findings were that mean population sodium intakes of Irish children were generally exceeding target intakes, while the main foods contributing to sodium intakes were processed meats and breads. The mean salt intakes of Irish children were lower by approximately 1g/d when compared to data from NCFS (2003-04), while for the most part similar foods contributed to sodium intake across studies.

Sodium intakes

There is no optimal method for estimating sodium intakes from spot urine in children, therefore two methods were used to predict population sodium intakes from the spot urine samples collected in the current study. Firstly, predictive equations developed by *Brown et al* were used to estimate sodium intakes as they were deemed the most accurate equations available to estimate population 24-hour sodium intakes from morning first void spot urine samples in children based on a study by *Rios-Leyvraz et al* (Rios-Leyvraz et al., 2018, Brown et al., 2013). The second method used to estimate 24-hour sodium intakes from spot urine was by correcting the sodium excretion values from spot urine for gender and age-specific urine output volumes for Australian children based on a study by *Grimes et al* (Grimes et al., 2017). Although this method is not widely used and may be prone to some random error, it has been shown to be useful at population level to provide estimates of sodium intake. A study in China of over 3000 adults found that when compared to 24-hour urinary data, the use of this method estimated sodium intakes more accurately than the use of predictive equations (Huang et al., 2018).

The estimated mean daily sodium intakes in the current study varied depending on the method used, with those estimated from the predictive equation method generally higher than those estimated from the urine output volume method. While it is possible that the development of predictive equations designed for children or the application of a timing factor based on the time of spot urine collected may enable more accurate predictions of 24-hour sodium excretion from spot urine, the estimated intakes from both methods used in the current study appear relatively feasible in relation to those seen in other studies (Grimes et al., 2017, Bates et al., 2014). Regardless of the method used to estimate sodium intakes, the FSAI target salt intakes were generally exceeded by all age groups of boys and girls; therefore, strategies to reduce population sodium intakes appear warranted. In cases where estimated mean salt intakes met the target intakes, it was generally the older children in the survey aged 11-12 years who have the same target salt intake as adults of 6g/d; therefore, the salt intakes of children in this age group should still be seen as an issue despite meeting target intakes as evidence suggests that their salt intakes will increase as they get older due to an increase in overall calorie consumption (Brown et al., 2009). Additionally, any potential limitations in the methods used to estimate sodium intakes in the current study should not result in intakes being seen as unproblematic. Potentially paradoxical findings are common in studies estimating sodium intakes due to varying methodologies (Cogswell et al., 2016); therefore, potential limitations such as using morning first void urine samples which tend to overestimate sodium intakes (Iwahori et al., 2017c) should not lessen the importance of strategies to reduce population sodium intakes.

In the current study mean daily salt intakes based on the use of predictive equations were 5.2g/d for 5-6 year olds, 5.6g/d for 7-10 year olds and 5.8g/d for 11-12 year olds, while estimated salt intakes using urine output volumes were 4.3g/d, 5.3g/d and 5.6g/d for children of the same respective age groups. These estimated mean salt intakes were generally above target intakes. The National Diet and Nutrition Survey (NDNS) (2008-2012) in the UK is the only study in Europe which estimated sodium intakes from 24-hour urine collections in a nationally representative sample of children. Based on mean 24-hour urinary sodium excretions, average daily salt intakes in the UK were 3.8 g/d for 4-6 year olds, 5.2g/d for 7-10 year olds and 6.8g/d for 11-18 year olds (Bates et al., 2014). These estimated mean salt intakes for children in the UK also generally exceeded target intakes (SACN, 2003). The 7-10 year old age group directly overlaps between both studies in which the mean daily salt intake of children in the UK appears relatively similar to the estimated mean intake of Irish children using the urine output volume method (5.3g/d vs 5.2g/d) but lower than the estimated mean intake of Irish children using the predictive equation method in the current study (5.3g/d vs 5.6g/d).

Sodium intakes from food sources

'Meat & meat products' (particularly processed meats) and 'bread & rolls' (particularly white sliced bread) were the main contributors to sodium intake, collectively accounting for almost half (46%) of total sodium consumption from food sources amongst Irish children. By comparing the sodium intakes from the dietary data to the urinary data in the current study, it can be crudely estimated that discretionary salt may account for approximately 17-24% of total sodium intake. Strategies to reduce the contribution of these food groups (particularly processed meats and breads) and discretionary salt to sodium intakes should be considered to lower population sodium intakes.

The mean daily sodium intakes of Irish children estimated from food sources in the current study appear to be lower in many cases when compared to dietary data available from other studies (Tornaritis et al., 2014, Meneton et al., 2009, RIVM, 2012a, Turkey Dietary Guidelines, 2016, Turkey Nutrition and Health Survey, 2010), although it must be noted that the methodologies used and age groups examined across the studies reviewed varied meaning that the estimated intakes from one study to another should be compared with caution. Additionally, the main contributors to sodium intakes in the current study were generally similar to those found in the studies reviewed which looked at the sources of sodium intakes in children (RIVM, 2012b, Bates et al., 2014, Grimes et al., 2017).

Comparison with the NCFS (2003-04)

Mean dietary sodium intakes in the current study were lower when compared to the mean intakes from the NCFS (2003-04), with decreases in mean daily salt intakes ranging from 1.0-1.2g/d across subgroups of age and gender. The key sources of sodium were similar in both the NCFS (2003-04) and the NCFS II (2017-18), with 'meat and meat products' and 'bread & rolls' the top two main contributors to sodium intakes in both studies accounting for a combined 45-46% of sodium intake across studies.

Current sodium reduction initiatives

Efforts to reduce sodium intake at an individual level in an attempt to lower blood pressure have been shown to be difficult and often ineffective (Okuda et al., 2014), which makes reformulation to reduce the sodium content of food products necessary in order to lower population sodium intakes to meet recommendations. In Ireland, the FSAI salt reduction programme began in 2003 with an aim of achieving voluntary, gradual and sustained reductions in the salt content of processed foods and as recorded in 2015, there has been significant reductions in the salt content of most foods sold in Ireland since the inception of the programme, such as breads (17-42%), processed meats (11-27%) and breakfast cereals (38-63%) (FSAI, 2016b).

The reduction in sodium intakes found in the current study compared to the previous is likely as a direct result of the FSAI salt reduction programme suggesting that reformulation has had the desired effect of lowering population sodium intakes. While the reduction in sodium intakes since the previous study may serve as an example as to how reformulation can be effective in reducing population sodium intakes, further sustained reduction across all categories of foods is needed if target population salt intakes are to be achieved. Processed meats and breads are widely consumed in the diets of all population groups in Ireland (IUNA, 2011, IUNA, 2005); therefore, the consumption levels of these foods are unlikely to change significantly under current dietary practices. Considering the proportion of sodium intake attributable to these foods, achieving even slight reductions in the sodium contents of these foods would assist towards lowering population salt intakes to meet targets (FSAI, 2016a).

While sodium has long been positively associated with hypertension, some studies have reported a j-shaped relationship between sodium intake and diseases rate (O'Donnell et al., 2014, Kalogeropoulos et al., 2015). However, the Trials of Hypertension Study (TOHP) measured sodium intakes in adults from multiple 24-

hour urine collections and based on 23-26 years of post-trial follow-up found there to be a direct linear relationship between sodium intake and mortality occurrence (Cook et al., 2016). Measurement bias or reverse causation may explain the j-shaped relationship found in studies (Cook et al., 2016, Cobb et al., 2014), therefore potential adverse health effects due to low sodium intakes at a population level appear unlikely and should not stall efforts to reduce population sodium intakes.

Strengths & limitations

The main strengths of this study are that it collected both urinary and detailed dietary data in a nationally representative sample of Irish children. The modifications made to the database to ensure that the most up to date sodium composition values were used for each food code meant that dietary sodium intakes and sources of sodium were estimated as accurately as possible. A limitation of the study is that it did not collect 24-hour urines and therefore the gold standard method of estimating sodium intakes was not applied making it difficult to draw strong conclusions from the estimated intakes, however it is still one of few national dietary surveys to collect urinary data in children which is advantageous for estimating sodium intakes compared to dietary data which doesn't account for discretionary salt.

Conclusion

In conclusion, regardless of the method used to estimate daily sodium intakes, mean sodium intakes of Irish children were generally exceeding recommendations, with the main sources of sodium being processed meats and breads. Although the mean salt intakes of Irish children were lower by approximately 1g/d in comparison to the NCFS (2003-04), continued reformulation to reduce the sodium content of all categories of foods, particularly those which made significant contributions to sodium intakes, is warranted to aid in lowering the salt intakes of Irish children to meet recommendations. Such reformulation may put less children would at risk of developing elevated blood pressure and hypertension and indirectly lower the proportion affected by hypertension related diseases in later life. Additionally, development of predictive equations designed for children to predict 24-hour sodium excretion from spot urine would aid in obtaining more accurate intake estimations.

Bibliography

Bates, B., Lennox, A., Prentice, A., Bates, C., Page, P., Nicholson, S. & Swan, G. 2014. National Diet and Nutrition Survey. Results from Years 1,2,3 and 4 (combined) of the Rolling Programme (2008/2009-2011/2012) *In:* Public Health England, W. H., 133-155 Waterloo Road, London SE1 8UG (ed.).

Brown, I. J., Dyer, A. R., Chan, Q., Cogswell, M. E., Ueshima, H., Stamler, J., Elliott, P. & Group, I. C.-O. R. 2013. Estimating 24-hour urinary sodium excretion from casual urinary sodium concentrations in Western populations: the INTERSALT study. *American journal of epidemiology,* 177**,** 1180-1192.

Brown, I. J., Tzoulaki, I., Candeias, V. & Elliott, P. 2009. Salt intakes around the world: implications for public health. *International Journal of Epidemiology,* 38**,** 791-813.

Campanozzi, A., Avallone, S., Barbato, A., Iacone, R., Russo, O., De Filippo, G., D'Angelo, G., Pensabene, L., Malamisura, B., Cecere, G., Micillo, M., Francavilla, R., Tetro, A., Lombardi, G., Tonelli, L., Castellucci, G., Ferraro, L., Di Biase, R., Lezo, A., Salvatore, S., Paoletti, S., Siani, A., Galeone, D., Strazzullo, P. & Group, M.-G. P. S. 2015. High sodium and low potassium intake among Italian children: relationship with age, body mass and blood pressure. *PloS one,* 10**,** e0121183-e0121183.

Chen, X. & Wang, Y. 2008. Tracking of blood pressure from childhood to adulthood: a systematic review and meta-regression analysis. *Circulation,* 117**,** 3171-3180.

Cobb, L. K., Anderson, C. A., Elliott, P., Hu, F. B., Liu, K., Neaton, J. D., Whelton, P. K., Woodward, M. & Appel, L. J. 2014. Methodological issues in cohort studies that relate sodium intake to cardiovascular disease outcomes: a science advisory from the American Heart Association. *Circulation,* 129**,** 1173-86.

Cogswell, M. E., Mugavero, K., Bowman, B. A. & Frieden, T. R. 2016. Dietary Sodium and Cardiovascular Disease Risk--Measurement Matters. *The New England journal of medicine,* 375**,** 580-586.

Cook, N. R., Appel, L. J. & Whelton, P. K. 2016. Sodium Intake and All-Cause Mortality Over 20 Years in the Trials of Hypertension Prevention. *Journal of the American College of Cardiology,* 68**,** 1609-1617.

EFSA 2016. EFSA NDA Panel (EFSA Panel on Dietetic Products, Nutrition and Allergies),Turck D, Bresson J-L, Burlingame B, Dean T, Fairweather-Tait S, Heinonen M, Hirsch-Ernst KI,Mangelsdorf I, McArdle H, Neuh€auser-Berthold M, Nowicka G, Pentieva K, Sanz Y, Siani A, Sj€odin A,Stern M, Tome D, Van Loveren H, Vinceti M, Willatts P, Aggett P, Martin A, Przyrembel H, Br€onstrup A,Ciok J, Gomez Ruiz JA, de Sesmaisons-Lecarre A and Naska A, 2016. Scientific opinion on dietaryreference values for potassium. EFSA Journal 2016;14(10):4592, 56 pp. doi:10.2903/j.efsa.2016.4592.

EFSA 2019. EFSA NDA Panel (EFSA Panel on Nutrition, Novel Foods and Food Allergens),Turck D, Castenmiller J, de Henauw S, Hirsch-Ernst K-I, Kearney J, Maciuk A, Mangelsdorf I, McArdle HJ,Pelaez C, Pentieva K, Siani A, Thies F, Tsabouri S, Vinceti M, Aggett P, Fairweather-Tait S, Martin A,Przyrembel H, Ciccolallo L, de Sesmaisons-Lecarre A, Martinez SV, Martino L and Naska A, 2019. ScientificOpinion on the dietary reference values for sodium. EFSA Journal 2019;17(9):5778, 191 pp.

Eyles, H., Bhana, N., Lee, S. E., Grimes, C., McLean, R., Nowson, C. & Wall, C. 2018. Measuring Children's Sodium and Potassium Intakes in NZ: A Pilot Study. *Nutrients,* 10**,** 1198.

Fagerland, M. W. 2012. t-tests, non-parametric tests, and large studies—a paradox of statistical practice? *BMC Medical Research Methodology,* 12**,** 78.

Food Standards Agency 2002. McCance and Widdowson's The Composition of Foods, 6th ed. Cambridge: Royal Society of Chemistry.

Food Standards Agency 2015. McCance and Widdowson's The Composition of Foods, 7th ed. Cambridge: Royal Society of Chemistry.

Foster, E. & Adamson, A. J. 2012. Development and validation of the Young Person's Food Atlas. *Proceedings of the Nutrition Society,* 71**,** E195.

FSAI 2016a. Salt and Health. Review of the Scientific Evidence and Recommendations for Public Policy in Ireland. Food Safety Authority of Ireland, Dublin.

FSAI 2016b. Salt Reducing in Processed Foods - Salt in Diet Still High. . *https://www.fsai.ie/news_centre/press_releases/salt_reduction_programme_031116.html (Accessed online May 2019).*

Grimes, C. A., Riddell, L. J., Campbell, K. J., Beckford, K., Baxter, J. R., He, F. J. & Nowson, C. A. 2017. Dietary intake and sources of sodium and potassium among Australian schoolchildren: results from the cross-sectional Salt and Other Nutrients in Children (SONIC) study. *BMJ open,* 7**,** e016639-e016639.

Harrington, K. E., Robson, P. J., Kiely, M., Livingstone, M. B., Lambe, J. & Gibney, M. J. 2001. The North/South Ireland Food Consumption Survey: survey design and methodology. *Public Health Nutr,* 4**,** 1037-42.

Huang, L., Woodward, M., Stepien, S., Tian, M., Yin, X., Hao, Z., Li, Z., Sun, J., Yu, Y., Zhou, B., Zhao, Y., Wu, Y. & Neal, B. 2018. Spot urine samples compared with 24-h urine samples for estimating changes in urinary sodium and potassium excretion in the China Salt Substitute and Stroke Study. *International Journal of Epidemiology,* 47**,** 1811-1820.

IUNA 2005. Irish Universities Nutrition Alliance. National Children's Food Survey (2003-2004): Survey Report. Available at www.iuna.net.

IUNA 2011. Irish Universities Nutrition Alliance (IUNA). National Adults Nutrition Survey: Summary Report. Available at www.iuna.net.

Kalogeropoulos, A. P., Georgiopoulou, V. V., Murphy, R. A., Newman, A. B., Bauer, D. C., Harris, T. B., Yang, Z., Applegate, W. B. & Kritchevsky, S. B. 2015. Dietary sodium content, mortality, and risk for cardiovascular events in older adults: the Health, Aging, and Body Composition (Health ABC) Study. *JAMA Intern Med,* 175**,** 410-9.

Krebs-Smith, S. M., Kott, P. S. & Guenther, P. M. 1989. Mean proportion and population proportion: two answers to the same question? *Journal of the American Dietetic Association,* 89**,** 671-676.

Lyons, J., Walton, J. & Flynn, A. 2013. Development of an online database of typical food portion sizes in Irish population groups. *Journal of nutritional science,* 2**,** e25-e25.

Meneton, P., Lafay, L., Tard, A., Dufour, A., Ireland, J., Ménard, J. & Volatier, J. L. 2009. Dietary sources and correlates of sodium and potassium intakes in the French general population. *European Journal Of Clinical Nutrition,* 63**,** 1169.

Mente, A., O'Donnell, M. J., Dagenais, G., Wielgosz, A., Lear, S. A., McQueen, M. J., Jiang, Y., Xingyu, W., Jian, B., Calik, K. B., Akalin, A. A., Mony, P., Devanath, A., Yusufali, A. H., Lopez-Jaramillo, P., Avezum, A., Jr., Yusoff, K., Rosengren, A., Kruger, L., Orlandini, A., Rangarajan, S., Teo, K. & Yusuf, S. 2014. Validation and comparison of three formulae to estimate sodium and potassium excretion from a single morning fasting urine compared to 24-h measures in 11 countries. *J Hypertens,* 32**,** 1005-14; discussion 1015.

O'Donnell, M., Mente, A., Rangarajan, S., McQueen, M. J., Wang, X., Liu, L., Yan, H., Lee, S. F., Mony, P., Devanath, A., Rosengren, A., Lopez-Jaramillo, P., Diaz, R., Avezum, A., Lanas, F., Yusoff, K., Iqbal, R., Ilow, R., Mohammadifard, N., Gulec, S., Yusufali, A. H., Kruger, L., Yusuf, R., Chifamba, J., Kabali, C., Dagenais, G., Lear, S. A., Teo, K. & Yusuf, S. 2014. Urinary sodium and potassium excretion, mortality, and cardiovascular events. *N Engl J Med,* 371**,** 612-23.

Okuda, N., Stamler, J., Brown, I. J., Ueshima, H., Miura, K., Okayama, A., Saitoh, S., Nakagawa, H., Sakata, K., Yoshita, K., Zhao, L. & Elliott, P. 2014. Individual efforts to reduce salt intake in China, Japan, UK, USA: what did people achieve? The INTERMAP Population Study. *J Hypertens,* 32**,** 2385-92.

Oliveira, A. C., Padrão, P., Moreira, A., Pinto, M., Neto, M., Santos, T., Madureira, J., Fernandes, E. d. O., Graça, P., Breda, J. & Moreira, P. 2015. Potassium urinary excretion and dietary intake: a cross-sectional analysis in 8-10 year-old children. *BMC pediatrics,* 15**,** 60-60.

Rios-Leyvraz, M., Bovet, P., Tabin, R., Genin, B., Russo, M., Rossier, M. F., Bochud, M. & Chiolero, A. 2018. Urine Spot Samples Can Be Used to Estimate 24-Hour Urinary Sodium Excretion in Children. *J Nutr,* 148**,** 1946-1953.

RIVM 2012a. DNFCS Core survey - Part 6, Micronutrients. https://www.rivm.nl/en/dnfcs-core-survey-part-6-micronutrients (Accessd online 24/01/2019).

RIVM 2012b. Dutch National Food Consumption Survey 2007-2010 Part 8-A Sources of micronutrients, Version 2, based on dataset. DFC_2010_core_20120822.

SACN 2003. Scientific Advisory Committee on Nutrition, Salt and Health. *Crown Copyright 2003. Published for the Food Standards Agency and the Department of Health under licence from the Controller of Her Majesty's Stationery Office*.

Seko, C., Taguchi, Y., Segawa, H., Odani, K., Aoi, W., Wada, S., Kitaoka, K., Masumoto, T. & Higashi, A. 2018. Estimation of salt intake and sodium-to-potassium ratios assessed by urinary excretion among Japanese elementary school children. *Clin Exp Hypertens,* 40**,** 481-486.

Tooze, J. A., Kipnis, V., Buckman, D. W., Carroll, R. J., Freedman, L. S., Guenther, P. M., Krebs-Smith, S. M., Subar, A. F. & Dodd, K. W. 2010. A mixed-effects model approach for estimating the distribution of usual intake of nutrients: the NCI method. *Statistics in medicine,* 29**,** 2857-2868.

Tornaritis, M. J., Philippou, E., Hadjigeorgiou, C., Kourides, Y. A., Panayi, A. & Savva, S. C. 2014. A study of the dietary intake of Cypriot children and adolescents aged 6-18 years and the association of mother's educational status and children's weight status on adherence to nutritional recommendations. *BMC public health,* 14**,** 13-13.

Turkey Dietary Guidelines 2016. Turkey Dietary Guidelines, Ministry of Health of Turkey Publication No: 1046, Ankara 2016.

Turkey Nutrition and Health Survey 2010. Hacettepe University, Ministry of Health (Turkey), Ankhara Numune Research and Training Hospital (Turkey). Turkey Nutrition and Health Survey 2010.

Chapter 4

Potassium intake and sources in Irish school-aged children (5-12y) and compliance with recommendations

Introduction

Blood pressure as a child is strongly associated with blood pressure as an adult, meaning that children with elevated blood pressure are more likely to encounter hypertension and its related health problems in later life (Chen and Wang, 2008). Dietary potassium intake is known to be negatively associated with hypertension, counteracting the blood pressure raising effect of dietary sodium (Tian et al., 2013). The European Food Safety Authority (EFSA) has set adequate intakes (AI) for potassium of 1100mg/d for 4-6 year olds, 1800mg/d for 7-10 year olds and 2700mg/d for 11-14 year olds (EFSA, 2016). These values were extrapolated from the AI for adults which was set based on the role of potassium in lowering blood pressure and reducing the risk of stroke (EFSA, 2016). However, a review of the literature as described in chapter 1 has shown that potassium intakes in children are typically below recommendations (Tornaritis et al., 2014, Bates et al., 2014, Campanozzi et al., 2015, Eyles et al., 2018, El Mallah et al., 2017).

Measuring excretion of potassium from 24-hour urine collections is widely regarded as the gold standard method of estimating potassium intake (Xu et al., 2019, Willett, 2012). However, as noted previously, collecting 24-hour urine samples can be costly and time consuming and is therefore not always practical for large studies (Mente et al., 2014). Research has shown that spot urine samples can be used to estimate average 24-hour potassium intakes at a population level (but not at an individual level) by using appropriate adjustment equations or by correcting for gender and age-specific population urine volume estimations (Mente et al., 2014, Kawasaki, 1993, Huang et al., 2018). The UK National Diet and Nutrition Survey (NDNS) (2008-2012) (Bates et al., 2014) is the only nationally representative dietary survey in Europe to use 24-hour urines to estimate potassium intakes in children. A substantial proportion of older children in the study were found to have potassium intakes below the UK Lower Reference Nutrient Intake for potassium, while potassium intakes were generally below the EFSAIs for all ages (Bates et al., 2014, Department of Health, 1991, EFSA, 2016). Cross-sectional studies in Italy, Portugal and New Zealand which estimated potassium intakes from 24-hour urine collections in children have also shown intakes below recommendations to be common (Campanozzi et al., 2015, Oliveira et al., 2015, Eyles et al., 2018).

While 24-hour urinary data is widely considered the gold standard method (Xu et al., 2019), dietary assessment methods (e.g. 24-hour recalls) have been shown to also provide reliable estimates of potassium intake (Willett, 2012). Dietary data also allows the key sources of potassium to be determined and is often collected either in the absence of or to complement urinary data. A previous national dietary survey of Irish children aged 5-12 years, the National Children's Food Survey (NCFS) (2003-04), collected dietary data and when compared to the EFSA AIs for potassium (EFSA, 2016), the mean potassium intakes from the study are above recommendations in those aged 5-6 years and 7-10 years but below recommendations in those aged 11-12 years (Hannon, 2006). The main sources of potassium were 'milk' (19%), 'potatoes & potato products' (19%), 'meat & meat products' (14%) and 'fruits & fruit juices' (11%). These findings were consistent with other studies which examined sources of potassium intakes amongst children globally, with cereal & cereal products, meat & meat products, dairy products and fruit and vegetables commonly found as main contributors to potassium intakes across studies (Sette et al., 2013, RIVM, 2012b, Bates et al., 2014, Grimes et al., 2017, Eyles et al., 2018).

The National Children's Food Survey II (NCFS II) (2017-18) collected updated dietary data in addition to spot urine samples in a nationally representative sample of Irish children aged 5-12 years. The first aim of this study was to estimate the mean potassium intakes of Irish children based on urinary excretion of potassium from the morning spot urine samples collected and based on the dietary data collected. The second aim was to determine the key sources of potassium from the dietary data. An additional aim was to investigate any changes in potassium intakes and the main foods contributing to potassium intakes since NCFS (2003-04) based on the dietary data collected in the two studies.

Methodology

Overview of study

Analyses for this study are based on data from the NCFS II, which was a nationally representative cross-sectional study that collected food and beverage consumption data in 600 Irish children aged 5-12 years in the Republic of Ireland between 2017 and 2018. A trained researcher visited each child and their parent/guardian(s) three times over the study period to enable the collection of a detailed 4-day weighed food diary from each participant and a morning first void spot urine sample from those willing. A detailed outline of the methodology of the study including the ethical approval and the sampling and recruitment procedure is discussed in chapter 2, while the methods relevant to this chapter are described below.

Urinary data

Urine collection, processing and analysis

Out of the total survey sample of 600 children, 95% (n=572) provided morning first void spot urine samples. These samples were obtained from each participant during the survey period using a sterile container which was then stored appropriately prior to same day collection by the researcher and transport to UCC/UCD for storage at -80℃. Samples were stored until processing, where they were thawed, centrifuged and then the appropriate amounts needed for analysis were aliquoted to sterile tubes using a micropipette. These aliquots were then stored at -20℃ until batch analysis. Aliquots were sent to Randox Laboratories where potassium concentration was measured using a Randox RX Daytona with an ion selective electrode, while creatinine concentration was measured in UCD by a standard spectrophotometric assay using a Randox RX Daytona Clinical Chemistry Analyser. Inter-assay coefficient for potassium was <3.8% and for creatinine was <4.3%. All samples were analysed in duplicate and the average of the two readings calculated.

Estimating potassium intakes in Irish children from urinary outputs

Mean daily potassium intakes were estimated by predicting 24-hour potassium excretion from the spot urines collected using two methods;

1) Firstly, gender-specific predictive equations as shown below were used to estimate 24-hour potassium excretion. In the absence of equations to predict 24-hour potassium excretion from spot urine designed for children, equations developed based on a study in Japanese adults by *Kawasaki et al* were used (Kawasaki, 1993). A study by *Mente et al* has shown these equations provide adequate estimations of potassium intake and are suitable for population studies (Mente et al., 2014*)*. The equations predict 24-hour potassium excretion by relating the concentration of potassium to creatinine in spot urine while also adjusting for age, weight and height (Kawasaki, 1993).

Estimated 24-hour potassium (mg/d):

Male = 39 x [7.2 x $\{SpotK/(SpotCrex10)\}^{0.5}$ x (-12.63 x age + 15.12 x weight + 7.39 x height – 79.9)]

Female = 39 x [7.2 x $\{SpotK/(SpotCrex10)\}^{0.5}$ x (-4.72 x age + 8.58 x weight + 5.09 x height – 74.5)]

- SpotK = potassium concentration in spot urine (mmol/l)
- SpotCre = creatinine concentration in the spot urine (mg/l or mg/dl x10)
- Age (years)
- Weight (kg)
- Height (cm)

2) The second method used to estimate 24-hour population potassium excretion was by correcting the population mean potassium values in spot urine for gender and age-specific 24-hour urine output volumes as shown below. In the absence of population urine output volume estimations for Irish children, volumes derived from a study on Australian children by *Grimes et al* were used which collected 24-hour urine samples in a large sample of children of a similar age range to the current study (Grimes et al., 2017).

Estimated 24-hour potassium (mg/d):

39 x (Population mean SpotK x Gender and age-specific urine output volume)

- SpotK = potassium concentration in spot urine (mmol/L)
- Urine output volume (L/day)

Compliance with dietary guidelines

The estimated mean daily potassium intakes from both methods (estimated based on urinary concentration of potassium) were compared to the EFSA AIs of 1100mg/d for 5-6 year olds, 1800mg/d for 7-10 year olds and 2700mg/d for 11-12 year olds (EFSA, 2016).

Dietary data

Food consumption data collection

Dietary intake data were collected using a 4-day weighed food diary, in which all foods, beverages and nutritional supplements consumed during the survey period were recorded. All foods and beverages consumed were quantified using a hierarchal method of food quantification established by the IUNA and used for previous surveys (www.iuna.net). The methods used to quantify the foods and beverages consumed in this study included direct weighing (76%), use of manufacturer's information (11%), use of a photographic atlas (7%) (Foster and Adamson, 2012), use of average portion sizes (2%) (Food Standards Agency, 2002a), estimated by the researcher based on their knowledge of the child's average portion size (2%), use of household measures (1%) (Harrington et al., 2001) and use of an online database of typical food portion sizes in the Irish population ascertained for foods based on past surveys (1%) (Lyons et al., 2013). Potassium intake was estimated using *Nutritics*©, an electronic software database which contains data from The UK Composition of Foods Integrated Dataset (COFIDS), including McCance and Widdowson 7th edition and 6th edition (used for a small number of foods) (Food Standards Agency, 2015, Food Standards Agency, 2002b). During the NCFS II, modifications were made to the food composition database to include the composition of any new foods common to the Irish market, recipes of composite dishes, fortified foods or nutritional supplements that were consumed during the survey.

Estimation of usual intakes

Usual distribution of potassium intake was calculated from the dietary data collected using the validated National Cancer Institute (NCI)-Method using SAS Enterprise Guide© Version 6.1 (SAS Institute Inc., Cary, NC, USA) (Tooze et al., 2010). Mean dietary potassium intakes (mg/d and mg/10MJ) are reported in the total population and by gender and age group.

Sources of potassium intake

The percent contribution of each food group to the mean daily intake of potassium was calculated by the mean proportion method (Krebs-Smith et al., 1989) and the key contributors were reported in order of importance for the total population. The mean proportion method provides information about the sources that are contributing to the nutrient intake 'per person' and is the preferred method when determining important food sources of a nutrient for individuals in the population group as opposed to investigating the sources of a nutrient within the food supply.

Statistical Analysis

SPSS© for Windows™ version 25 was used for all statistical analysis. Differences in potassium intakes between boys and girls and between the NCFS (2003-04) and the NCFS II (2017-18) were assessed using independent samples t-tests, while differences in potassium intakes between age groups were assessed using a one-way analysis of variance (ANOVA) test. All statistical tests were carried out regardless of normality (due to the large sample size). As sample size increases so does the robustness of t-tests and ANOVA tests to identify deviations from normality, thus parametric tests are recommended for large samples (Fagerland, 2012). To minimise type 1 errors (as a result of multiple testing), the Bonferoni adjustment was used by dividing the alpha level (0.05) by the number of comparisons. Therefore, intakes were considered significantly different from each other if $P < 0.01$. Also due to the large sample in this study even a small difference between group means was highly statistically significant. Thus, greater emphasis was placed on a descriptive, rather than a formal statistical analysis of the data.

Results

Urinary Data

Predictive equation method

Based on the use of predictive equations to estimate potassium intakes (Kawasaki, 1993), the mean daily potassium intake of 5-12 year olds was 1876mg/d (boys 2151mg/d; girls 1587mg/d) **(Table 1)**. When split by age group, mean daily potassium intakes were 1884mg/d for 5-6 year olds, 1865mg/d for 7-10 year olds and 1890mg/d for 11-12 year olds **(Table 1)**. When split by gender and age group, mean daily potassium intakes for boys were 2170mg/d for 5-6 year olds, 2116mg/d for 7-10 year olds and 2203mg/d for 11-12 year olds. Mean daily potassium intakes for girls of the same respective age groups were 1600mg/d, 1609mg/d and 1526mg/d **(Table 1)**. Mean potassium intakes of boys and girls aged 5-6 years and boys aged 7-10 years were above the age-specific EFSA AIs, however all other age groups of boys and girls examined had mean potassium intakes below the AI.

Urine output volume method

The estimated mean daily potassium intake of those aged 5-12 years using urine output volumes was 1448mg/d (boys 1581mg/d; girls 1308mg/d) **(Table 1)**. When split by age group, mean daily potassium intakes were 1347mg/d for 5-6 year olds, 1409mg/d for 7-10 year olds and 1510mg/d for 11-12 year olds **(Table 1)**. When analysed by gender and age group, mean daily potassium intakes for boys were 1513mg/d in 5-6 year olds, 1495mg/d in 7-10 year olds and 1718mg/d in 11-12 year olds. Mean daily potassium intakes for girls of the same respective age groups were 1183mg/d, 1332mg/d and 1283mg/d **(Table 1)**. Mean potassium intakes using this method were below the EFSA AIs for all age groups of boys and girls examined except for boys and girls aged 5-6 years.

Dietary data

From the dietary data, the mean potassium intake of 5-12 year olds was 2019mg/d (boys 2195; girls 1858) **(Tables 2 & 3)**. When split by age group, mean potassium intakes were 1907mg/d for 5-6 year olds, 2023mg/d for 7-10 year olds and

2144mg/d for 11-12 year olds **(Table 2)**. For boys, mean potassium intakes for 5-6 year olds, 7-10 year olds and 11-12 year olds were 2027mg/d, 2202mg/d and 2382mg/d respectively **(Table 3)**. Mean potassium intakes for girls of the same respective age groups were 1791mg/d, 1860mg/d and 1927mg/d **(Table 3)**. Mean potassium intakes of boys and girls aged 5-6 years and 7-10 years were above the EFSA AI, however boys and girls aged 11-12 years had mean potassium intakes below the EFSA AI.

Boys had a significantly higher potassium intake than girls (2195mg/d vs 1858mg/d) **(Table 3)**. When adjusted for energy, boys still had a significantly higher potassium intake than girls (3352mg/10MJ vs 3216mg/10MJ), indicating that the higher mean intake found is due to boys consuming more potassium and not just due to their overall greater energy intake **(Table 3)**. Those aged 7-10 years had a significantly higher potassium intake than those aged 5-6 years (2023mg/d vs 1907mg/d), while those aged 11-12 years had significantly higher potassium intake than those aged 7-10 years (2144mg/d vs 2023mg/d) **(Table 2)**. However, when adjusted for energy, those aged 5-6 years had a significantly higher potassium intake than those aged 7-10 years (3328mg/10MJ vs 3278mg/10MJ), while those aged 7-10 years had significantly higher potassium intake than those aged 11-12 years (3278mg/d vs 3235mg/d), indicating that the higher mean potassium intakes amongst the older children is due to an overall greater energy intake as opposed to a higher potassium consumption **(Table 2)**.

When under-reporters were excluded, mean daily potassium intake of 5-12 year olds was 2083mg/d (data not shown) which was similar to the potassium intake in the total population (including under-reporters) indicating that under-reporters did not influence estimates of potassium intake.

The main sources of potassium were 'meat & meat products' (18%) ('meat dishes and fresh meat' 12%; 'processed meats' 6%), 'milk' (14%), 'potato & potato products' (13%) and 'fruit & fruit juices' (12%) **(Table 4)**.

Changes since NCFS (2003-04)

Changes in potassium consumption in Irish children over the last 15 years were investigated by comparing the mean potassium intake and key sources of potassium in the current study to those from the NCFS (2003-04). The mean potassium intake in the current study was lower than that reported in the NCFS (2019mg/d vs 2190mg/d), with the mean daily potassium intakes of boys and girls in the current study found to be consistently lower when compared to mean intakes from the NCFS (2003-04) **(Table 5)**. Overall, the key sources of potassium in the current study were the same as those from the NCFS but slightly different in order. The key sources of potassium reported in the NCFS were 'milk' (19%), 'potatoes and potato products' (19%) 'meats and meat products' (14%) ('meat dishes and fresh meat' 8.5%; 'processed meats' 5.5%) and 'fruit & fruit juices' (11%) **(Table 6)**.

Table 1. Mean 24-hour urinary excretion of potassium in Irish school-aged children (n=572) by gender and age group using predictive equations and urine output volumes

	Mean urinary potassium (mg/d) ± SD							
	Age group (years)							
	n	**All (5-12y)**	**n**	**5-6y**	**n**	**7-10y**	**n**	**11-12y**
Predictive equation method*								
Total Population	572	1876 ± 653	144	1884 ± 688	285	1865 ± 662	143	1890 ± 606
Boys	287	2151 ± 630	71	2170 ± 656	143	2116 ± 674	73	2203 ± 511
Girls	285	1587 ± 545	73	1600 ± 598	142	1609 ± 542	70	1526 ± 495
Urine output volume method†								
Total Population	572	1448	144	1347	285	1409	143	1510
Boys	287	1581	71	1513	143	1495	73	1718
Girls	285	1308	73	1183	142	1332	70	1283

*Gender specific equations by *Kawasaki et a*l used for predictive equation method (Kawasaki et al., 1993).

†Urine output method using gender and age specific urine output volumes for Australian children derived from a study by *Grimes et al.* (Grimes et al., 2017).

·SDs not included in urine output volume method intakes as mean intakes were adjusted at population level

Table 2. Mean dietary intakes of potassium and potassium per 10MJ in Irish school-aged children (n=600) by age group

	Mean ± SD			
	Age group (years)			
	All (5-12y) (n=600)	5-6y (n=151)	7-10y (n=299)	11-12y (n=150)
Potassium (mg/d)	2019 ± 486	1907 ± 438[a]	2023 ± 490[b]	2144 ± 502[€]
Potassium (mg/10MJ)	3281 ± 462	3328 ± 462[a]	3278 ± 465[b]	3235 ± 453[c]

Significant (P<0.01) differences between age groups denoted by different superscript lowercase letters

Table 3. Mean dietary intakes potassium and potassium per 10MJ of energy in Irish children by gender and age-group (n=600)

	Boys				Girls			
	Mean ± SD				Mean ± SD			
Age group (years)	**All(5-12y) (n=300)**	**5-6y (n=75)**	**7-10y (n=149)**	**11-12y (n=76)**	**All (5-12y) (n=300)**	**5-6y (n=76)**	**7-10y (n=150)**	**11-12y (n=74)**
Potassium (mg/d)	2195 ± 494	2027 ± 436	2202 ± 499	2382 ± 480	1858 ± 418*	1791 ± 407	1860 ± 420	1927 ± 417
Potassium (mg/10MJ)	3352 ± 463	3380 ± 461	3349 ± 467	3325 ± 455	3216 ± 452*	3277 ± 456	3213 ± 453	3153 ± 436

* Denotes statistically significant difference (P<0.01) from that of boys within the rows via independent samples t-test adjusted for multiple testing

Table 4. Mean daily potassium intake and % contribution to potassium intake by food group in Irish school-aged children (n=600)

Food Groups	**Mean Daily Intake (mg/d)**	**% Contribution**
Meat & meat products	359	18.1
Meat dishes and fresh meat	*247*	*12.3*
Processed meats	*112*	*5.7*
Milk	316	15.3
Potatoes & potato products	274	13.3
Chipped, fried and roasted potato products	*162*	*7.8*
Fresh potatoes (boiled, baked, mashed)	*113*	*5.5*
Fruit & fruit juices	235	11.6
Bananas	*64.6*	*3.1*
Fruit juices & smoothies	*61.8*	*2.9*
Other fruits	*108*	*5.6*
Bread & rolls	149	7.7
Vegetables & vegetable dishes	109	5.4
Breakfast cereals	107	5.3
Sugars, confectionery, preserves & savoury snacks	95.9	4.8
Grains, rice, pasta and savouries	73.8	4.0
Biscuits, cakes & pastries	62.9	3.3
Yogurt	*46.5*	*2.4*
Creams, ice-creams & chilled desserts	41.7	2.2
Fish & fish dishes	39.2	1.9
Soups, sauces & miscellaneous foods	37.1	1.9
Beverages	25.2	1.3
Eggs & egg dishes	14.0	0.7
Cheese	11.6	0.6
Nuts, seeds, herbs & spices	4.7	0.2
Butter, spreading fats & oils	1.8	0.1
Nutritional supplements	0.1	0.0
Total	2003	100

Table 5. Mean dietary intakes of potassium in Irish children in NCFS (2003-04) and NCFSII (2017-18) by gender

NCFS (2003-04) Mean dietary potassium (mg/d) ± SD			NCFSII (2017-18) Mean dietary potassium (mg/d) ± SD		
Total (n=594)	**Boys (n=293)**	**Girls (n=301)**	**Total (n=600)**	**Boys (n=300)**	**Girls (n=300)**
2190 ± 502	2298 ± 511	2084 ± 471	2019 ± 486*	2195 ± 494*	1858 ± 418*

* Denotes statistically significant difference (P<0.01) from that of NCFS (2003-04) within the rows via independent samples t-test adjusted for multiple testing

Table 6. Mean daily potassium intake and % contribution to potassium intake by food group in Irish school-aged children in NCFS (2003-04) (n=594) and NCFSII (2017-18) (n=600)

	NCFSII (2017-18)		NCFS (2003-04)	
Food group	**Mean daily intake (mg/d)**	**% contribution**	**Mean daily intake (mg/d)**	**% contribution**
Meat & meat products	359	18.1	303	14.0
Meat dishes and fresh meat	*247*	*12.3*	*187*	*8.5*
Processed meats	*112*	*5.7*	*116*	*5.5*
Milk	316	15.3	429	19.2
Potatoes & potato products	274	13.3	422	19.2
Chipped, fried and roasted potato products	*162*	*7.8*	*268*	*12.3*
Fresh potatoes	*113*	*5.5*	*154*	*6.9*
Fruit & fruit juices	235	11.6	241	10.7
Bananas	*64.6*	*3.1*	*49.4*	*2.2*
Fruit juices & smoothies	*61.8*	*2.9*	*119*	*5.2*
Other fruits	*108*	*5.6*	*73.1*	*3.3*
Other foods	819	41.8	795	37.9
Total	**2003**	**100**	**2190**	**100**

Discussion

The main aim of this study was to estimate the potassium intakes of Irish children aged 5-12 years based on the urinary excretion of potassium from morning spot urine samples and based on the dietary data collected. The second aim was to determine the main food groups contributing to these intakes. An additional aim was to examine any changes in potassium intakes and sources of potassium intake between the NCFS (2003-04) and the current study. The main findings were that the mean daily potassium intakes of Irish children were generally above recommendations for those aged 5-6 years and 7-10 years but below recommendations for those aged 11-12 years irrespective of the method used to estimate intakes, with the main food groups contributing to potassium intakes being 'meat & meat products', 'milk', 'potatoes & potato products' and 'fruit & fruit juices'. The mean potassium intakes of Irish children were lower in comparison to the mean intakes from the NCFS (2003-04), while similar foods were key sources of potassium intakes in both studies.

Urinary data

Potassium intakes

Mean daily potassium intakes were estimated from the spot urines collected using two methods. Firstly, a predictive equation developed by *Kawasaki et al* was used to estimate potassium intakes from spot urines (Kawasaki, 1993). In the absence of equations to predict 24-hour potassium excretion from spot urine designed specifically for children, these equations were deemed the most appropriate available based on a study by *Mente et al*, which found that these equations provide adequate estimations of potassium intake across a diverse range of adult populations and age groups (Mente et al., 2014). The second method used to estimate 24-hour potassium intakes was by correcting the potassium excretion values from spot urines for gender and age-specific urine output volumes for Australian children based on a study by *Grimes et al* (Grimes et al., 2017). Although this method is not widely used, it has been shown to be useful to provide population level estimates of potassium intake (Huang et al., 2018).

Irrespective of the method used, mean daily potassium intakes estimated based on urinary excretion of potassium were generally above the age-specific EFSA AIs for those aged 5-6 years and 7-10 years but below the AIs for those aged 11-12 years. Relative to potassium intake levels typically seen in other studies of children (Bates et al., 2014, Sette et al., 2011), the estimated intakes from the predictive equation method seem plausible while those from the urine output volume method appear to have been potentially underestimated. The use of morning first void samples may have underestimated potassium intakes due to the hormone aldosterone (which promotes potassium excretion in its active state) being inactive during sleep (Iwahori et al., 2017c), therefore, both methods used in the current study have limitations and the estimated intakes may need to be interpreted with caution. However, the methods used to estimate potassium intakes in the current study were deemed the most suitable methods available to estimate potassium intakes from spot urines based on a review of the literature (Mente et al., 2014, Huang et al., 2018). Therefore, increasing potassium intakes to meet recommendations based on these findings should still be considered an important step to reduce the proportion of Irish children at risk of developing higher blood pressure and the associated outcomes in later life.

Comparison to other studies

In the current study, the intakes estimated using the predictive equation method were closer to levels typically seen in children in other western countries and are therefore more likely accurately reflect the potassium intakes of Irish children (Bates et al., 2014, Sette et al., 2011). The mean daily potassium intakes from this method were 1884mg/d for 5-6 year olds, 1865mg/d for 7-10 year olds and 1890mg/d for 11-12 year olds and were above the EFSA AIs for all age groups of children with the exception of those aged 11-12 years. In the UK, based on mean 24-hour potassium excretion measured as part of the National Diet and Nutrition Survey (NDNS) (2008-2012), average daily potassium intakes in the UK were 1248mg/d for 4-6 year olds, 1682mg/d for 7-10 year olds and 2046mg/d for 11-18 year olds (Bates et al., 2014). These estimated potassium intakes of children in the UK were below EFSA AIs with the exception of those aged 4-6 years (EFSA, 2016). The 7-10 year old age group directly overlaps between studies in which case children of that age group in Ireland appear to have a slightly higher mean daily potassium intake than children in the UK (1865mg/d vs 1682mg/d). When compared to data from cross sectional studies which measured potassium intakes in children using urinary data, the estimated potassium intakes of Irish children appear to be either relatively similar to or in many cases higher than those of children from Italy, Portugal, Australia, New Zealand and Lebanon (Campanozzi et al., 2015, Oliveira et al., 2015, Grimes et al., 2017, Eyles et al., 2018, El Mallah et al., 2017).

Dietary data

Dietary intakes and sources of potassium

While 24-hour urinary data is widely considered the gold standard method for estimating potassium intakes, estimates from spot urine samples are prone to some error (Mercado et al., 2018). However, research has shown that dietary assessment methods such as food records or 24-hour recalls can provide reliable estimates of potassium intake (Dennis et al., 2003, Willett, 2012). Therefore, in the absence of 24-hour urines, the estimated potassium intakes based on the dietary data collected in the current study are considered to accurately reflect the potassium intakes of Irish children compared to those estimated based on urinary excretion of potassium from the spot urines collected. The estimated mean potassium intake of Irish children based on the dietary data was 2019mg/d, with higher mean intakes observed in all age groups of boys and girls from this method compared to those estimated based on urinary excretion of potassium. However, the estimated mean potassium intakes from the dietary data were also above the EFSA AIs for those aged 5-6 years and 7-10 years but below the AI for those aged 11-12 years (EFSA, 2016). Therefore, despite the potassium intakes estimated from the dietary data being higher than those from the urinary data, increasing potassium intakes still appears necessary to ensure all age groups of Irish children meet target intakes.

The mean potassium intake estimated from the dietary data collected in the current study was higher in boys compared to girls (2195mg/d vs 1858mg/d). When adjusted for energy, boys still had a significantly higher potassium intake than girls, indicating that their higher potassium intake was due to them consuming more potassium and not just due to an overall greater energy consumption. Therefore, while strategies to ensure all age groups of boys and girls meet recommended potassium intakes are important, they appear particularly relevant to girls. These estimated intakes from the dietary data in the current study appear relatively low when compared to the potassium intakes of children measured using dietary data in other European National Dietary Surveys in Cyprus France, Italy and the Netherlands, which had mean potassium intakes ranging from 2166mg/d to 2758mg/d (Tornaritis et al., 2014, Meneton et al., 2009, Sette et al., 2011, RIVM, 2012a). While the lower estimated potassium intake of Irish children when compared to other studies may be reflective of low potassium intake amongst Irish children, the variation in methodologies across studies may also contribute to the lower potassium intake of Irish children compared to children from other EU countries.

The main food groups contributing to potassium intakes in the current study were 'meat & meat products' (18%), 'milk' (14%), 'potatoes & potato products' (13%) and 'fruit & fruit juices (12%). These main contributors to potassium intakes were generally similar to those found in the studies reviewed globally which looked at the sources of potassium intakes in children, which also found that cereal & cereal products, meat & meat products, dairy products and fruit and vegetables were key sources of potassium intake (Sette et al., 2013, RIVM, 2012b, Bates et al., 2014, Grimes et al., 2017, Eyles et al., 2018).

Comparison with NCFS (2003-04)

Changes in potassium consumption amongst Irish children over the last 15 years were assessed by comparing the dietary data in the current study to the dietary data from the NCFS (2003-04). The mean dietary potassium intake of Irish children aged 5-12 years in the current study was 2019mg/d and lower than the mean intake of 2190mg/d from the NCFS (2003-04). The mean dietary potassium intakes of boys and girls in the current study were consistently lower when compared to the mean intakes from the NCFS (2003-04).

The key sources of potassium were similar between the NCFS II and NCFS with 'meat & meat products', milk, 'potatoes & potato products' and 'fruit & fruit juices' making important contributions to intakes of potassium in Irish children. Slight differences in the contribution from individual food groups were observed between the NCFS and NCFS II which are reflective of the key dietary changes observed in Irish children since 2003-04 with lower intakes of milks and potatoes and higher consumption of fresh meat and meat dishes (IUNA, 2019).

Implications

Based on the estimated mean potassium intakes found in the current study, strategies to increase potassium intakes amongst Irish children appear necessary to ensure that all age groups of children, particularly those aged 11-12 years, meet recommendations (EFSA, 2019). As seen in the previous chapter, sodium intakes exceeding recommendations appear common amongst Irish children indicating that many Irish children may be at risk of developing elevated blood pressure that would make them more likely to become hypertensive adults (Chen and Wang, 2008). While reducing population salt intakes has many challenges (Dötsch et al., 2009), potassium can counteract the blood pressure raising effect of sodium and therefore successful implementation of strategies to increase potassium intakes amongst Irish children may aid in reducing the proportion of children at risk at risk of developing elevated blood pressure and hypertension.

General findings from the NCFS II (2017-18) show that average fruit and vegetable consumption amongst Irish children is low at about 3 servings per day, which is short of the recommended 5-7 servings per day (IUNA, 2019, WHO, 2003). Many fruits and vegetables are rich sources of potassium, therefore, there appears to be potential for public health initiatives promoting the consumption of fruits and vegetables amongst Irish children as a means of increasing potassium intakes to meet recommendations. Successful implantation of strategies to increase potassium intakes amongst Irish children, in conjunction with continued efforts to lower population salt intakes, would lower the sodium to potassium intake ratios (Na:K) of Irish children and may aid in reducing the proportion of Irish children at risk of developing elevated blood pressure and hypertension as will be discussed in chapter 5.

Strengths and limitations

The main strength of this study is that it is the first study to collect urinary data in a nationally representative sample of Irish children allowing the estimation of potassium excretion. The detailed dietary assessment methodology including use of weighed food diaries with detailed brand level information was another strength of the study allowing the sources of potassium in the diet to be estimated as accurately as possible. A possible limitation of the study is that 24-hour urines were not collected, however the methods used to estimate potassium intakes from the spot urines were deemed the most suitable methods available in the absence of 24-hour urines, while the dietary data collected should also provide adequate estimates of intakes.

Conclusion

In conclusion, potassium intakes were generally above recommendations for those aged 5-6 years and 7-10 years but below recommendations for those aged 11-12 years. The main food groups contributing to potassium intakes were found to be 'meat & meat products', 'milk', 'potatoes & potato products' and 'fruit & fruit juices'. The mean potassium intake of Irish children was lower than that reported in the NCFS (2003-04). Dietary strategies to increase potassium intakes of Irish children are needed to meet recommendations. Successful implementation of such strategies may reduce the proportion of Irish children at risk of developing elevated blood pressure and hypertension. Further research should include development of equations to predict 24-hour potassium excretion from spot urine in childhood population groups.

Bibliography

Bates, B., Lennox, A., Prentice, A., Bates, C., Page, P., Nicholson, S. & Swan, G. 2014. National Diet and Nutrition Survey. Results from Years 1,2,3 and 4 (combined) of the Rolling Programme (2008/2009-2011/2012) *In:* Public Health England, W. H., 133-155 Waterloo Road, London SE1 8UG (ed.).

Campanozzi, A., Avallone, S., Barbato, A., Iacone, R., Russo, O., De Filippo, G., D'Angelo, G., Pensabene, L., Malamisura, B., Cecere, G., Micillo, M., Francavilla, R., Tetro, A., Lombardi, G., Tonelli, L., Castellucci, G., Ferraro, L., Di Biase, R., Lezo, A., Salvatore, S., Paoletti, S., Siani, A., Galeone, D., Strazzullo, P. & Group, M.-G. P. S. 2015. High sodium and low potassium intake among Italian children: relationship with age, body mass and blood pressure. *PloS one,* 10**,** e0121183-e0121183.

Chen, X. & Wang, Y. 2008. Tracking of blood pressure from childhood to adulthood: a systematic review and meta-regression analysis. *Circulation,* 117**,** 3171-3180.

Dennis, B., Stamler, J., Buzzard, M., Conway, R., Elliott, P., Moag-Stahlberg, A., Okayama, A., Okuda, N., Robertson, C., Robinson, F., Schakel, S., Stevens, M., Van Heel, N., Zhao, L. & Zhou, B. F. 2003. INTERMAP: the dietary data--process and quality control. *J Hum Hypertens,* 17**,** 609-22.

Department of Health 1991. Dietary Reference Values; A Guide *London: HMSO. Crown Copyright. ISBN 0 11 3213964*

Dötsch, M., Busch, J., Batenburg, M., Liem, G., Tareilus, E., Mueller, R. & Meijer, G. 2009. Strategies to Reduce Sodium Consumption: A Food Industry Perspective. *Critical Reviews in Food Science and Nutrition,* 49**,** 841-851.

EFSA 2016. EFSA NDA Panel (EFSA Panel on Dietetic Products, Nutrition and Allergies),Turck D, Bresson J-L, Burlingame B, Dean T, Fairweather-Tait S, Heinonen M, Hirsch-Ernst KI,Mangelsdorf I, McArdle H, Neuh€auser-Berthold M, Nowicka G, Pentieva K, Sanz Y, Siani A, Sj€odin A,Stern M, Tome D, Van Loveren H, Vinceti M, Willatts P, Aggett P, Martin A, Przyrembel H, Br€onstrup A,Ciok J, Gomez Ruiz JA, de Sesmaisons-Lecarre A and Naska A, 2016. Scientific opinion on dietaryreference values for potassium. EFSA Journal 2016;14(10):4592, 56 pp. doi:10.2903/j.efsa.2016.4592.

EFSA 2019. EFSA NDA Panel (EFSA Panel on Nutrition, Novel Foods and Food Allergens),Turck D, Castenmiller J, de Henauw S, Hirsch-Ernst K-I, Kearney J, Maciuk A, Mangelsdorf I, McArdle HJ,Pelaez C, Pentieva K, Siani A, Thies F, Tsabouri S, Vinceti M, Aggett P, Fairweather-Tait S, Martin A,Przyrembel H, Ciccolallo L, de Sesmaisons-Lecarre A, Martinez SV, Martino L and Naska A, 2019. ScientificOpinion on the dietary reference values for sodium. EFSA Journal 2019;17(9):5778, 191 pp.

El Mallah, C., Merhi, K., Ghattas, H., Shatila, D., Francis, S., Hlais, S., Toufeili, I. & Obeid, O. 2017. Elevated urinary Na/K ratio among Lebanese elementary school children is attributable to low K intake. *Eur J Nutr,* 56**,** 1149-1156.

Eyles, H., Bhana, N., Lee, S. E., Grimes, C., McLean, R., Nowson, C. & Wall, C. 2018. Measuring Children's Sodium and Potassium Intakes in NZ: A Pilot Study. *Nutrients,* 10**,** 1198.

Fagerland, M. W. 2012. t-tests, non-parametric tests, and large studies—a paradox of statistical practice? *BMC Medical Research Methodology,* 12**,** 78.
Food Standards Agency 2002a. Food Portion Sizes (Maff handbook). Edited by Mills, A., Patel S. & Crawley, H. *TSO; 3rd Revised edition edition (1 Feb. 2002),* 0112429610.
Food Standards Agency 2002b. McCance and Widdowson's The Composition of Foods, 6th ed. Cambridge: Royal Society of Chemistry.
Food Standards Agency 2015. McCance and Widdowson's The Composition of Foods, 7th ed. Cambridge: Royal Society of Chemistry.
Foster, E. & Adamson, A. J. 2012. Development and validation of the Young Person's Food Atlas. *Proceedings of the Nutrition Society,* 71**,** E195.
Grimes, C. A., Riddell, L. J., Campbell, K. J., Beckford, K., Baxter, J. R., He, F. J. & Nowson, C. A. 2017. Dietary intake and sources of sodium and potassium among Australian schoolchildren: results from the cross-sectional Salt and Other Nutrients in Children (SONIC) study. *BMJ open,* 7**,** e016639-e016639.
Hannon, E. M. 2006. The National Children's Food Survey: Micronutrient intakes and risk-benefit analysis of micronutrient fortificiation of foods in Irish children. PhD, University College Cork.
Harrington, K. E., Robson, P. J., Kiely, M., Livingstone, M. B., Lambe, J. & Gibney, M. J. 2001. The North/South Ireland Food Consumption Survey: survey design and methodology. *Public Health Nutr,* 4**,** 1037-42.
Huang, L., Woodward, M., Stepien, S., Tian, M., Yin, X., Hao, Z., Li, Z., Sun, J., Yu, Y., Zhou, B., Zhao, Y., Wu, Y. & Neal, B. 2018. Spot urine samples compared with 24-h urine samples for estimating changes in urinary sodium and potassium excretion in the China Salt Substitute and Stroke Study. *International Journal of Epidemiology,* 47**,** 1811-1820.
IUNA 2019. Irish Universities Nutrition Alliance. National Children's Food Survey II (2017-2018): Summary Report. Available at www.iuna.net.
Kawasaki, T., Itoh, K., Uezono, K., & Sasaki, H. 1993. A SIMPLE METHOD FOR ESTIMATING 24 H URINARY SODIUM AND POTASSIUM EXCRETION FROM SECOND MORNING VOIDING URINE SPECIMEN IN ADULTS. Clinical and Experimental Pharmacology and Physiology, 20(1), 7–14. doi:10.1111/j.1440-1681.1993.tb01496.x.
Krebs-Smith, S. M., Kott, P. S. & Guenther, P. M. 1989. Mean proportion and population proportion: two answers to the same question? *Journal of the American Dietetic Association,* 89**,** 671-676.
Lyons, J., Walton, J. & Flynn, A. 2013. Development of an online database of typical food portion sizes in Irish population groups. *Journal of nutritional science,* 2**,** e25-e25.
Meneton, P., Lafay, L., Tard, A., Dufour, A., Ireland, J., Ménard, J. & Volatier, J. L. 2009. Dietary sources and correlates of sodium and potassium intakes in the French general population. *European Journal Of Clinical Nutrition,* 63**,** 1169.
Mente, A., O'Donnell, M. J., Dagenais, G., Wielgosz, A., Lear, S. A., McQueen, M. J., Jiang, Y., Xingyu, W., Jian, B., Calik, K. B., Akalin, A. A., Mony, P., Devanath, A., Yusufali, A. H., Lopez-Jaramillo, P., Avezum, A., Jr., Yusoff, K., Rosengren, A., Kruger, L., Orlandini, A., Rangarajan, S., Teo, K. &

Yusuf, S. 2014. Validation and comparison of three formulae to estimate sodium and potassium excretion from a single morning fasting urine compared to 24-h measures in 11 countries. *J Hypertens,* 32**,** 1005-14; discussion 1015.

Mercado, C. I., Cogswell, M. E., Loria, C. M., Liu, K., Allen, N., Gillespie, C., Wang, C.-Y., de Boer, I. H. & Wright, J. 2018. Validity of predictive equations for 24-h urinary potassium excretion based on timing of spot urine collection among adults: the MESA and CARDIA Urinary Sodium Study and NHANES Urinary Sodium Calibration Study. *The American Journal of Clinical Nutrition,* 108**,** 532-547.

Oliveira, A. C., Padrão, P., Moreira, A., Pinto, M., Neto, M., Santos, T., Madureira, J., Fernandes, E. d. O., Graça, P., Breda, J. & Moreira, P. 2015. Potassium urinary excretion and dietary intake: a cross-sectional analysis in 8-10 year-old children. *BMC pediatrics,* 15**,** 60-60.

RIVM 2012a. DNFCS Core survey - Part 6, Micronutrients. https://www.rivm.nl/en/dnfcs-core-survey-part-6-micronutrients (Accessd online 24/01/2019).

RIVM 2012b. Dutch National Food Consumption Survey 2007-2010 Part 8-A Sources of micronutrients, Version 2, based on dataset. DFC_2010_core_20120822.

Sette, S., Le Donne, C., Piccinelli, R., Arcella, D., Turrini, A. & Leclercq, C. 2011. The third Italian National Food Consumption Survey, INRAN-SCAI 2005–06 – Part 1: Nutrient intakes in Italy. *Nutrition, Metabolism and Cardiovascular Diseases,* 21**,** 922-932.

Sette, S., Le Donne, C., Piccinelli, R., Mistura, L., Ferrari, M. & Leclercq, C. 2013. The third National Food Consumption Survey, INRAN-SCAI 2005-06: major dietary sources of nutrients in Italy. *Int J Food Sci Nutr,* 64**,** 1014-21.

Tian, N., Zhang, Z., Loustalot, F., Yang, Q. & Cogswell, M. E. 2013. Sodium and potassium intakes among US infants and preschool children, 2003-2010. *The American journal of clinical nutrition,* 98**,** 1113-1122.

Tooze, J. A., Kipnis, V., Buckman, D. W., Carroll, R. J., Freedman, L. S., Guenther, P. M., Krebs-Smith, S. M., Subar, A. F. & Dodd, K. W. 2010. A mixed-effects model approach for estimating the distribution of usual intake of nutrients: the NCI method. *Statistics in medicine,* 29**,** 2857-2868.

Tornaritis, M. J., Philippou, E., Hadjigeorgiou, C., Kourides, Y. A., Panayi, A. & Savva, S. C. 2014. A study of the dietary intake of Cypriot children and adolescents aged 6-18 years and the association of mother's educational status and children's weight status on adherence to nutritional recommendations. *BMC public health,* 14**,** 13-13.

WHO 2003. World Health Organisation European Region. Food based dietary guidelines in the WHO European Region. Copenhagen.

Willett, W. 2012. *Nutritional epidemiology*, Oxford University Press. 3rd edition.

Xu, J., Du, X., Bai, Y., Fang, L., Liu, M., Ji, N., Zhong, J., Yu, M. & Wu, J. 2019. Assessment and validation of spot urine in estimating the 24-h urinary sodium, potassium, and sodium/potassium ratio in Chinese adults. *Journal of Human Hypertension*.

Chapter 5

Role of sodium to potassium intake ratio of Irish school-aged children (5-12y)

Introduction

While the individual effects of sodium and potassium intakes on blood pressure have been long established, there is now a consensus that an individual's sodium to potassium intake ratio (Na:K) is a more important predictor of high blood pressure (hypertension) than either sodium or potassium intake alone (Perez and Chang, 2014, Tzoulaki et al., 2012, Stamler et al., 1989). The World Health Organisation (WHO) recommend a Na:K of ≤1.0mmol/mmol for people of all ages (including children) based on meeting recommendations for individual sodium and potassium intakes (WHO, 2012a, WHO, 2012b). Achieving a molar ratio ≤1.0 is considered beneficial for health and to prevent hypertension (WHO, 2012a). However, compliance with a target molar ratio of ≤1.0 is typically low (Campanozzi et al., 2015, Oliveira et al., 2015, Grimes et al., 2017, Eyles et al., 2018, Seko et al., 2018, El Mallah et al., 2017) and molar ratios between 1.0 and 2.0 have been shown to exhibit lower CVD risk in adults, therefore molar ratios ≤2.0 and can be seen as an interim suboptimal goal for people to lower blood pressure (Iwahori et al., 2017a, Cook et al., 2009).

While Na:K is an important predictor of hypertension in adults (Perez and Chang, 2014), research has also shown that a lower Na:K during childhood appears to protect against rises in blood pressure (Geleijnse et al., 1990). Therefore, measurement of Na:K in children may serve as a good indicator of their level of risk of developing elevated blood pressure or hypertension. Due to the significant association between blood pressure as a child and as an adult (Chen and Wang, 2008, Lane and Gill, 2004), reducing Na:K amongst children may help to reduce the proportion of children who develop hypertension and indirectly aid in reducing the prevalence of hypertension related diseases amongst adults. As previously discussed (Chapters 3 & 4), measuring urinary excretion of sodium and potassium from 24-hour urine collections is the gold standard method of estimating sodium and potassium intakes (Mente et al., 2014, Xu et al., 2019). However, in cases where sodium and potassium excretion are measured in spot urine samples, an individual's Na:K can be estimated by applying timing bias corrections to account for circadian rhythms in sodium and potassium excretion and provide 24-hour Na:K estimations (Iwahori et al., 2017b).

Cross sectional studies in Italy, Portugal, Australia, New Zealand, Japan and Lebanon which used either 24-hour or spot urine collections to measure Na:K in children found mean molar ratios ranging from 2.0 to 4.5, with target molar ratios of ≤1.0 and ≤2.0 exceeded in all studies (Campanozzi et al., 2015, Oliveira et al., 2015, Grimes et al., 2017, Eyles et al., 2018, Seko et al., 2018, El Mallah et al., 2017).

The National Children's Food Survey II (2017-18) is the first study to collect urine samples for the estimation of sodium and potassium intakes in a nationally representative sample of Irish children. The first aim of this study was to utilise the spot urine samples collected to estimate the Na:K of Irish children and to assess compliance with target ratios. The second aim of the study was to determine the food groups associated with a lower Na:K from the dietary data collected. An additional aim was to examine any changes in the dietary Na:K of Irish children over the last 15 years by comparing the dietary data in the current study to that from the previous national dietary survey of Irish children, the National Children's Food Survey (NCFS) (2003-04).

Methodology

Overview of study

Analyses for this study are based on data from the NCFS II, which was a nationally representative cross-sectional study that collected food and beverage consumption data in 600 Irish children aged 5-12 years in the Republic of Ireland between 2017 and 2018. A trained researcher visited each child and their parent/guardian(s) three times over the study period to enable the collection of a detailed 4-day weighed food diary from each participant and a morning first void spot urine sample from those willing to provide one. A detailed outline of the methodology of the study including the ethical approval and the sampling and recruitment procedure is discussed in chapter 2, while the methods relevant to this chapter are described below. In order to examine any changes in sodium and potassium consumption amongst Irish children over the last 15 years, dietary data from the NCFS (2003-04) were also examined, which was a nationally representative cross-sectional study of Irish children carried out between 2003 and 2004 and as outlined in chapter 2 had a similar methodology to the current study.

Urinary data

Urine collection, processing and analysis

Out of the total survey sample of 600 children, 95% (n=572) provided morning first void spot urine samples. The samples were obtained using a sterile container which was then stored appropriately prior to same day collection by a researcher and transported to UCC/UCD for storage at -80°C. Samples were stored until batch processing, where they were thawed, centrifuged and then the appropriate amounts needed for analysis were aliquoted to sterile tubes using a micropipette. These aliquots were then stored at -20°C until batch analysis. Aliquots were sent to Randox Laboratories where sodium and potassium concentration were measured using a Randox RX Daytona with an ion selective electrode. Inter-assay coefficient for sodium was <2.2% and for potassium was <3.8% %. All samples were analysed in duplicate and the average of the two readings calculated.

Estimating 24-hour urinary Na:K

Urinary Na:K was calculated for each participant by dividing spot sodium (mmol/L) by spot potassium (mmol/L). Na:K measured in morning spot urines is known to be overestimated due to the circadian rhythms associated with sodium and potassium excretion, therefore timing bias correction was applied by subtracting a value of 0.6 from each individual's spot Na:K to estimate 24-hour Na:K based on a study by *Iwahori et al* (Iwahori et al., 2017b).

Compliance with target Na:K ratio

Mean urinary molar Na:K estimated from spot urines are reported for the total population and split by gender and age group. These estimated Na:K of Irish children were compared to target molar ratios of ≤1.0 and ≤2.0 and the percentage of children complying with these targets was also determined (WHO, 2012a, WHO, 2012b, Cook et al., 2009)

Dietary data

Food consumption data collection

As described in previous chapters, dietary intake data were collected using a 4-day weighed food diary, in which all foods, beverages and nutritional supplements consumed during the survey period were recorded and then quantified using a hierarchal method of food quantification established by the IUNA and used for previous surveys (www.iuna.net). Dietary sodium and potassium intakes were estimated using *Nutritics*©, an electronic software database which contains data from The UK Composition of Foods Integrated Dataset (COFID), including McCance and Widdowson 7th edition and 6th edition (used for a small number of foods) (Food Standards Agency, 2015, Food Standards Agency, 2002). During the NCFS II, modifications were made to the food composition database to include the composition of any new foods common to the Irish market, recipes of composite dishes, fortified foods or nutritional supplements that were consumed during the survey. The sodium composition values of each food and beverage consumed were also checked and updated where appropriate using packaging labels provided by participants.

Estimating dietary Na:K

Dietary data typically underestimates sodium intakes (cannot account for discretionary salt) and overestimates potassium intakes when compared to urinary measures of sodium and potassium (Huang et al., 2014). Therefore, Na:K estimated from dietary data will be generally lower than ratios estimated from urinary data. However, to examine any changes in the Na:K of Irish children over the last 15 years, the dietary Na:K of children from the NCFS (2003-04) (methodology of study outlined in chapter 2) and the current study were estimated. The mean daily dietary sodium and potassium intakes of each participant from both studies were converted from mg/d to mmol/d by dividing by the respective molecular weights of sodium (23) and potassium (39). Dietary molar Na:K were then calculated by dividing the mean daily sodium intake (mmol/d) by the mean daily potassium intake (mmol/d) of each participant. Dietary molar Na:K are reported in the total population and split by gender and age group in the current study, and in the total population and by gender from the NCFS (2003-04).

Statistical analysis

SPSS© for Windows™ version 25 was used for all statistical analysis. Differences in dietary molar Na:K between boys and girls and between NCFS (2003-04) and NCFS II (2017-18) were assessed using independent samples t-tests, while differences in dietary Na:K between age groups were assessed using a one-way analysis of variance (ANOVA) test. On the basis of dietary Na:K, participants were divided into 3 groups: low, medium or high dietary Na:K (stratified by age and gender). Differences in dietary sodium and potassium intake and dietary Na:K between participants with low, medium and high dietary Na:K, as well as the food groups associated with a higher or lower Na:K were assessed using a Kruskal Wallis test. Parametric tests were carried out regardless of normality (due to the large sample size). As sample size increases so does the robustness of statistical analysis to identify deviations from normality, thus parametric tests are recommended for large samples (Fagerland, 2012). To minimise type 1 errors (as a result of multiple testing), the Bonferoni adjustment was used by dividing the alpha level (0.05) by the number of comparisons. Therefore, $P<0.001$ was used to indicate significant differences. Also due to the large sample in this study even a small difference between group means was highly statistically significant. Thus, greater emphasis was placed on a descriptive, rather than a formal statistical analysis of the data.

Results

Urinary data

The mean urinary molar Na:K of 5-12 year olds was 2.5 (boys 2.2; girls 2.8) **(Table 1)**. When split by age group, the mean urinary molar ratios of 5-6 year olds, 7-10 year olds and 11-12 year olds were 2.3, 2.6 and 2.5 respectively **(Table 1)**. The mean urinary molar ratios of boys aged 5-6 years, 7-10 years and 11-12 years were 1.9, 2.4 and 2.0 respectively, while the mean urinary molar ratios of girls of the same respective age groups were 2.7, 2.8 and 3.0 **(Table 1)**.

The mean urinary molar ratios of 2.2 for boys and 2.8 for girls respectively exceed the WHO recommendation of ≤1.0. The level of compliance with this target ratio was found to be low, with just 19% of children having a urinary molar ratio ≤1.0 (boys 24%; girls 14%) **(Table 2)**. When split by age group, 25% of 5-6 year olds, 17% of 7-10 year olds and 18% of 11-12 year olds had a urinary molar ratio ≤1.0 **(Table 2)**. For boys, 31% of 5-6 year olds, 19% of 7-10 year olds and 27% of 11-12 year olds had a urinary molar Na:K ≤1.0, while 19%, 15% and 9% of girls of the same respective age groups had a urinary molar Na:K ≤1.0 **(Table 2)**.

The mean urinary molar ratios of boys and girls also exceed a proposed alternative suboptimal target of ≤2.0 (Cook et al., 2009), with 47% of 5-12 year olds having a urinary molar ratio ≤2.0 (boys 53%; girls 41%) **(Table 2)**. When split by age group, 54% of 5-6 year olds, 44% of 7-10 year olds and 45% of 11-12 year olds had a urinary molar ratio ≤2.0 **(Table 2)**. For boys, 68% aged 5-6 years, 46% aged 7-10 years and 52% aged 11-12 years had a urinary molar ratio ≤2.0, while 45%, 41% and 39% of girls of the same respective age groups had a urinary molar ratio ≤2.0 **(Table 2)**.

Dietary data

Dietary Na:K

The mean dietary molar Na:K of 5-12 year olds was 1.5 (boys 1.5; girls 1.5 **(Table 3)**. When split by age group, the mean dietary molar Na:K of those aged 5-6 years, 7-10 years and 11-12 years were 1.4, 1.5 and 1.5 respectively **(Table 3)**. For boys, the mean dietary molar Na:K of those aged 5-6 years, 7-10 years and 11-12 years were 1.4, 1.5 and 1.4 respectively, while the mean dietary molar ratios of girls of the same respective age groups were 1.4, 1.5 and 1.7 **(Table 3)**. There were no significant differences in dietary Na:K between boys and girls or between age groups **(Table 3)**.

Foods associated with a lower Na:K

The food groups positively associated with a lower Na:K were ‘breakfast cereals’, ‘milk & yogurt’, ‘potatoes & potato products’, ‘vegetables & vegetable dishes’, ‘fruit & fruit juices’ and ‘fresh meat’ **(Table 4)**. The food groups negatively associated with a lower Na:K were ‘savoury foods’, ‘bread & rolls’, ‘cheese’, ‘processed meats’ and ‘soft drinks’ **(Table 4)**.

Changes since NCFS (2003-04)

The mean dietary Na:K was significantly lower when compared to that of the NCFS (2003-04) (1.50mmol/mmol vs 1.65mmol/mmol), with the mean dietary Na:K of both boys and girls significantly lower when compared to those from the NCFS (2003-04) **(Table 5)**.

Table 1. Mean urinary molar Na:K ratios in Irish school-aged children by gender and age group

	Mean urinary Na:K (mmol/mmol) ± SD							
			Age group (years)					
	n	**All (5-12y)**	**n**	**5-6y**	**n**	**7-10y**	**n**	**11-12y**
Total population	572	2.5 ± 1.8	144	2.3 ± 1.9	285	2.6 ± 1.8	143	2.5 ± 1.7
Boys	287	2.2 ± 1.5	71	1.9 ± 1.6	143	2.4 ± 1.6	73	2.0 ± 1.4
Girls	285	2.8 ± 1.9	73	2.7 ± 2.1	142	2.8 ± 1.9	70	3.0 ± 1.8

Table 2. Percentage (%) of Irish school-aged children in compliance with target molar ratios ≤1.0 and ≤2.0 by gender and age group

	% meeting target ratio			
	Age group (years)			
	All (5-12y)	**5-6y**	**7-10y**	**11-12y**
Target ratio ≤1.0				
Total population	19%	25%	17%	18%
Boys	24%	31%	19%	27%
Girls	14%	19%	15%	9%
Target ratio ≤2.0				
Total population	47%	54%	44%	45%
Boys	53%	68%	46%	52%
Girls	41%	45%	41%	39%

Table 3. Mean dietary molar Na:K of Irish school-aged children by gender and age group

	Mean dietary Na:K (mmol/mmol) ± SD							
	Age group (years)							
	n	**All (5-12y)**	**n**	**5-6y**	**n**	**7-10y**	**n**	**11-12y**
Total population	600	1.50 ± 0.5	151	1.43 ± 0.4	299	1.52 ± 0.5	150	1.53 ± 0.5
Boys	300	1.49 ± 0.4	75	1.44 ± 0.5	149	1.54 ± 0.4	76	1.42 ± 0.4
Girls	300	1.51 ± 0.5	76	1.41 ± 0.3	150	1.49 ± 0.5	74	1.67 ± 0.6

*No statistically significant differences ($P<0.001$) in dietary Na:K were observed between boys and girls or between age groups

Table 4. Dietary intake of sodium, potassium, dietary molar Na:K and food group intakes in Irish children (n=600) by tertile of dietary molar Na:K (stratified by age and gender)

	Low (n=195)		Medium (n=207)		High (n=198)		**P Value**	
	Mean	SD	Mean	SD	Mean	SD		
Dietary Na:K (mmol/mmol)	**1.05**	**0.17**	**1.42**	**0.13**	**1.97**	**0.4**	**0.000**	↑
Mean daily intake of sodium (mg)	**1387**	**373**	**1746**	**463**	**1935**	**554**	**0.000**	↑
Mean daily intake of potassium (mg)	**2254**	**551**	**2096**	**562**	**1695**	**493**	**0.000**	↓
Food Groups (g/d)								
Grains, rice & pasta	47.7	46.3	34.3	38.5	34.7	39.9	0.001	↔
Savoury foods	**23.6**	**40.4**	**27.7**	**42.8**	**46.9**	**56.8**	**0.000**	↑
Bread & rolls	**69.5**	**35.5**	**88.2**	**42.1**	**97.1**	**52**	**0.000**	↑
Breakfast cereals	**69.5**	**64.9**	**55.2**	**49.5**	**37.2**	**36.8**	**0.000**	↓
Biscuits, cakes & pastries	30.5	24.5	33.2	26.3	29.4	27.7	0.102	↔
Milk & yogurt	**285**	**186**	**257**	**170**	**170**	**133**	**0.000**	↓
Creams, ice-creams & chilled desserts	25	30.9	30	47.1	24.5	40.4	0.180	↔
Cheese	**7.8**	**10.4**	**10.9**	**14.5**	**13.1**	**14.2**	**0.000**	↑
Butter, spreading fats & oils	5.2	4.7	7.2	6.1	8	8.1	0.001	↔
Eggs & egg dishes	7.9	15.8	8.7	16.6	12	19.4	0.056	↔
Potatoes & potato products	**69.6**	**47.6**	**67.5**	**53.6**	**46.9**	**41.8**	**0.000**	↓
Veg & veg dishes	**62.1**	**48.9**	**51.9**	**52.8**	**31.4**	**33.9**	**0.000**	↓
Fruit & fruit juices	**202**	**147**	**144**	**94**	**127**	**105**	**0.000**	↓
Fish & fish dishes	14.9	39.7	13.1	24.6	11.6	20.7	0.372	↔
Meat & meat products	113	73	120	67	115	66	0.396	↔
Processed meats	**29.8**	**24.6**	**43.9**	**34.9**	**49.5**	**41.6**	**0.000**	↑
Meat dishes	49.1	62.8	47.6	60.7	47.2	53.8	0.932	↔
Fresh meat	**34.6**	**35.6**	**28.5**	**31.4**	**18.7**	**23.1**	**0.000**	↓
Beverages (excluding milk)	**577**	**289**	**660**	**372**	**678**	**315**	**0.000**	↑
Water as a beverage	451	304	442	343	456	300	0.473	↔
Soft drinks (all types)	**106**	**136**	**180**	**246**	**189**	**247**	**0.000**	↑
Tea & coffee	18	63	35	94	31	81	0.092	↔
Other beverages	2	14	3	14	2	16	0.475	↔
Sugars, confectionary, preserves & savoury snacks	28.8	25.4	32.4	27	34.5	27.5	0.018	↔
Soups, sauces & miscellaneous foods	20.9	41	26	36.2	27.6	45.2	0.230	↔
Nutritional supplements	24.3	54.6	17.2	44.2	15.1	38.6	0.110	↔
Nuts, seeds, herbs & spices	1.1	5.4	0.6	2.7	0.55	2.41	0.045	↔

P-Value <0.001 denotes significant differences across tertiles
↑= associated with a higher Na:K, ↔ = associated with neither a high nor lower Na:K, ↓=associated with a lower Na:K

Table 5. Mean dietary molar Na:K in Irish school-aged children in NCFS (2003-04) and NCFSII (2017-18) by gender

Mean dietary Na:K (mmol/mmol) ± SD					
NCFS (2003-04)			**NCFSII (2017-18)**		
Total population (n=594)	**Boys (n=293)**	**Girls (n=301)**	**Total population (n=600)**	**Boys (n=300)**	**Girls (n=300)**
1.65 ± 0.40	1.65 ± 0.41	1.65 ± 0.39	1.50 ± 0.46*	1.49 ± 0.44*	1.51 ± 0.49*

* Denotes statistically significant difference ($P<0.001$) from that of NCFS (2003-04) via independent samples t-test adjusted for multiple testing

Discussion

The main aims of this study were to estimate the mean urinary Na:K of Irish children based on urinary excretion of sodium and potassium from the morning spot urine samples collected as part of the NCFS II (2017-18), to assess compliance with target ratios and to determine the foods associated with a lower Na:K. An additional aim was to examine any changes in dietary Na:K since the previous NCFS (2003-04). The main findings were that the mean urinary molar Na:K of Irish children of 2.5 was higher than target molar ratios of ≤1.0 (WHO, 2012a) and ≤2.0 (Cook et al., 2009), while compliance with target ratios was also low with just 19% and 47% of children meeting target molar ratios of ≤1.0 and ≤2.0 respectively. These findings indicate that Irish children may be at risk of developing higher blood pressure under current dietary practices. Children with a lower Na:K had higher intakes of 'breakfast cereals', 'milk & yogurt', 'potatoes & potato products', 'vegetables & vegetable dishes', 'fruit & fruit juices' and 'fresh meat' and lower intakes of 'savoury foods', 'breads, 'cheese', 'processed meats' and 'soft drinks'. The dietary Na:K of Irish children in the NCFS II was lower when compared to that from the NCFS (2003-04) (1.50mmol/mmol vs 1.65mmol/mmol).

Urinary data

Urinary Na:K

Achieving a molar Na:K of ≤1.0 as recommended by the WHO is considered beneficial for health and to prevent hypertension (WHO, 2012a), however the mean urinary molar ratios of 2.2 for boys and 2.8 for girls exceed this target. The mean urinary molar Na:K of all age groups of Irish boys and girls exceed a target molar ratio ≤1.0, with just 24% of boys and 14% of girls achieving a urinary molar ratio ≤1.0. Compliance with a molar Na:K ≤1.0 is generally low amongst most population groups (Ware et al., 2017), however a molar Na:K of between 1.0 and 2.0 has been shown to exhibit a lower CVD risk in adults and therefore the Na:K of Irish children in the current study were also compared to a suboptimal target molar ratio ≤2.0 (Cook et al., 2009). The mean urinary molar ratio of all age groups of Irish children also generally exceeded this range. An estimated 53% of boys and

41% of girls had a urinary molar ratio ≤2.0, however considering that this is seen as an interim suboptimal target the proportion exceeding this target is relatively high. These findings indicate that many Irish children may currently be at risk of developing elevated blood pressure or hypertension in later life.

Comparison to other studies

The mean urinary molar Na:K in the current study was 2.3 for 5-6 year olds, 2.6 for 7-10 year olds and 2.4 for 11-12 year olds, with target molar ratios of ≤1.0 and ≤2.0 consistently exceeded by all age groups. In the UK, the National Diet and Nutrition Survey (NDNS) (2008-2012) measured 24-hour urinary excretion of sodium and potassium in children aged 4-18 years and based on this data, the estimated mean molar Na:K for children in the UK was 2.1 for 4-6 year olds, 2.1 for 7-10 year olds and 2.3 for 11-18 year olds (Bates et al., 2014). The 7-10 year old age group overlaps across studies and children of this age group in the UK appear to have a lower mean Na:K than Irish children (2.1 vs 2.6). As lower intakes of both sodium and potassium were observed in the UK study when compared to ours, the variation in methodologies between studies is more likely to explain the difference in Na:K observed between the two studies. The NDNS (2008-12) estimated Na:K from 24-hour urine collections as opposed to the current study which collected spot urines. Nonetheless, the estimated Na:K of all age groups of children in the UK also exceed target molar ratios of ≤1.0 and ≤2.0.

Cross-sectional studies from various countries around the world which collected urinary data to estimate Na:K in children have also shown ratios exceeding recommendations to be common. An Italian study of children aged 6-18 years found a mean molar Na:K of 3.5 for boys and 3.4 for girls based on the 24-hour urines collected (Campanozzi et al., 2015). A study in Portugal of those aged 8-10 years which collected 24-hour urines found a mean molar Na:K of 3.2 in boys and 2.5 in girls (Oliveira et al., 2015). In Australia, the mean molar Na:K from a study of children aged 4-12 years was estimated to be 2.4 (Grimes et al., 2017), while in New Zealand the mean molar Na:K of those aged 8-11 years was estimated to be 2.0 (Eyles et al., 2018), with both studies collecting 24-hour urines. A study in Japan of children aged 9-11 years estimated the mean molar Na:K to be 4.5 based on the collection of spot urines (Seko et al., 2018), while in Lebanon, also based on the collection of spot urines, the mean molar Na:K of those aged 6-10 years was estimated to be 2.4 (El Mallah et al., 2017). Although the studies examined varied in size and methodology, the Na:K of children from the studies reviewed appear relatively similar to those of Irish children, indicating that Na:K exceeding recommendations are common amongst childhood populations and not limited to just children in Ireland.

Dietary data

Dietary determinants of Na:K

Dietary data generally underestimate sodium intake and overestimate potassium intake when compared to urinary measures of sodium and potassium (Huang et al., 2014). Therefore, Na:K estimated from dietary data will be generally lower than that estimated from urinary data by approximately 20% when compared to measurement of Na:K in 24-hour urines (Huang et al., 2014). In the current study, those in the low dietary Na:K group had an average dietary molar Na:K of 1.05, compared to an average dietary molar Na:K of 1.97 in those with a high dietary Na:K. The mean dietary Na:K even in those with a low Na:K exceeded an optimal target molar ratio ≤1.0 despite underestimation of sodium intake and overestimation of potassium intake, highlighting how difficult achieving a molar ratio ≤1.0 can be under current dietary practices.

The food groups positively associated with a lower Na:K were 'breakfast cereals', 'milk & yogurt', 'potatoes & potato products', 'vegetables & vegetable dishes', 'fruit & fruit juices' and 'fresh meat'. The food groups negatively associated with a lower Na:K in the current study were 'savoury foods', 'bread & rolls', 'cheese', 'processed meats' and 'soft drinks'. As expected, the foods found to be negatively associated with a lower Na:K were generally foods high in sodium such as processed meats and breads, while the foods found to be positively associated with a lower Na:K were potassium rich foods such as fruit and vegetables and fresh meats. As most soft drinks have a relatively low sodium content, the exact reason they were negatively associated with a lower Na:K is unclear, however one possible explanation may be that soft drink consumption is positively associated with poorer general dietary habits and a higher consumption of processed foods (Vartanian et al., 2007, Bes-Rastrollo et al., 2006). Strategies to lower the Na:K of Irish children should focus on increasing the consumption of foods found to be positively associated with a lower Na:K and lowering the consumption of foods found to be negatively associated with a higher Na:K.

Comparison with NCFS (2003-04)

Comparing the dietary Na:K in the current study to that from the NCFS (2003-04) gives an opportunity to explore any changes in Na:K in Irish children over the last 15 years. The mean dietary molar Na:K of Irish children in the current study was lower in comparison to the mean dietary ratio from the NCFS (2003-04) (1.50mmol/mmol vs. 1.65mmol/mmol). The lower mean Na:K of Irish children found in the current study can be partly explained by the lower sodium intakes of Irish children when compared to the NCFS (2003-04) as described in chapter 3, with the lower sodium intakes in the current study likely to be as a result of the FSAI voluntary salt reduction programme (FSAI, 2016). However, as described in chapter 4, the potassium intakes of Irish children were also lower when compared to those from the NCFS (2003-04) which meant that the reduction in mean dietary Na:K was not as large as it could have been, highlighting the importance of increasing population potassium intakes as a vital step in effectively lowering population Na:K.

Implications of the findings

The large proportion of Irish children found to exceed target Na:K indicates that many Irish children may be at a high risk of developing elevated blood pressure or hypertension under current dietary practices. While the morbidities associated with hypertension may not occur until adulthood, the significant relationship that exists between blood pressure as a child and as an adult (Chen and Wang, 2008, Lane and Gill, 2004) means that developing elevated blood pressure or hypertension during childhood may make Irish children more susceptible to hypertension related diseases in later life (Daniels et al., 1998). Therefore, strategies to reduce the proportion of Irish children at risk of developing hypertension such as lowering Na:K should be considered which may indirectly aid in reducing hypertension related diseases amongst Irish adults.

Both reducing sodium intakes and increasing potassium intakes amongst Irish children appear necessary in order to reduce the proportion of children exceeding target Na:K. The food groups found to be positively associated with a lower Na:K in the current study were similar to the foods recommended in the Food Based Dietary Guidelines (FBDG) for those in the WHO European region (WHO, 2003) such as dairy, cereals and fruit and vegetables while the foods negatively associated with a lower Na:K were those recommended in moderation or with consumption limits such as processed meats. Therefore, strategies targeting an increased population compliance with the FBDG would aid in lowering Na:K amongst Irish children. The lower mean dietary Na:K in the current study compared to NCFS (2003-04) was enabled by the lower sodium intakes in the current study which were likely aided by the FSAI salt reduction programme; however, continued and improved engagement with such initiatives designed to lower population sodium intakes and increase population potassium intakes is needed if the Na:K of Irish children are to be lowered to meet recommendations.

Strengths and limitations

The main strength of this study is the nationally representative sample of Irish children aged 5-12 years included in the NCFS II and the collection of both urinary and dietary data to allow for accurate estimations of sodium and potassium intakes. While 24-hour urine collection is the gold standard for estimating sodium and potassium intake, this study used morning first void spot urine samples and applied appropriate timing bias correction to account for circadian rhythms in sodium and potassium excretion. The application of timing bias correction has been shown to accurately reflect 24-hour Na:K and so the findings from this study serves as a good indicator of the level of risk of Irish children developing elevated blood pressure or hypertension.

Conclusion

In conclusion, compliance with target Na:K amongst Irish school-aged children is low, with just 19% of children meeting the WHO recommendation for a molar Na:K ≤1.0 and 47% of children meeting an alternative suboptimal target molar Na:K of ≤2.0. The foods found to be positively associated with a lower Na:K were ‘breakfast cereals’, ‘milk & yogurt’, ‘potatoes & potato products’, ‘vegetables & vegetable dishes’, ‘fruit & fruit juices’ and ‘fresh meat’, while the foods found to be negatively associated with a lower Na:K in the current study such as ‘savoury foods’, ‘bread & rolls’, ‘cheese’, ‘processed meats’ and ‘soft drinks’. The findings of this study suggest that many Irish children may be at a high risk of developing hypertension under current dietary practices. Due to the link between blood pressure as a child and blood pressure in adulthood, interventions to lower the prevalence of Irish adults affected by hypertension related diseases in later life should target children. The dietary Na:K of Irish children were found to be lower when compared to those from the NCFS (2003-04); however, continued and improved engagement with initiatives designed to lower Na:K appears necessary if Irish children are to meet the recommended Na:K. Targeting an increased compliance with FBDG in addition to continued support of initiatives such as the FSAI salt reduction programme may lessen the proportion of Irish children who develop hypertension and indirectly reduce the prevalence of hypertension related diseases in Irish adults.

Bibliography

Bates, B., Lennox, A., Prentice, A., Bates, C., Page, P., Nicholson, S. & Swan, G. 2014. National Diet and Nutrition Survey. Results from Years 1,2,3 and 4 (combined) of the Rolling Programme (2008/2009-2011/2012) *In:* Public Health England, W. H., 133-155 Waterloo Road, London SE1 8UG (ed.).

Bes-Rastrollo, M., Sanchez-Villegas, A., Gomez-Gracia, E., Martinez, J. A., Pajares, R. M. & Martinez-Gonzalez, M. A. 2006. Predictors of weight gain in a Mediterranean cohort: the Seguimiento Universidad de Navarra Study 1. *Am J Clin Nutr,* 83**,** 362-70; quiz 394-5.

Campanozzi, A., Avallone, S., Barbato, A., Iacone, R., Russo, O., De Filippo, G., D'Angelo, G., Pensabene, L., Malamisura, B., Cecere, G., Micillo, M., Francavilla, R., Tetro, A., Lombardi, G., Tonelli, L., Castellucci, G., Ferraro, L., Di Biase, R., Lezo, A., Salvatore, S., Paoletti, S., Siani, A., Galeone, D., Strazzullo, P. & Group, M.-G. P. S. 2015. High sodium and low potassium intake among Italian children: relationship with age, body mass and blood pressure. *PloS one,* 10**,** e0121183-e0121183.

Chen, X. & Wang, Y. 2008. Tracking of blood pressure from childhood to adulthood: a systematic review and meta-regression analysis. *Circulation,* 117**,** 3171-3180.

Cook, N. R., Obarzanek, E., Cutler, J. A., Buring, J. E., Rexrode, K. M., Kumanyika, S. K., Appel, L. J., Whelton, P. K. & Trials of Hypertension Prevention Collaborative Research, G. 2009. Joint effects of sodium and potassium intake on subsequent cardiovascular disease: the Trials of Hypertension Prevention follow-up study. *Archives of internal medicine,* 169**,** 32-40.

Daniels, S. R., Loggie, J. M., Khoury, P. & Kimball, T. R. 1998. Left ventricular geometry and severe left ventricular hypertrophy in children and adolescents with essential hypertension. *Circulation*, 97**,** 1907-11.

El Mallah, C., Merhi, K., Ghattas, H., Shatila, D., Francis, S., Hlais, S., Toufeili, I. & Obeid, O. 2017. Elevated urinary Na/K ratio among Lebanese elementary school children is attributable to low K intake. *Eur J Nutr*, 56**,** 1149-1156.

Eyles, H., Bhana, N., Lee, S. E., Grimes, C., McLean, R., Nowson, C. & Wall, C. 2018. Measuring Children's Sodium and Potassium Intakes in NZ: A Pilot Study. *Nutrients*, 10**,** 1198.

Food Standards Agency 2002. McCance and Widdowson's The Composition of Foods, 6th ed. Cambridge: Royal Society of Chemistry.

Food Standards Agency 2015. McCance and Widdowson's The Composition of Foods, 7th ed. Cambridge: Royal Society of Chemistry.

FSAI 2016. Salt Reducing in Processed Foods - Salt in Diet Still High. . *https://www.fsai.ie/news_centre/press_releases/salt_reduction_programme_031116.html (Accessed online May 2019).*

Geleijnse, J. M., Grobbee, D. E. & Hofman, A. 1990. Sodium and potassium intake and blood pressure change in childhood. *British Medical Journal,* 300**,** 899.

Grimes, C. A., Riddell, L. J., Campbell, K. J., Beckford, K., Baxter, J. R., He, F. J. & Nowson, C. A. 2017. Dietary intake and sources of sodium and potassium among Australian schoolchildren: results from the cross-sectional Salt and

Other Nutrients in Children (SONIC) study. *BMJ open,* 7**,** e016639-e016639.

Huang, Y., Van Horn, L., Tinker, L. F., Neuhouser, M. L., Carbone, L., Mossavar-Rahmani, Y., Thomas, F. & Prentice, R. L. 2014. Measurement error corrected sodium and potassium intake estimation using 24-hour urinary excretion. *Hypertension (Dallas, Tex. : 1979),* 63**,** 238-244.

Iwahori, T., Miura, K. & Ueshima, H. 2017a. Time to Consider Use of the Sodium-to-Potassium Ratio for Practical Sodium Reduction and Potassium Increase. *Nutrients,* 9**,** 700.

Iwahori, T., Miura, K., Ueshima, H., Chan, Q., Dyer, A. R., Elliott, P. & Stamler, J. 2017b. Estimating 24-h urinary sodium/potassium ratio from casual ('spot') urinary sodium/potassium ratio: the INTERSALT Study. *Int J Epidemiol,* 46**,** 1564-1572.

Lane, D. A. & Gill, P. 2004. Ethnicity and tracking blood pressure in children. *J Hum Hypertens,* 18**,** 223-8.

Mente, A., O'Donnell, M. J., Dagenais, G., Wielgosz, A., Lear, S. A., McQueen, M. J., Jiang, Y., Xingyu, W., Jian, B., Calik, K. B., Akalin, A. A., Mony, P., Devanath, A., Yusufali, A. H., Lopez-Jaramillo, P., Avezum, A., Jr., Yusoff, K., Rosengren, A., Kruger, L., Orlandini, A., Rangarajan, S., Teo, K. & Yusuf, S. 2014. Validation and comparison of three formulae to estimate sodium and potassium excretion from a single morning fasting urine compared to 24-h measures in 11 countries. *J Hypertens,* 32**,** 1005-14; discussion 1015.

Oliveira, A. C., Padrão, P., Moreira, A., Pinto, M., Neto, M., Santos, T., Madureira, J., Fernandes, E. d. O., Graça, P., Breda, J. & Moreira, P. 2015. Potassium urinary excretion and dietary intake: a cross-sectional analysis in 8-10 year-old children. *BMC pediatrics,* 15**,** 60-60.

Perez, V. & Chang, E. T. 2014. Sodium-to-potassium ratio and blood pressure, hypertension, and related factors. *Advances in nutrition (Bethesda, Md.),* 5**,** 712-741.

Seko, C., Taguchi, Y., Segawa, H., Odani, K., Aoi, W., Wada, S., Kitaoka, K., Masumoto, T. & Higashi, A. 2018. Estimation of salt intake and sodium-to-potassium ratios assessed by urinary excretion among Japanese elementary school children. *Clin Exp Hypertens,* 40**,** 481-486.

Stamler, J., Rose, G., Stamler, R., Elliott, P., Dyer, A. & Marmot, M. 1989. INTERSALT study findings. Public health and medical care implications. *Hypertension,* 14**,** 570-7.

Tzoulaki, I., Patel, C. J., Okamura, T., Chan, Q., Brown, I. J., Miura, K., Ueshima, H., Zhao, L., Van Horn, L., Daviglus, M. L., Stamler, J., Butte, A. J., Ioannidis, J. P. A. & Elliott, P. 2012. A nutrient-wide association study on blood pressure. *Circulation,* 126**,** 2456-2464.

Vartanian, L. R., Schwartz, M. B. & Brownell, K. D. 2007. Effects of soft drink consumption on nutrition and health: a systematic review and meta-analysis. *American journal of public health,* 97**,** 667-675.

Ware, L. J., Swanepoel, B. & Schutte, A. E. 2017. Urinary sodium-to-potassium ratio: it may be SMART, but is it easy? *Public Health Nutrition,* 20**,** 758-760.

WHO 2003. World Health Organisation European Region. Food based dietary guidelines in the WHO European Region. Copenhagen.

WHO 2012a. Guideline: Potassium intake for adults and children. Geneva, World Health Organization (WHO), 2012.

WHO 2012b. Guideline: Sodium intake for adults and children. Geneva, World Health Organization (WHO), 2012.

Xu, J., Du, X., Bai, Y., Fang, L., Liu, M., Ji, N., Zhong, J., Yu, M. & Wu, J. 2019. Assessment and validation of spot urine in estimating the 24-h urinary sodium, potassium, and sodium/potassium ratio in Chinese adults. *Journal of Human Hypertension*.

Chapter 6

General Discussion

Blood pressure as a child has a significant association with blood pressure as an adult, meaning that children with elevated blood pressure or hypertension are at higher risk of encountering hypertension in later life (Chen and Wang, 2008). Dietary sodium and potassium intakes have been shown to effect blood pressure (Perez and Chang, 2014), therefore estimation of sodium and potassium intakes in children may give a good indication of their risk of developing elevated blood pressure or hypertension and being affected by hypertension related diseases in later life. The overall aim of this thesis was to investigate the individual and combined roles of sodium and potassium in the diets of school-aged children in Ireland. Analyses were conducted using data from the National Children's Food Survey II (NCFS II) (2017-18) which collected urinary and dietary data in a nationally representative sample of Irish children (n=600).

The first aim of this study was to estimate sodium/salt intake and dietary sources in Irish children and to examine any changes in sodium intake and sources since the previous NCFS (2003-04). Mean daily salt intake was estimated based on urinary excretion of sodium in the spot urines collected in the current study using two well established methods (predictive equations and adjusting for urine output volume). Using predictive equations, the mean daily salt intake of Irish children was 5.2g/d for 5-6 year olds, 5.6g/d for 7-10 year olds and 5.8g/d for 11-12 year olds, while the mean daily salt intake estimated using urine output volumes was 4.3g/d, 5.3g/d and 5.6g/d for children of the same respective age groups. These estimated intakes generally exceed the Food Safety Authority of Ireland (FSAI) target maximum population salt intakes of 3g/d for 4-6 year olds, 5g/d for 7-10 year olds and 6g/d for 11-14 year olds (FSAI, 2016). Sodium intakes from food sources only (excluding discretionary salt) and the key sources of sodium intake in Irish children were estimated based on the 4-day weighed food diaries also collected as part of the study. Mean daily salt intakes estimated from this method were 3.8g/d for 5-6 year olds, 4.2g/d for 7-10 year olds and 4.5g/d for 11-12 year olds. As dietary data cannot account for discretionary salt added at the table or in cooking, by comparing the sodium intakes from the dietary data to the urinary data, it was estimated that discretionary salt may account for approximately 17-24% of total sodium intake in Irish children. The key food-groups contributing to sodium intake were processed meats and breads accounting for almost half (46%) of sodium intake from food sources only. The mean salt intake of Irish children in this study (2017-18) was lower by approximately 1g/d than that reported from the NCFS (2003-04), however there were no differences in the main foods contributing to sodium intake across studies with breads and processed meats accounting for a large proportion of sodium intake. Based on the intakes of sodium observed in this study, strategies to reduce sodium intakes in the childhood years should be considered as evidence suggests that modest reductions in sodium intakes during childhood can help to reduce the rate at which blood pressure increases with age and prevent hypertension related diseases in later life (Brown et al., 2009).

Dietary potassium intake has been shown to be negatively associated with hypertension, counteracting the blood pressure raising effect of sodium (Tian et al., 2013). The second aim of this study was to estimate potassium intake and sources in Irish children, as well as to investigate any changes in potassium intake and the main foods contributing to potassium intake since the NCFS (2003-04). The European Food Safety Authority (EFSA) has an adequate intake (AI) for potassium of 1100mg/d for 4-6 year olds, 1800mg/d for 7-10 year olds and 2700mg/d for 11-14 year olds (extrapolated from adults based on the role of potassium in lowering blood pressure and reducing the risk of stroke) (EFSA, 2016). The mean potassium intake of Irish children estimated by urinary excretion of potassium using predictive equations was 1884mg/d for 5-6 year olds, 1865mg/d for 7-10 year olds and 1890mg/d for 11-12 year olds, while the mean potassium intake using urine output volumes was 1347mg/d, 1409mg/d and 1510mg/d for children of the same respective age groups. The mean potassium intake of Irish children estimated from the dietary data collected was 1907mg/d for 5-6 year olds, 2023mg/d for 7-10 year olds and 2144mg/d for 11-12 year olds. Regardless of the method used to estimate intake, the mean potassium intake was generally above the AI for those aged 5-6 years and 7-10 years but below the AI for those aged 11-12 years. The key sources of potassium were meat & meat products (18%), milk (14%), potatoes & potato products (13%) and fruit & fruit juices (12%). The mean potassium intake in the current study were lower in the NCFS II (2017-18) than the NCFS (2003-04), however the key sources of potassium were similar across both studies with meats, milk, potatoes and fruits being the main sources of potassium in Irish children. Based on the estimated intake in the current study, increasing potassium intake amongst Irish children appears necessary to ensure all age groups of children in particular older children meet recommendations to protect against rises in blood pressure (Kanbay et al., 2013).

There is a consensus that an individual's Na:K is a better predictor of hypertension than either sodium or potassium intake alone and there is evidence that a lower Na:K during childhood can protect against rises in blood pressure and prevent the development of hypertension (Geleijnse et al., 1997, Perez and Chang, 2014). A molar Na:K ≤1.0 as recommended by the World Health Organisation (WHO) is considered beneficial for health and to prevent hypertension (WHO, 2012), while a molar Na:K ≤2.0 has been shown to exhibit lower cardiovascular disease (CVD) risk in adults and can be seen as an interim suboptimal target ratio (Cook et al., 2009). The final aim of this study was to estimate the mean urinary Na:K of Irish children, to assess compliance with target ratios and to determine the foods associated with a lower Na:K. An additional aim was to examine any changes in the dietary Na:K of Irish children over the last 15 years by comparing the dietary data in the current study to that from the previous national dietary survey of Irish children, the National Children's Food Survey (NCFS) (2003-04).

The mean urinary molar Na:K of Irish children was 2.5, exceeding the target molar Na:K of ≤1.0 and ≤2.0. Compliance with the target Na:K was also found to be low with just 19% and 47% of children adhering to target molar Na:K ≤1.0 and ≤2.0 respectively. Children with a lower dietary Na:K had higher intakes of 'breakfast cereals', 'milk & yogurt', 'potatoes & potato products', 'vegetables & vegetable dishes', 'fruit & fruit juices' and 'fresh meat' and lower intakes of 'savoury foods' (e.g. pizza and quiche), 'breads', 'cheese', 'processed meats' and 'soft drinks'. The mean dietary Na:K of Irish children in the current study was significantly lower when compared to that of the NCFS (2003-04) (1.50mmol/mmol vs 1.65mmol/mmol). Based on the estimated Na:K in the current study and the low compliance with target Na:K, there may be some risk of Irish children developing elevated blood pressure or hypertension under current dietary practices. Therefore, strategies to lower the Na:K in Irish children should be considered.

Based on the overall findings of this study, it appears that strategies to both reduce sodium intakes and increase potassium intakes are required to effectively lower Na:K amongst Irish children, which may reduce the proportion of children at risk of developing elevated blood pressure or hypertension. With regards to reducing sodium intakes, while the success of the FSAI salt reduction programme implemented in 2003 (FSAI, 2016) is reflected in the lower sodium intakes of Irish children in the current study (2017-18) compared to the NCFS (2003-04), continued and improved engagement with such programmes appears necessary to further reduce sodium intakes in Irish children to meet recommendations. Considering the proportion of sodium intake attributable to processed meats and breads, even slight reductions in the sodium contents of such foods would assist towards lowering sodium intakes. Additionally, considering that up to one-fifth of salt intake in the current study is attributable to discretionary salt, efforts to reduce discretionary salt use amongst Irish children are needed. It has been shown that providing healthy eating classes to primary school aged children on the harmful effects of salt and recommended salt intakes may enable significant reductions in sodium intakes to occur (He et al., 2015).

While reducing population sodium intakes has many challenges (Dötsch et al., 2009) successful implementation of strategies to increase potassium intakes amongst Irish children may also aid in reducing Na:K. Considering that fruits and vegetables are rich sources of potassium and that average fruit and vegetable consumption in the NCFS II was approximately 3 servings per day which is well below the recommended 5-7 servings per day (IUNA, 2019, WHO, 2003), there appears to be potential for initiatives designed to increase fruit and vegetable consumption amongst Irish children as a means of increasing potassium intakes. One such initiative currently in operation in Ireland is the 'Food Dudes Healthy Eating Programme', which offers repeated tastings of fruit and vegetables to children in primary schools in an effort to introduce them as a regular component of the diet, while incentives and rewards are then offered for continued consumption of fruit and vegetables as part of everyday lunch in school (Food Dudes, 2019). While the success of this programme is difficult to measure, the introduction of such initiatives is a step in the right direction and continued engagement with such programmes may improve dietary habits in Irish children with subsequent improvements in potassium intakes (along with other nutrients).

The foods found to be positively associated with a lower dietary Na:K in the current study were in line with those recommended in the Food Based Dietary Guidelines (FBDG) for the WHO European region (WHO, 2003) such as fruits & vegetables, milks and fresh meat, while the foods negatively associated with a lower dietary Na:K were those recommended to be consumed in small amounts such as processed meats and savoury/'top shelf foods'. Therefore, the introduction of any initiatives designed to increase healthy eating practices and improve compliance with FBDG amongst Irish children should be welcomed as they are likely to contribute to lowering Na:K and reducing the proportion of children at risk of developing hypertension.

The main strength of this study was the nationally representative sample of Irish children aged 5-12 years included in the NCFS II and the collection of both urinary and dietary data to allow for accurate estimations of sodium and potassium intakes. The detailed dietary assessment methodology including use of weighed food diaries with detailed brand level information was another strength. The modifications made to the food composition database to ensure that the most up to date sodium composition values were used for each food code meant that dietary sodium and potassium intakes and sources of sodium and potassium were estimated as accurately as possible. A limitation of the study is that it did not collect 24-hour urines, however the study used well established methods to estimate sodium and potassium intake and Na:K from the spot urines collected. Continued research is needed to develop appropriate predictive equations to estimate 24-hour sodium and potassium excretion from spot urines specifically for children.

To conclude, mean sodium intakes of Irish children generally exceeded recommendations, while mean potassium intakes were typically meeting recommendations for those aged 5-6 years and 7-10 years but below recommendations for those aged 11-12 years. Compliance with target molar Na:K of ≤1.0 and ≤2.0 was low at just 19% and 47% respectively. These findings indicate that Irish children may be at risk of developing elevated blood pressure or hypertension under current dietary practices. Targeting increased compliance with the FBDG in addition to continued and improved engagement with initiatives designed to lower Na:K appears necessary if Irish children are to meet the target Na:K.

Bibliography

Brown, I. J., Tzoulaki, I., Candeias, V. & Elliott, P. 2009. Salt intakes around the world: implications for public health. *International Journal of Epidemiology,* 38**,** 791-813.

Chen, X. & Wang, Y. 2008. Tracking of blood pressure from childhood to adulthood: a systematic review and meta-regression analysis. *Circulation,* 117**,** 3171-3180.

Cook, N. R., Obarzanek, E., Cutler, J. A., Buring, J. E., Rexrode, K. M., Kumanyika, S. K., Appel, L. J., Whelton, P. K. & Trials of Hypertension Prevention Collaborative Research, G. 2009. Joint effects of sodium and potassium intake on subsequent cardiovascular disease: the Trials of Hypertension Prevention follow-up study. *Archives of internal medicine,* 169**,** 32-40.

Dötsch, M., Busch, J., Batenburg, M., Liem, G., Tareilus, E., Mueller, R. & Meijer, G. 2009. Strategies to Reduce Sodium Consumption: A Food Industry Perspective. *Critical Reviews in Food Science and Nutrition,* 49**,** 841-851.

EFSA 2016. EFSA NDA Panel (EFSA Panel on Dietetic Products, Nutrition and Allergies),Turck D, Bresson J-L, Burlingame B, Dean T, Fairweather-Tait S, Heinonen M, Hirsch-Ernst KI,Mangelsdorf I, McArdle H, Neuh€auser-Berthold M, Nowicka G, Pentieva K, Sanz Y, Siani A, Sj€odin A,Stern M, Tome D, Van Loveren H, Vinceti M, Willatts P, Aggett P, Martin A, Przyrembel H, Br€onstrup A,Ciok J, Gomez Ruiz JA, de Sesmaisons-Lecarre A and Naska A, 2016. Scientific opinion on dietaryreference values for potassium. EFSA Journal 2016;14(10):4592, 56 pp. doi:10.2903/j.efsa.2016.4592.

Food Dudes 2019. Food Dudes Health Eating Programme. Accessed online on 22/11/2019 https://www.fooddudes.ie/about-food-dudes/. *Food Activity Research Unit, School of Psychology at Bangor University, Wales.*

FSAI 2016. Salt and Health. Review of the Scientific Evidence and Recommendations for Public Policy in Ireland. Food Safety Authority of Ireland, Dublin.

Geleijnse, J. M., Hofman, A., Witteman, J. C., Hazebroek, A. A., Valkenburg, H. A. & Grobbee, D. E. 1997. Long-term effects of neonatal sodium restriction on blood pressure. *Hypertension,* 29**,** 913-7.

He, F. J., Wu, Y., Feng, X.-X., Ma, J., Ma, Y., Wang, H., Zhang, J., Yuan, J., Lin, C.-P., Nowson, C. & MacGregor, G. A. 2015. School based education programme to reduce salt intake in children and their families (School-EduSalt): cluster randomised controlled trial. *BMJ (Clinical research ed.),* 350**,** h770-h770.

IUNA 2019. Irish Universities Nutrition Alliance. National Children's Food Survey II (2017-2018): Summary Report. Available at www.iuna.net.

Kanbay, M., Bayram, Y., Solak, Y. & Sanders, P. W. 2013. Dietary potassium: a key mediator of the cardiovascular response to dietary sodium chloride. *Journal of the American Society of Hypertension : JASH,* 7**,** 395-400.

Perez, V. & Chang, E. T. 2014. Sodium-to-potassium ratio and blood pressure, hypertension, and related factors. *Advances in nutrition (Bethesda, Md.),* 5**,** 712-741.

Tian, N., Zhang, Z., Loustalot, F., Yang, Q. & Cogswell, M. E. 2013. Sodium and potassium intakes among US infants and preschool children, 2003-2010. *The American journal of clinical nutrition,* 98**,** 1113-1122.

WHO 2003. World Health Organisation European Region. Food based dietary guidelines in the WHO European Region. Copenhagen.

WHO 2012. Guideline: Potassium intake for adults and children. Geneva, World Health Organization (WHO), 2012.

<u>Appendix A</u>

Publications related to this thesis

Irish Universities Nutrition Alliance (2019) National Children's Food Survey II (2017-2018): Summary Report. Cork. Ireland Available at www.iuna.net. (contributing author)

Morrissey E, Kehoe L, Moore Heslin A, Buffini M, McNulty BA, Nugent AP, Kearney J, Flynn A & Walton J (2019) Estimates of Sodium and Potassium intake and their molar ratio in Irish children: Preliminary findings from NCFS II. *Proceedings of The Nutrition Society* (in press)

Publications related to this training period

Shaw M, Nugent AP, McNulty BA, Walton J, McHugh M, Kane A, Moore Heslin A, **Morrissey E**, Mullan K, & Woodside JV (2019) What is the availability of iodised salt in supermarkets on the island of Ireland? *European Journal of Clinical Nutrition*, 73, 1636-1638.

Morrissey E, Giltinan M, Kehoe L, Nugent AP, McNulty BA, Flynn A & Walton J (2019) Urinary ratio of sodium and potassium in Irish Adults. *Proceedings of the Nutrition Society*. 78(OCE1) DOI: 10.1017/S0029665119000090

Morrissey E, Giltinan M, Kehoe L, Nugent AP, McNulty BA, Flynn A & Walton J (2020) Sodium and potassium intakes and their ratio in adults (18-90y). *Nutrients Journal* ***2020***, 12(4), 938

Conference Presentations

Nutrition Society 2018 Winter Conference Student Competition, Royal Society of Medicine, London. *Urinary ratio of sodium and potassium in Irish adults* **(Oral presentation)**

Federation of European Nutrition Societies (FENS) 2019 Conference, Convention Centre, Dublin. *Estimates of sodium and potassium intake and their molar ratio in Irish children* **(Oral presentation)**