Nutritional Intake, Body Composition, Plasma Lipids and Fat-Soluble Vitamins, Red Blood Cell Fatty Acid Profile and Behaviour of Omani School Children

A Thesis submitted

for the degree of Doctor of Philosophy (Ph.D)

By

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Author's Declaration

I declare that the work presented in this PhD thesis titled "**Nutritional Intake, Body Composition, Plasma Lipids and Fat-Soluble Vitamins, Red Blood Cell Fatty Acid Profile and Behaviour of Omani School Children**" has not been previously submitted for another degree in this or any other educational institution. In addition, I confirm that the recruitment and follow up of the participants, data analyses and interpretation and most of the laboratory work were undertaken by me and the work done by other persons and used in the thesis have been acknowledged.

Name: Samia AL Ghannami

Signed: _____

Date: 18th February 2017

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Abbreviations

AA	Arachidonic acid
ADD	Attention-Deficit Disorder
ADHD	Attention-Deficit/Hyperactivity Disorder
ADHDCIS	ADHD Combined Inattention/Hyperactivity
AHA	American Heart Association
AI	Adequate intake
ALA	Alpha linolenic acid
ALP	Alkaline phosphatase
AMDR	Acceptable macronutrient distribution range
ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
ATP	Adenosine triphosphate
BMI	Body mass index
BSRT	Buschke Selective Reminding Test
CDC	Centers for Disease Control and Prevention
CI	Confidence interval
CNS	Central nervous system
COPD	Chronic obstructive pulmonary disease
COWAT	Controlled Oral Word Association Test
COX	Cyclooxygenase
CPRS	Conners' Parent Rating Scales
CTRS	Conners' Teacher Rating Scales
CVD	Cardiovascular disease
DALY	Daily Adjusted Life-Year
DHA	Docosahexaenoivc acid
DLPFC	Dorsolateral prefrontal cortex
DNA	Deoxyribonucleic acid
DPA	Docosapentaenoic acid
DSM	Diagnostic and Statistical Manual of Mental Disorders
EAE	Experimental autoimmune encephalomyelitis
EDTA	Ethylenediamine tetraacetic acid
EFAD	Essential fatty acid deficiency
EPA	Eicosapentaenoic acid

EPG	Ethanolamine phosphoglyceride
FA	Fatty acid
FAME	Fatty acid methyl ester
FAO	Food and Agricultural Organization of the United Nations
GCC	Gulf Cooperation Council
GDP	Gross Domestic Product
GI	Glycaemic index
GL	Glycaemic load
GSHS	Global school-based student health survey
HACCP	Hazard analysis and critical control points
HAD	Docosahexaenoic acid
HbA1	Hemoglobin, subunit alpha 1
HBV	Hepatitis B Virus
HCV	Hepatitis C Virus
HDL	High density lipoprotein
HIV	Human immunodeficiency virus
HPLC	High performance liquid chromatography
HPV	Human Papillomavirus
ICD-10	International Classification of Diseases, 10th revision
IFG	Impaired fasting glucose
IGF	Insulin-like growth factor
IGT	Impaired glucose tolerance
IL	Interleukin
IQ	Intelligence quotient
IU	International unit
IUPAC	International Union of Pure and Applied Chemistry
Kcal	Kilocalorie
LCPUFA	Long-chain polyunsaturated fatty acid
LNRC	Lipidomics and Nutrition Research Centre
MA	Mead acid
MS	Multiple sclerosis
MUFA	Monounsaturated fatty acid
NCD	Non-communicable disease
NIHCQ	National Initiative for Children’s Health Quality
OA	Oleic acid

OMR	Omani Rial
PAB	Polycyclic aromatic hydrograms
PCDD/F	Polychlorinated dibenzodioxins and furans
PDAY	Pathobiological determinants of atherosclerosis in youth
PHIS	Predominantly hyperactive/impulsive subtype of ADHD
PIS	Predominantly inattentive subtype of ADHD
PTH	Parathyroid hormone
PUFA	Polyunsaturated fatty acid
RBC	Red blood cell
RCPM	Raven's Coloured Progressive Matrices
RDA	Recommended daily allowance
SCD	Sickle cell disease
SFA	Saturated fatty acid
SPSS	Statistical Package for the Social Sciences
TGs	Triglycerides
TMT	Trial Making Test
TOL	Tower of London test
U5MR	Under Five mortality rate
UNDP	United Nations Development Programme
UNICEF	United National Children's Emergency Fund
USFA	Unsaturated fatty acid
UV/Vis	Ultraviolet-visible spectrophotometry
VLDL	Very low density lipoprotein
WC	Waist circumference
WCST	Wisconsin Card-Sorting Test
WHO	World Health Organization
YLL	Years of life lost

List of Publications

Journal articles

1. **Al-Ghannami SS,** Sedlak E, Hussein IS, Min Y, Al-Shmmkhi SM, Al-Oufi HS, Al-Mazroui A and Ghebremeskel K (2016) Red Blood Cell Fatty Acid Profile of Oman Preadolescent School Children Before and After Intervention with Docosahexaenoic Acid Enriched Omega 3 Capsules or Oily Fish. Prostaglandins Leukotrienes and Essential Fatty Acids (Under review)

2. **Al-Ghannami SS**, Ghebremeskel K, Hussein IS, Min Y, Jeyaseelan L, Al-Shammakhi SM; Al-Mamary F, Al-Adawi S (2016) Attention Deficit Hyperactivity Disorder and parental factors in School Children Aged 9-10 Years in Urban Region of Oman. *BMC Pediatrics (*Under review*)*

3. **Al-Ghannami SS,** Sedlak E, Hussein IS, Min Y, Al- Shmmkhi SM, Al-Oufi HS, Al-Mazroui A and Ghebremeskel K (2016) Vitamin D deficiency is prevalent in healthy Omani school children: Omega-3 fatty acids have a mitigating effect. *Nutrition International Journal of Applied and Basic Nutrition 32:73-78*

Conference abstracts

1. Ghebremeskel K, **Al-Ghannami SS**, Hussein IS, Min Y, Delextrat A, Hayes L, Al-Adawi S, Al-Mazroui A, Al-Oufi HS (2014) The effect of fish consumption, fish oil supplementation and physical exercise on body composition, blood biochemistry, cognitive function and fitness of Omani school children. (*Invited Opening Lecture*) International Conference on Seafood Safety, Quality and Traceability Systems, Muscat, Sultanate of Oman, March 5, 2014.

2. Huessein I, **Al-Ghannami SS**, Ghebremeskel K and Min Y (2014). Fish consumption and iodine and vitamin D status of children. *Micronutrient Global Conference, Addis Ababa, Ethiopia, June 2 – 7.*

3. **Al-Ghannami SS**, Sedlak E, Hussein IS, Min Y, Al-Shmmkhi SM, Al-Oufi HS, Al-Mazroui A, Ghebremeskel K (2014). The effect of omega 3 fatty acid

supplementation on plasma vitamin D status of school children. *11th Congress of the International Society for the Study of Fatty Acids and Lipids, Stockholm, Sweden (June 28/July 2).*

4. **Al-Ghannami SS**, Sedlak E, Hussein IS, Min Y[1], Al-Shmmkhi SM, Al-Oufi HS, Al Al-Mazroui A, Ghebremeskel K (2014). Low dose omega 3 fatty acids reduce fat mass and systolic blood pressure in school children. *11th Congress of the International Society for the Study of Fatty Acids and Lipids, Stockholm, Sweden (June 28/July 2).*

5. **Al-Ghannami SS**, Al-Adawi S, Sedlak E, Hussein IS, Min Y, Al-Shmmkhi SM, Al-Oufi HS, Al Al-Mazroui A and Ghebremeskel K (2014) Fish consumption for a short period of time improves cognitive ability of healthy Omani school children. *11th Congress of the International Society for the Study of Fatty Acids and Lipids, Stockholm, Sweden (June 28/July 2).*

6. **Al-Ghannami SS**, Sedlak E, Hussein IS, Min Y, Al-Shmmkhi SM, Al-Oufi HS, Al Al-Mazroui A and Ghebremeskel K (2014). Erythrocyte palmitoleic acid correlates positively with fat mass and plasma triglycerides in normal weight school children. *11th Congress of the International Society for the Study of Fatty Acids and Lipids, Stockholm, Sweden (June 28/July 2).*

7. Abuknesha N, **Al Ghannami SS**, Min Y, Hussein IS, Al Oufi H, Ibrahim FA and Ghebremeskel K (2016) The effect of oily fish meal and fish oil supplement on plasma phosphatidylcholine fatty acids of Omani children. *12th Congress of the International Society for the Study of Fatty Acids and Lipids, Stellenbosch, South Africa (September 5-9).*

Abstract

Background: The traditional Omani diet of dates, milk, rice, brown bread, fish and vegetables has undergone considerable change, now resembling a Western diet that is high in calories, high glycaemic index carbohydrates, total fat and saturated, trans and omega 6 fatty acids, and low in omega-3 fatty acids and essential micronutrients. The available data on daily food intake and its impact on micro- and macro-nutrients are scanty in the Arab world. Obtaining these data is especially important in light of the growing prevalence of non-communicable diseases (NCDs) – cardiovascular diseases, diabetes, cancer and respiratory diseases – which now account for more than 60% of the global disease burden and mortality, and contribute to more than 50% of annual deaths in Arabian countries, including Oman. Moreover, obesity, an antecedent of NCDs, has reached epidemic proportions in the region. Since NCDs develop gradually during the course of the lifespan, various national and international committees on NCDs have recommended that children and young adults be the primary focus of any action plan that aims to prevent and control non-communicable diseases.

Specific aims: The aims of the study are:

a) To assess the nutrient intake, body composition, blood lipids, blood pressure, blood glucose and cognitive behaviour of Omani school children;

b) To assess the level of Vitamin A, D, E, and Beta Carotene among the Omani school children

c) To assess the level of red blood cell fatty acids of Omani school children

d) To investigate the effect of fish consumption on red blood cell omega-3 fatty acids and plasma fat-soluble vitamins;

e) To investigate the impact of omega-3 fatty acids obtained from fish oil capsule on the red blood cell omega-3 fatty acids and plasma fat-soluble vitamins;

Methods: Children ages 9 and 10 years (n = 314) were recruited from three randomly selected schools in the Muscat Governorate. The schools were assigned to a fish, fish oil, or control group and the children were accordingly provided a lightly grilled oily fish, a re-esterified triacylglycerol fish oil capsule, or no fish for 12 weeks. Baseline body

weight, height and body mass index were assessed and a non-fasting blood sample collected at baseline and after 12 weeks of intervention. Data on food intake were gathered using a 24-hour recall questionnaire; also collected were data on weight, height, blood pressure, triglycerides and fasting glucose. In addition, teachers completed the National Initiative for Children's Health Quality Vanderbilt Assessment Scales-Teacher Assessment Scale to assess the prevalence and sub-types of ADHD.

Results: At baseline, a significant number of the children had low levels of vitamin D, and omega-3 fatty acids. The low levels of vitamin D and omega-3 fatty acids were ameliorated significantly by fish consumption and fish oil supplementation. In terms of weight, the prevalence of overweight or obesity for the total sample was 28.2% (10%, 46%) and 22.6% (8%, 38%). That is, about one fourth of the study subjects were overweight or obese. With regards to ADHD, the prevalence rate of PIS, PHIS and ADHDCIH among Omani school children was 7.3%, 3% and 8.8%, respectively.

After 12 weeks intervention, the children who received fish oil (54.1±17.5 nmol/L; $p<0.001$) and fish (49.2±17.4 nmol/L; $p<0.05$) had elevated levels of vitamin D than those who did not (42.3±17.5 nmol/L). The fish oil (1.2±0.70 μmol/L) and fish (1.20±0.7 μmol/L) groups also had higher concentrations of beta carotene than the placebo group (0.85±0.43 μmol/L; $p<0.0001$). Systolic and diastolic blood pressure ($p=0.0001$) and plasma triglycerides ($p<0.05$) but not HDL, LDL and total cholesterol ($p>0.05$) were lower in the fish oil group compared with those who were fed oily fish.

Conclusions: This study provides important and underreported data on nutrient intake levels by school children in Arab world. For the first time, these data will be available as a benchmark for future research and health programs in the region. A large number of boys and girls had diets that failed to provide the recommended levels of daily nutrients. This study also indicates that ADHD is relatively common among Omani school children; additional studies are needed to assess the generalisability of these findings.

Vitamin D deficiency is prevalent in Omani school children, but can be mitigated with omega-3 fatty acid supplementation. This study also provides evidence that Omani pre-adolescents have a low level n-3 fatty acid index that can be ameliorated by fish oil supplementation or consumption of oily fish. Hence, there is a need for a child-focused program of food fortification, school feeding programmes, targeted intervention with n-3 fatty acid enriched food products, family nutrition education and outdoor activities to alleviate the problem.

CHAPTER 1:
Introduction, Hypothesis and Specific Aims

The second half of the 20th century witnessed major health transitions in the world, propelled by socio-economic and technological changes that profoundly altered life expectancy and ways of living. These changes also created an unprecedented human capacity to use science to prolong and enhance life.

In the past, life expectancy was often limited by uncontrolled epidemics. But after the Second World War, due to the development of the vaccine and antibiotics, as well as the improvement of life conditions, NCDs emerged as a major problem in industrialized countries. Heart disease, mental disorders, cancer, diabetes, and chronic pulmonary disease became a burden for health systems unprepared for these developments. For a while, these diseases were associated with economic development and considered diseases of the rich. By the dawn of the third millennium, however, NCDs began to sweep the entire globe, with developing countries suddenly confronted by the double burden of infectious and non-infectious diseases in a poor environment characterized by ill-prepared health systems (World Health Organization, 2003b).

Today, NCDs are the leading worldwide cause of death. They are strongly influenced by four main behavioural risk factors – unhealthy diet, insufficient physical activity, and use of tobacco and alcohol – which lead to elevated blood pressure, raised blood glucose and cholesterol levels, and excess body weight.

1.1 Non-Communicable Diseases (NCDs) – Definition

A non-communicable disease is a medical condition or a disease state which, by definition, is non-infectious and non-transmissible : they may be chronic diseases of long duration and slow progression, or they may result in rapid death such as some types of stroke. According to the World Health Organization (2005), NCDs are the major cause of adult mortality and morbidity worldwide, primarily cardiovascular diseases (including heart disease and stroke), diabetes, cancer and chronic respiratory diseases (including chronic obstructive pulmonary disease and asthma).

Non-communicable diseases (NCDs) impose a large burden on human health worldwide. Currently, more than 60% of all deaths are due to NCDs (Figure 1-1). Moreover, what were once considered “diseases of affluence” have now encroached on developing countries. In 2008, for example, WHO reported that roughly four out of five NCD deaths occurred in low- and middle-income countries (World Health Organization, 2011a), a sharp increased from just under 40% in 1990 (Murray and Lopez, 1997). NCDs are also affecting persons of all ages, with one-quarter of all NCD-related deaths

involving persons below the age of 60 (World Health Organization, 2011a). NCDs also account for 48% of the healthy life years lost (Disability Adjusted Life Years–DALYs) worldwide, versus 40% for communicable diseases, maternal and perinatal conditions and nutritional deficiencies, and 1% for injuries (World Health Organization, 2005).

As an umbrella category, NCDs have been a difficult group to define. Even the term "non-communicable diseases" is a misnomer, since NCDs include some diseases – notably, cancers of the liver, stomach, and cervix – that are at least partly caused by infection, and usually exclude mental illnesses, despite their significant contribution to long-term disability.

1.1.1 Prevalence of NCDs Worldwide

According to WHO estimates, NCDs were responsible for 36 million deaths globally in 2008, accounting for 63% of 57 million total deaths (Hunter and Reddy, 2013). The global mortality due to NCDs increased from 57% of total mortality in 1990 to 65% in 2010 (Murray and Lopez, 2013). In 2008, 80% of the world's 36 million NCD-related deaths occurred in low- and middle-income countries, which are home to most of the world's population (World Health Organization, 2011a). NCDs are unequally distributed within populations, as well, often disproportionately affecting the socioeconomically disadvantaged (Leeder et al., 2004).

The World Health Organization reports that NCDs are by far the leading cause of death in the world, representing over 60% of all deaths. Out of the 36 million people who died from NCDs in 2005, half were under age 70 and half were women (Alwan et al., 2010). Risk factors such as a person's background, lifestyle and environment are known

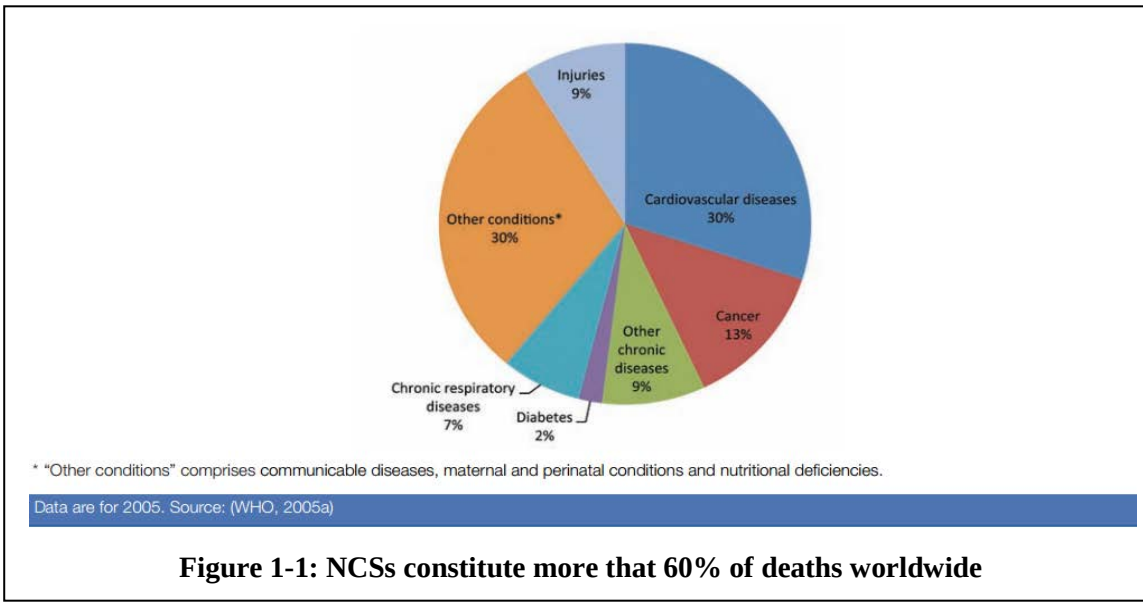

Figure 1-1: NCSs constitute more that 60% of deaths worldwide

to increase the likelihood of certain NCDs. Hence, each year, at least 5 million people die because of tobacco use and about 2.8 million die from being overweight. In the same way, high cholesterol accounts for roughly 2.6 million deaths and 7.5 million die because of high blood pressure.

1.1.2 Cardiovascular Disease

The six types of cardiovascular disease (CVD) include the heart muscle (coronary heart disease), brain (cerebrovascular disease), arms and legs (peripheral arterial disease) and the associated blood vessels. Deep vein thrombosis or pulmonary embolism is the last type, and involves blood clots which dislodge from veins in the leg and move to the heart or lungs (World Health Organization, 2013c).

The risk factors for developing CVDs (with the exception of congenital and rheumatic heart diseases) involve modifiable behavioural risk factors, metabolic risk factors and non-modifiable risk factors. Non-modifiable risk factors include a person's age, ethnicity, family history and gender. The modifiable behavioural risk factors include the harmful use of alcohol, physical inactivity, unhealthy diets and tobacco use (Alwan, 2008, Alwan, 2011). The metabolic risk factors are caused by these behavioural risk factors and increase the risk of developing CVD, and include increased blood pressure (hypertension), increased blood sugar (diabetes) and increased blood cholesterol, as well as overweight/obesity (Mendis et al., 2011, World Health Organization, 2009).

Coronary Heart Disease (CHD) is the type of CVD with the highest rate of mortality in developed countries (38%) and the highest cause for burden of disease in developing countries (28%) (Wagner and Brath, 2012, Gaziano et al., 2010). However, it is predicted that the rate in developing countries will increase by as much as 137% for men and 120% for women (Leeder et al., 2004).

Overweight/Obesity is an important risk factor to be considered since it is related to other metabolic risk factors, such as raised blood pressure, raised blood sugar, raised blood lipids (cholesterol and triglycerides) and dyslipidaemia for the development of a CVD (National Heart Lung and Blood Institute, 2002, Grundy, 2004). As an individual's BMI increases, so does the risk for coronary heart disease, stroke and diabetes (World Health Organization, 2000).

Raised blood pressure, also known as hypertension, is not only one of the major risk factors for coronary heart disease and stroke, but can also cause heart failure, renal

impairment, blindness, peripheral vascular disease and the rupture of blood vessels (Mendis et al., 2011, World Health Organization, 2013b, World Health Organization, 2009, World Health Organization and International Society of Hypertension Writing Group, 2003). The prevalence of hypertension was 40% in all adults over 25 years globally, with approximately 1 billion people were suffering from uncontrolled hypertension in 2008 alone (Alwan, 2011). Hypertension causes 12.8% of total deaths and is responsible for 3.7% of global DALYS (Alwan, 2011, World Health Organization, 2009).

Impaired glucose tolerance and impaired fasting glycaemia are two other important risk factors for the development of diabetes and CVD (World Health Organization and UNAIDS, 2007). The risk of developing a CVD or atherosclerotic disease is higher for those with either Type 1 or Type 2 diabetes (Laing et al., 2003, Kannel and McGee, 1979), with 60% of mortality in those with diabetes being attributed to a CVD (Mendis et al., 2011). Research suggests that CVD mortality is directly related to plasma glucose, and the risk increases in those with a CVD and diabetes, as compared to those with just CVD (DECODE Study Group, 2003, Eberly et al., 2003).

Approximately one third of strokes are caused by high cholesterol (World Health Organization, 2009, Mathers et al., 2008), which increases the risk of atherosclerosis, and therefore the risk of heart disease and stroke (World Health Organization and UNAIDS, 2007). Raised blood cholesterol refers to a lipoprotein profile which contains high levels of low density lipoprotein cholesterol (LDL), also known as ‘bad’ cholesterol, and triglycerides. High levels of LDL cholesterol are deposited into blood vessels, which can then cause atherosclerosis (World Health Organization, 2009, Mendis et al., 2011). In 2008, raised blood cholesterol had a prevalence of 39%, causing 2.6 million deaths and 29.7 million DALYS worldwide (Alwan, 2011, World Health Organization, 2009).

1.1.3 Diabetes Mellitus

Diabetes Mellitus is a chronic disease that involves the body’s production or utilization of insulin, and is identified as either Type 1 or Type 2. Type 1diabetes has its onset in childhood when the pancreas fails to produce the insulin required to break down glucose in the blood stream. Type 2 (adult onset) diabetes results from the inability of the body to effectively utilize insulin which leaves it unable to break down the glucose in the blood stream (World Health Organization, 2014c). An excess of blood glucose in the

blood stream, known as hyperglycaemia, can cause serious complications including damaging nerves and blood vessels. When left untreated, this can lead to amputation, blindness and cardiovascular disease (Mendis et al., 2011).

It is estimated that 347 million people have Type 2 diabetes, with 1.5 million deaths in 2012 directly attributable to the disease (Danaei et al., 2011, Mathers et al., 2014). Type 2 diabetes accounts for 90% of global diabetes cases (World Health Organization Consultation, 1999), with an estimated 175 million of these cases being undiagnosed (Aguiree et al., 2013).

Type 1 diabetes, also known as childhood-onset diabetes, is found in approximately 497,100 children between 0-14 years globally of which approximately 64,000 are found in the Middle East/North Africa region, with 10,700 new cases being enrolled each year. Because Type 1 diabetes involves the inability of the pancreas to produce insulin, these children need regular insulin-therapy is needed to break down their blood glucose (Aguiree et al., 2013).

1.1.4 Cancer

There are over 100 different types of cancers, each affecting different areas of the body. While each type of cancer is its own disease, there are five main recognized types: (1) cancers that involves the skin or tissues lining internal organs (carcinoma), (2) those that involve the bone, cartilage, fat, muscle, blood vessels and connective or supportive tissue (sarcoma), (3) those that start in bone marrow (leukaemia), (4) in the cells of the immune system (lymphoma and myeloma), and (5) in the brain and spinal cord (central nervous system cancers) (National Cancer Institute, 2014). Each of these cancers occurs when new cells are created without a cause and old or injured cells do not undergo apoptosis when necessary. The accumulation of these extra cells produces a mass of tissue called a tumour.

Tumours can be benign or malignant. Benign tumours are non-cancerous tumours that can be safely removed without the need for further treatment. Malignant tumours are cancerous and grow to other areas of the body, a process known as metastasis, which is the major cause of death from cancer (World Health Organization, 2014b).

While both men and women are affected by cancer, they are susceptible to different forms of the disease: men are vulnerable to lung, prostate, colorectum, stomach and liver cancers; whereas women are prone to breast, colorectum, lung, cervix and

stomach cancers (World Health Organization, 2014b). Overall, the most common cancers are lung, liver, stomach, colorectal, breast and oesophageal cancers, with almost 8.2 million cancer-related deaths worldwide (Stewart and Wild, 2014).

1.2 Risk Factors for NCDs

The prevalence of risk factors varies between countries by incomes group, according to specific risk factors, and by sex. High, middle, and low-income countries present differing risk profiles. Some risk factors are high or are becoming higher in middle-income countries, such as tobacco use among men, which is highest among the lower-middle-income countries of the Western Pacific Region and the European Region. The rate of overweight and obesity among adults is highest in upper-middle-income countries, while physical inactivity is highest in high-income countries. The rates of inactivity in middle-income countries are rising among women, and have already reached parity with high-income country levels among men. Several key risk factors are highest in high-income countries, including: adult per capita alcohol consumption; physical inactivity among women, total fat consumption and elevated total cholesterol.

The WHO objectives from the 2008–2013 Action Plan for the Global Strategy for Prevention and Control of NCDs (World Health Organization, 2008) highlight several interventions for reducing the shared behavioural risk factors implicated in the development of NCDs. Unfortunately, the 2008–2013 Action Plan did not discuss the brain or brain disorders, even though, brain disorders (neurological, neurosurgical and psychiatric diseases together) have risen and overtaken all other burdens of chronic diseases. Numerous epidemiological studies on mental disorders throughout the world have shown that approximately one-third of the adult population suffers from a mental disorder each year (Kessler et al., 2009). According to one estimates, brain disorders account for approximately 13% of global disease, surpassing both cardiovascular diseases and cancer (Collins et al., 2011).

1.2.1 Smoking and Tobacco Use

Smoking increases the risk of developing respiratory diseases, CVD, diabetes and cancer (Patton et al., 2012). Jha and Chaloupka (1999) estimate that, globally, 82,000-99,000 youth below the age of 20 start smoking daily, with the majority of adult smokers having started below the age of 25. According to one study, 10% of children between age 13-15 smoke cigarettes and 10% use other tobacco products (Viner et al., 2012). It has

also been estimated that approximately 40% of all children worldwide are exposed to second hand smoke (Eriksen et al., 2012).

It has been suggested that tobacco smoke, whether direct or through second-hand exposure, is responsible for 10% of all cases of CVD (World Health Organization, 2009). Tobacco increases the risk of dying from CVDs by 2-3 fold and the risk of lung cancer 20-30 fold, and is thus one of the most important risk factors to address in the prevention of NCDs (Boutayeb and Boutayeb, 2005). There is established evidence that quitting smoking results in a decrease in mortality from coronary heart disease (World Health Organization and UNAIDS, 2007), and that those who quit smoking between 35 and 44 years have the same survival rates as non-smokers (Doll et al., 2004).

However, tobacco consumption in developing countries continues to rise by 3.4% each year (Boutayeb and Boutayeb, 2005), while the disease burden attributed to both direct and second-hand tobacco smoke accounted for the deaths of 5.4 million people in 2004. This is expected to increase to 8.3 million by 2030, at which point tobacco-attributed deaths will account for 10% of total global mortality (Mathers et al., 2008) and 6.3% of DALYs in 2010 (Murray and Lopez, 2013).

1.2.2 Excessive Use of Alcohol

The harmful use of alcohol is frequently identified as one of the modifiable risk factors implicated in social and psychological harms, and the development of NCDs. The specific physical harm caused by alcohol has been linked to the formation of toxic acetaldehyde and free radicals (Tuma and Casey, 2003).

Alcohol has been implicated as a risk factor in the development of 8 types of cancer: cancers of the oral cavity, pharynx, larynx, oesophagus, liver, colon, rectum and breast (Baan et al., 2007, International Agency for Research on Cancer, 1988, Singletary and Gapstur, 2001, Klatsky et al., 1988). The amount of alcohol consumed on a daily basis and the risk of developing one of these types of cancers is unique to each type of cancer.

Alcohol consumption has also been linked to the risk of developing hypertension or atrial fibrillation in a dose-dependent fashion for both men and women (Taylor et al., 2009, Samokhvalov et al., 2010). With heavy alcohol consumption the risk for stroke increases (Patra et al., 2010). Harmful alcohol use is also associated with liver cirrhosis,

pancreatitis and Type 2 diabetes (Kao et al., 2001, Wannamethee et al., 2003, Irving et al., 2009, Rehm et al., 2010).

Harmful use of alcohol is estimated to account for 45% DALYS globally, where "harmful use" is defined by the level and frequency with which alcohol is ingested, where a high level and ‘binge’ pattern of consumption is identified as most harmful (Mendis et al., 2011).

1.2.3 Physical Inactivity

A sedentary lifestyle is the biggest factor that can lead to becoming overweight and obese, which can then cause metabolic changes implicated in the development of NCDs. In contrast, it has been shown that moderate to high fitness levels substantially reduce the risk of developing a CVD (Habib and Saha, 2010), and is also a protective factor in men with diabetes at all BMI levels (World Health Organization, 2010).

Objective Three in the 2008–2013 WHO Action Plan (2008) endorses the promotion of physical activity in member states in order to reduce the effect of a sedentary lifestyle on the development of NCDs and to assist in the management of existing NCDs. The Action Plan also endorses the implementation of school-based physical activity programs and the creation of a physical environment that is supportive of safe recreational activity (Alwan, 2008). These goals are important for promoting physical activity among youth and for reducing the rise of overweight and obesity.

The global targets identified in the 2013–2020 WHO Action Plan (World Health Organization, 2013a) include a 10% reduction in physical inactivity, a 25% reduction in raised blood pressure, improvements in the physical education available at educational settings, and the creation of opportunities for physical activity before, during, and after the school day.

1.2.4 Unhealthy Diet and NCDs

The consumption of foods high in saturated fats, trans fats, salt and sugar have been found to lead to 14 million (40%) of overall deaths caused by NCDs each year (World Health Organization, 2004). Certain types of cancer are increased by eating preserved foods and consuming large amounts of alcohol, while the risks of certain types of cancer are reduced by increasing fruit and vegetable intake, since aspects of chemoprevention are found in foods with a high fibre content, Vitamin A and Vitamin C (Habib and Saha, 2010).

The changing nature of food itself is a contributory factor for the development of many chronic diseases. In fact, the way food is being grown, harvested, stored and transported plays a significant role in the nutritional quality of food, especially fruits and vegetables. This becomes vital in the context of Oman where the harsh weather conditions and high salinity of soil makes the country unsuitable for farming and, therefore, has to rely on the importation of food from other countries. It is well-known that food grown locally is higher in nutritional quality food that has been packed and shipped over long distances: cooking and storing food in aluminium vessels, cans and foil, may increase its aluminium content, particularly in cases of salty, acidic or alkaline foods (Ribes et al., 2008); aluminium is also implicated in some neurodegenerative disorders (Domingo, 2006). The quality of food has also changed drastically due to commercial farming. Wang et al. (2010) reported that the DHA content of chicken meat, which was about 170mg/100g in 1970, is now only 13 mg/100g; concurrently, the fat content has increased. Hence, to receive the same amount of DHA from a chicken, one now has to consume a larger – and fattier – portion, as compared with chicken produced in 1970.

Dietary habits when paired with a sedentary lifestyle are also major factors that lead to overweight and obesity. Globally, in 2005, 1 billion people were overweight and 300 million were obese (World Health Organization, 2009).

The highest number of DALYs for NCD risk factors are attributed to an unhealthy diet and a high BMI (Rahim et al., 2014b). In 2008, 2.3% of global DALYs were attributed to overweight and obesity (World Health Organization, 2009), while in 2010, an unhealthy diet and a sedentary lifestyle together accounted for 10.2% of the global DALYs. As already noted, dietary habits and obesity that result in an increase in BMI are the main risk factors for the development of Type 2 diabetes, stroke, CVDs, and some types of cancers (World Health Organization, 2009). This is due to the metabolic changes that are implicated in the development of insulin resistance, an increase in blood pressure, an increase in cholesterol and heart failure (Kenchaiah et al., 2002, World Health Organization, 2003b).

1.2.4.1 Nutritional Problems and Hazards of Western and Intensified Food Patterns

As previously mentioned, changing dietary habits are in large part responsible for the increased availability in sugars, animal fats, animal products, and a decrease in the

availability of vegetables (Madanat et al., 2008). Globalization and urbanization not only impact the types of food people eat but also increases their level of physical inactivity (Popkin, 2009). This is called a 'nutritional transition' that is a global change in dietary habits that affect the most important risk factors for NCDs. The primary processes through which globalization affects income, lifestyles and food availability are increased mechanization and industrialization, which alter diet patterns and physical activity (Popkin, 2006). The current nutritional transition is often characterized as shift towards a 'Western' diet which contains high energy and high fat intake, added free sugars, salty foods and low levels of dietary fibre, vegetables and fruits (Popkin, 1993, Jacka et al., 2010).

Cordain et al. (2005b) examined the evolution of the Western diet from that of our ancient ancestors and determined that the current Western diet is primarily composed of foods that affect glycaemic load, fatty acid composition, macronutrient composition, micronutrient density, acid-base balance, sodium-potassium ratio and fibre content. The foods that are implicated include "dairy products, cereals, refined cereals, refined sugars, refined vegetable oils, fatty meats, salt and combinations of these foods" (Cordain et al., 2005b).

Simopoulos (2002a) posits that the way the human body metabolizes food has been relatively constant despite nutrition transitions, and is optimized for the types of food more characteristic of the human diet 40,000 years ago. The Agricultural Revolution 10,000 years ago changed the availability and types of foods in ways that are drastically different from the optimal diet for human physiology and metabolism. It is suggested that our bodies are not suited for the current environment characterized by an over-abundance of the kinds of food associated with the "Western" diet.

1.2.4.2 Glycaemic index

Refined grains, sugars and carbohydrate-rich foods have a higher glycaemic index than unprocessed foods such as fruits and vegetables. The impact of these foods on blood glucose can be measured by the Glycaemic Index and the Glycaemic Load. The Glycaemic Index measures the potential of a food or combination of foods to raise blood glucose (Jenkins et al., 1981). It takes into account a number of factors, including the fibre, fat and protein content, the method of preparation or physical form, the nature of the starch (and its interaction with fibre), the particle size and rate of digestion (Thorne et al., 1983, Krezowski et al., 1986). The Glycaemic Load assesses the total glycaemic

effect of the diet and involves both the Glycaemic Index of specific foods and total dietary carbohydrates (Salmerón et al., 1997, Salmeron et al., 1997).

Both of these measures are essential for understanding the effect of diet on the development of disease. When blood glucose is elevated, the pancreas is stimulated to produce insulin, thereby increasing insulin levels in the blood (Cordain et al., 2005b). The long-term consumption of high glycaemic foods can result in chronic hyperglycaemia (high glucose in the bloodstream) and hyperinsulinemia (high insulin in the blood stream). Both conditions are pivotal in the development of insulin resistance, which can lead to obesity, chronic heart disease, Type 2 diabetes, hypertension and dyslipidemia (Ludwig, 2002, Liu and Willett, 2002).

A diet with high GL and with a low intake of cereal dietary fibre was associated with an increased risk of Type 2 Diabetes in both men and women (Salmeron et al., 1997, Salmerón et al., 1997). It has also been found that when glucose is absorbed over a long period of time, there is a prolonged suppression of free fatty acids and lower blood glucose concentrations (Jenkins et al., 2002). In addition, increase in glucose is associated with a decrease in antioxidants in the blood, and it has been found that supplementation with vitamin E improves insulin function (Paolisso et al., 1993, Ceriello et al., 1998).

The risk of colorectal cancer is increased with the intake of high GI and GL foods, although some doubts persist as to whether women are equally susceptible to this risk as are men (Franceschi et al., 2001, Michaud et al., 2005). There has also been a demonstrated relationship between a higher GI and the risk of developing breast and ovarian cancer (Augustin et al., 2001, Augustin et al., 2003). Those who consume a Western diet are also at a significantly higher risk of developing COPD than those with a prudent or traditional diet (Varraso et al., 2007).

In contrast, a low GI diet was associated with high levels of HDL cholesterol, which is important in maintaining cardiovascular health (Jenkins et al., 2002).

1.2.4.3 Refined/Readily Soluble Carbohydrates

Carbohydrates account for up to 80% of the diet (Asp, 1994), of which there are two types. The first is the digestible type, which is primarily composed of monosaccharides that provide glucose to the tissues, found in such foods as white breads, refined and processed foods and sweetened beverages (Harvard School of Public Health,

2015). The second type is the undigestible type, which is fermented in the colon to short-chain fatty acids and include oligosacchardies and dietary fibre (Asp, 1994). Foods that contain undigestible carbohydrates are not or only minimally processed or refined, but include fruits and vegetables, as well as whole-grains and legumes (Harvard School of Public Health, 2015). Mann et al. (2007) indicate that foods containing undigestible carbohydrates are the most appropriate source of carbohydrates in the diet. The WHO suggests that the optimal intake of carbohydrates should come from vegetables and fruits and should make up 55-75%, or 400 g/day of total energy (World Health Organization, 2003a).

Carbohydrates have been studied extensively, particularly concerning their effects on CVD and diabetes. Gross et al. (2004) found a significant correlation between Type 2 diabetes and, when controlled for energy intake, corn syrup, which is a commonly found digestible-type carbohydrate. They also found that a high intake of refined carbohydrates and a low intake of dietary fibres are significantly associated with Type 2 diabetes. An inverse relation between dietary intake of whole-grain foods and the development of coronary heart disease, cardiovascular diseases and Type 2 diabetes have been well documented in the literature (Liu, 2002, Liu et al., 1999, Truswell, 2002, McKeown et al., 2002, Mellen et al., 2008). In one study (Knekt et al., 1994) found lower risk of developing CVD in men and women, had higher dietary intakes of vitamin C and carotenoids (antioxidants). They further suggested that vegetables and fruits contain other factors that conferred the protective effects against CVD. WHO has also suggested that increasing the consumption of fruits and vegetables, as well as whole-grains and legumes, is associated with a decreased risk of developing a CVD (World Health Organization, 2003a).

Consumption of refined sugars, vegetable oil, dairy products and alcohol all of which contain little fibre (Cordain, 2002) and constitute 48.2% of the energy intake of a typical US diet. Refined grains, which are 85% of the grains consumed in the US, contain 400% less fibre than whole grains and are also implicated in the low dietary fibre content of the US diet (Cordain et al., 2005b). Dietary fibre has been found to slow the digestion and absorption of food and regulate metabolic hormones which results in an improved glycaemic response, lower serum insulin concentrations and plasma lipids (Anderson and Akanji, 1991, Vinik and Jenkins, 1988, Chandalia et al., 2000). In particular, insoluble fibre in whole-grains has been found to have an inverse association with the risk of developing diabetes. Therefore, when looking at carbohydrates, it

appears that the fibre content may partially account for the beneficial effects of the non-refined foods (Pereira et al., 1998, Romieu et al., 2004).

1.2.4.4 Salt Intake

Salt (sodium chloride) is found in many natural foods, but is particularly high in processed foods, such as breads and meats, as well as snack foods, condiments and stock cubes (World Health Organization, 2013b). The World Health Organization recommends that the daily intake of salt should be limited to 5g/day. However, the average salt intake per person in most countries is between 9 and 12 g/day with the highest levels found in China (World Health Organization, 2007, Stamler et al., 2003).

Salt is an important consideration when examining the relationships between diet and NCDs since a high dietary intake of salt can lead to hypertension, and has been associated with a greater risk of a stroke, cardiovascular event, gastric cancer and Type 2 diabetes (Strazzullo et al., 2009, Tsugane, 2005, Shikata et al., 2006).

Morgan et al. (1978) demonstrated that blood pressure can be reduced in those who suffer from hypertension by reducing the dietary intake of salt The World Health Organization, has attributed 62% of strokes and 49% of coronary heart diseases to high blood pressure and hypertension (He and MacGregor, 2010).

Hypertension is also a risk factor in Type 2 diabetes, and can result in the development of a CVD or mortality from a CVD. But high blood pressure can also be reduced in those with Type 2 diabetes by restricting their salt intake. This reduction in blood pressure may also protect organs from the damage that results from diabetes (Ekinci et al., 2011).

Gastric cancer has also been associated with higher intake of salt and salty foods, which may occur in one of two ways. First, salt and salty foods may increase the risk of developing a Helicobacter pylori infection, a known risk factor for the development of gastric cancers. Second, high levels of salt may produce hypertonicity which can result in atrophic gastritis, thereby increasing the risk of stomach cancer (Joossens et al., 1996, Tsugane, 2005). This is also supported by the World Health Organization (2003a).

1.2.4.5 Cholesterol

Cholesterol is a fat-like substance with a waxy consistency that is produced in the liver. Every human cell needs a minute amount of cholesterol in order to function

properly, so a limited supply of cholesterol is obligatory. Due to its waxy consistency, cholesterol can stick to the interior of blood vessel walls. Over time, cholesterol, fat and other substances can accumulate, thereby narrowing the blood vessels. This is the initial stage of atherosclerosis. Atherosclerosis is responsible for coronary heart diseases, stroke and diseases of peripheral circulatory system. But Okuyama et al. (2007) and Perlmutter and Lober (2013) reject the claim that cholesterol is the main culprit for heart-related diseases, arguing instead that some lipoproteins. such as LDL, have phospholipids that form highly potent inflammatory agents on oxidation, regardless of cholesterol. And death from heart attack is a death from ischemia, which is worsened by arrhythmia, and from thrombosis, brought on by a predisposition to inflammatory plaques in the arteries.

Cholesterol is the chief sterol found in humans, and apart from being the precursor of steroid hormones and bile acids, it has a crucial role in the structure of the cell membranes where it adjusts their fluidity by reducing it in the areas where unsaturated fatty acids predominate and increasing it in the areas where saturated fatty acids prevail.

The daily cholesterol intake of westerners generally varies between 600 and 1,000 mg. The actual cholesterol absorbed is restricted to 50% of the amount ingested up to 500 mg, above which absorption falls to 35%. High cholesterol intake raises plasma cholesterol, although there is a negative feedback mechanism in which the liver reduces its endogenous synthesis of cholesterol when the exogenous cholesterol supply increases and vice-versa (Behrman and Gopalan, 2005).

Plasma cholesterol is, in fact, only partially regulated by dietary intake of cholesterol. However, the type of fatty acids ingested is extremely important since saturated fatty acids raise cholesterol whereas unsaturated fatty acids lower it:

- If the dietary cholesterol is lowered to 100 mg/day, it was found that the serum cholesterol is decreased by 5 mg/dl.
- If the dietary fat is highly saturated fatty acids, a +300 mg cholesterol intake results in an increase in serum cholesterol by 40 mg/dl.
- If the dietary fat is rich in monounsaturated fatty acids such as olive oil, a + 300 mg cholesterol intake leads to a neutral effect, i.e. no effect is observed on serum cholesterol level.

- If the dietary fat is rich in polyunsaturated fatty acids such as cotton seed, corn and soy bean oil, a + 300 mg cholesterol intake leads to a decrease or reduction in serum cholesterol by 35 mg/dl (Hegsted et al., 1965).

Furthermore, it should be noted that the cholesterol absorbed from food is not the only source of blood cholesterol, since cholesterol can be synthesized endogenously by the liver and gastrointestinal tract cells from acetyl-CoA (an intermediate metabolite). Thus hexoses, glycerol, fatty acids and certain deaminated amino acids can contribute a carbon skeleton or atoms for the denovo synthesis of cholesterol if their intake is high (Behrman and Gopalan, 2005).

1.2.5 Oxidative Stress and Antioxidant Nutrients

1.2.5.1 Oxidative stress and NCDs

Oxidative stress is damage to cell structure and cell function by overly reactive oxygen-containing molecules, and occurs when there is an imbalance between free radical production and antioxidant capacity. Actually, the generation of free radicals is a normal and continuous cell process (Shami and Moreira, 2004). In adequate proportions, their presence enables the production of energy through adenosine triphosphate (ATP), phagocytosis, cell growth regulation and defence during the infectious process. However, once formed, the highly reactive free radicals can start a chain reaction producing toxic effects (Barreiros and Jorge, 2006) that damage all vital components of the cell, including proteins, lipids, and DNA (Badid et al., 2010, Halliwell, 2011). In humans, oxidative stress is thought to be involved in the development of cancer (Halliwell, 2007), Parkinson's disease, Alzheimer's disease (Valko et al., 2007, Pohanka, 2013), atherosclerosis, heart failure (Singh et al., 1995), myocardial infarction (Ramond et al., 2013, Dean et al., 2011), fragile X syndrome (de Diego-Otero et al., 2009), Sickle Cell Disease (Amer et al., 2006), lichen planus (Aly and Shahin, 2010), vitiligo (Arican and Kurutas, 2008), autism (James et al., 2004), infection (Pohanka, 2013), and chronic fatigue syndrome (Kennedy et al., 2005). However, reactive oxygen species can be beneficial, as they are used by the immune system to attack and kill pathogens (Segal, 2005).

There is increasing evidence in both experimental and clinical studies that chronic oxidative stress plays a major role in the pathogenesis of both types of diabetes mellitus. Free radicals are formed disproportionately in diabetes by glucose oxidation, nonenzymatic glycation of proteins, and the subsequent oxidative degradation of

glycated proteins. (Maritim et al., 2003). Information about the use and benefits of antioxidants in persons with diabetes is also limited. Persons with diabetes may be more prone to oxidative stress because hyperglycemia depletes natural antioxidants and facilitates the production of free radicals. Other factors such as homocysteine, insulin resistance, and aging may also be contributory (Penckofer et al., 2002).

Oxidative stress has also been associated with the development of cardiovascular disease, although the exact role of antioxidants in the primary and secondary prevention of coronary heart disease is still under study. Epidemiologic evidence indicates that antioxidants may decrease cardiovascular risk, but clinical trial data remain inconclusive (Penckofer et al., 2002).

The cellular redox imbalance created by oxidative stress is found to be present in cancerous as opposed to normal noncancerous cells, which has led many researchers to suspect that such imbalances may be pivotal in the development of various forms of cancer. It is thought that DNA mutation plays a crucial role in the process, although the precise mechanism remains unknown (Valko et al., 2006).

1.2.5.2 Antioxidants and Oxidative Stress

As noted above, oxidative stress denotes an imbalance between oxidants and antioxidants in favour of oxidants. Since antioxidants are intimately involved in the prevention of cellular damage – the common pathway for cancer, aging, and a variety of other diseases – this imbalance robs the body of its own capacity to detoxify and repair damaged cells.

An antioxidant is a molecule that inhibits the oxidation of other molecules, it can safely interact with free radicals and terminate the chain reaction before vital molecules are damaged. Antioxidants terminate these chain reactions by being oxidized themselves. So, antioxidants are often reducing agents such as thiols, ascorbic acid, or polyphenols (Sies, 1997). Both plants and animals maintain complex systems of antioxidants, such as glutathione, vitamin C, vitamin A, and vitamin E as well as enzymes such as catalase, superoxide dismutase and various peroxidases.

Although there are several enzyme systems within the human body that scavenge free radicals, the principle micronutrient antioxidants are vitamin E, beta-carotene, and vitamin C. Additionally, selenium, a trace metal that is required for proper function of one of the body's antioxidant enzyme systems, is sometimes included in this category.

Since the body cannot manufacture these micronutrients, they must be supplied in the diet (Greenberg et al., 1994). On the other hand, Poston et al. (2004) did not find any improvements in pregnant women with pre-eclampsia, when supplemented daily with 1000 mg vitamin C and 400 IU vitamin E from the second trimester of pregnancy until delivery. Instead, they found an increase the rate of babies born with low birth weight. In other words, vitamins alone cannot work wonders since they occur in nature with a range of other nutrients and it is likely that their interactions are vitally important.

Vitamin E (d-alpha tocopherol) is a fat soluble vitamin present in nuts, seeds, vegetable and fish oils, whole grains (especially wheat germ), fortified cereals, and apricots. The current recommended daily allowance (RDA) is 15 IU per day for men and 12 IU per day for women.

Vitamin C (ascorbic acid) is a water soluble vitamin present in citrus fruits and juices, green peppers, cabbage, spinach, broccoli, kale, cantaloupe, kiwi, and strawberries. The RDA is 60 mg per day. Intake above 2000 mg may be associated with adverse side effects in some individuals.

Beta-carotene (a precursor to vitamin A, retinol) is present in liver, egg yolk, milk, butter, spinach, carrots, squash, broccoli, yams, tomato, cantaloupe, peaches, and grains. Because beta-carotene is converted to vitamin A by the body there is no set requirement. Instead, the RDA is expressed as retinol equivalents (Hennekens et al., 1994).

1.3 Fatty Acids: An Overview

Fatty acids are carboxylic acids with a long aliphatic tail (chain) which may vary from 4 to 30 carbon atoms. Most of the fatty acids found in plasma membrane have between 16 and 24 evenly numbered carbon atoms. The predominant fatty acids are straight chain, and can be saturated (SFA) or unsaturated (USFA). Fatty acids are the major lipids, and therefore one the most fundamental categories of biological lipids.

Several systems of nomenclature are used for fatty acids. Trivial or common names are the historical names most frequently used in literature. The International Union of Pure and Applied Chemistry (IUPAC) system of nomenclature numbers the carbon atoms in fatty acids sequentially from the end of the chain. The double bond configuration is labelled using Z/E notation (Z for *cis* and E for *trans*). In the *cis* configuration, the two hydrogen atoms are situated on the same side of the double bond,

whereas in the *trans* configuration, the two hydrogen atoms lie on each side of the double bond.

Another system of nomenclature in use is the delta system, in which the Greek delta symbol (Δ) is used to indicate the position of double bond. Here, the Greek symbol omega (ω), or the letter *n*, denotes the position of the first double bond from the methyl end. The delta symbol is preceded by a *cis*- or *trans*- prefix indicating the configuration of the double bond.

1.3.1 Saturated Fatty Acids (SFAs)

Saturated fatty acids (SFAs) contain only single carbon-carbon bonds; there are no double bonds within the acyl chain. Most SFAs occurring in nature have an unbranched and even number of carbon atoms, with the general formula: $CH3\ (CH2)_n\ COOH$, where n varies from 7-21 depending on the source. SFAs are extremely stable, being the least reactive of chemical compounds; their melting point increases with chain length. Hence, decanoic and longer chain fatty acids are solid at room temperature.

Saturated fatty acids are further classified into three subgroups: short, medium and long chain fatty acids. Short chain fatty acids contain less than eight carbon atoms. Butyric (4:0), and caproic (6:0) are the most important members of this group, and occur mainly in milk fat. Medium chain fatty acids are fatty acids with 8-14 carbon atoms. Capric (10:0), lauric (12:0) and myristic (14:0) are members of this group. The long chain fatty acids contain more than 14 carbon atoms, of which plamitic (16:0) stearic (18:0) are the most important (plamitic acid is the most widely occurring SFA). Saturated fatty acids longer than stearic (18:0), arachidic (20:0), behenic (22:0) and lingcreic (24:0) are minor dietary components (Ratnayake and Galli, 2009).

1.3.2 Unsaturated Fatty Acids (USFAs)

Unsaturated fatty acids (USFAs) are organic compounds containing one or more double bonds and, hence, are capable of undergoing additional reactions. They are further classified into monounsaturated (MUFA) and polyunsaturated fatty acids (PUFA).

Monounsaturated fatty acids (MUFAs) contain a single carbon-carbon double bond. The presence of a single double bond allows for the two (*cis* and the *trans*) configurations. The *cis* configuration results in a non-straight structure, which confers more fluidity to membranes. The *trans* configuration creates a straight chain, which

increases cell membrane rigidity, with properties similar to saturated fatty acids. The double bond is most frequently located at the Δ9 position. Oleic acid (cis-9-octadecenoic) is the most common cis-MUFA and is the most widely distributed of all natural lipids. The fatty acids present in animal cell membranes have *cis* configurations (Shantha and Napolitano, 1992).

1.3.3 Polyunsaturated Fatty Acids (PUFAs)

Polyunsaturated fatty acids (PUFAs) have two methylene-interrupted double bonds, i.e., with two or more double bonds of the *cis*-configuration separated by a single methylene group. The presence of several double bonds lowers their melting point and produces extremely flexible molecules. The influence of a fatty acid's structure on its melting-point is such that branched chains and cis double bonds will lower the melting point compared with that of equivalent saturated chains. The melting point of a fatty acid also depends upon whether the chain is even- or odd-numbered; the latter have higher melting points (Rustan and Drevon, 2005). Therefore, the high "liquidity" of cell membranes is usually due to the presence of unsaturated fatty acids. Besides their vital role in cellular membranes, PUFAs are also the major constituents of plasma lipoprotein particles, phospholipids, triglycerides, and cholesterol esters (Le et al., 2009).

The natural PUFA with methylene-interrupted double bonds (with *cis* configuration) can be divided into twelve families, depending upon the location of the double bond (from the n-1 to n-12 position) (Gunstone, 1999). In term of human health and nutrition, the most important families are n-3, n-6 and n-9, all of which are metabolized using the same group of enzymes. The three types of omega-3 fatty acids involved in human physiology are α linolenic acid (ALA), found in plant oils, and eicosapentaenoic acid (EPA) and docosahexaenoivc acid (DHA), both commonly found in marine oils; marine algae and phytoplankton are primary sources of omega-3 fatty acids.

1.3.4 Essential Fatty Acids (EFAs)

An 'essential' nutrient is one that is needed for the normal development and function of cells throughout the life cycle (Cunnane, 2003). The phrase "essential fatty acid" was first coined by Burr and Burr in 1929 when these FAs were used to reverse the adverse symptoms in young rodents fed on a fat-free diet. The fat-free diet resulted in dermatitis, kidney lesion, infertility, impaired growth, and premature death. These symptoms were reversed with the introduction of linoleic acid (LA) and α-linoleic acid

(ALA) in their diets (Burr and Burr, 1973). It was discovered, however, that ALA was not as effective as LA in reversing the symptoms.

In humans, the importance of LA was not realized until 1958 when Arild Hansen and his colleagues demonstrated that LA deficient milk was associated with skin symptoms and growth retardation (Hansen et al., 1958, Holman et al., 1982). The essentiality of ALA for humans was established later when it was discovered that ALA deficiency caused neurological and visual impairment and that these lesions were treatable by supplementation with ALA (Holman et al., 1982).

It is increasingly recognized that PUFAs are essential for the human diet, as the body is unable to synthesize LA and ALA, and the de novo synthesis of EPA and DHA do not meet the body's metabolic needs (Gomez Candela et al., 2011). EFA deficiency can occur in both young and old subjects and its effects are both rapid and extreme; on the other hand, after supplementation, the symptoms can disappear (Holman, 1960). It is now accepted that the clinical manifestations related to LA and ALA are due to the deficiency of their longer chain metabolites, such as arachidonic acid (AA), eicosapentaenoic (EPA) and docosahexaenoic (DHA) acids. Hence, AA, EPA, and DHA are considered conditional EFAs since their production may be inadequate under certain conditions, thereby requiring exogenous supplementation (Le et al., 2009).

1.3.5 Endogenous Synthesis of Long-Chain Polyunsaturated Fatty Acids

Long-chain polyunsaturated fatty acids (LCPUFAs) are important components of membrane lipids in all tissues. The most important of these are omega-6 fatty acids, linoleic acid, and the omega-3 fatty acids. Among these three families of PUFAs, only oleic acid (OA), a parent n-9 fatty acid, can be synthesized by mammals from simple carbon precursors. Both the parent n-3 and n-6 fatty acids must be ingested, since mammals cannot insert the double bonds required to produce ALA and LA (Pudelkewicz et al., 1968). Once ingested, ALA and LA can be desaturated and elongated to varying degrees (Innis, 1991, Wang et al., 2005) The pathway leading to the biosynthesis of DHA in mammals from docosapentaenoic acid (DPA) has only recently been deciphered, called the Sprecher pathway (Voss et al., 1991, Sprecher et al., 1995), which is now accepted as a working model for the process, although the exact enzymes and mechanism involved in retro-conversion are not yet fully delineated (Pereira et al., 2003).

1.3.6 Clinical and Biochemical Markers of Essential Fatty Acid Deficiency

Essential fatty acid deficiency (EFAD) typically occurs when less than 1-2% of total calories are provided by EFAs (Holman, 1960). In humans, biochemical changes consistent with EFAD can occur in as little as a few days in infants. In older patients, the symptoms of EFAD may take 4-6 weeks to appear. Clinical signs of EFAD include growth retardation, hair loss, infertility, coagulopathies, dry and scaly skin (Alfin-Slater and Aftergood, 1968). The biochemical indicator of EFAD is increased oleic acid (OA) conversion to mead (MA, 20:3 n-9) and di-homo mead (22:3 n-9) acids (Siguel et al., 1987). Conversion of OA to MA (n-9) only occurs when there are low dietary levels of both ALA and LA. Hence, a mead and arachidonic acid ratio of less than 0.2 is equated with linoleic acid sufficiency (Mascioli et al., 1996).

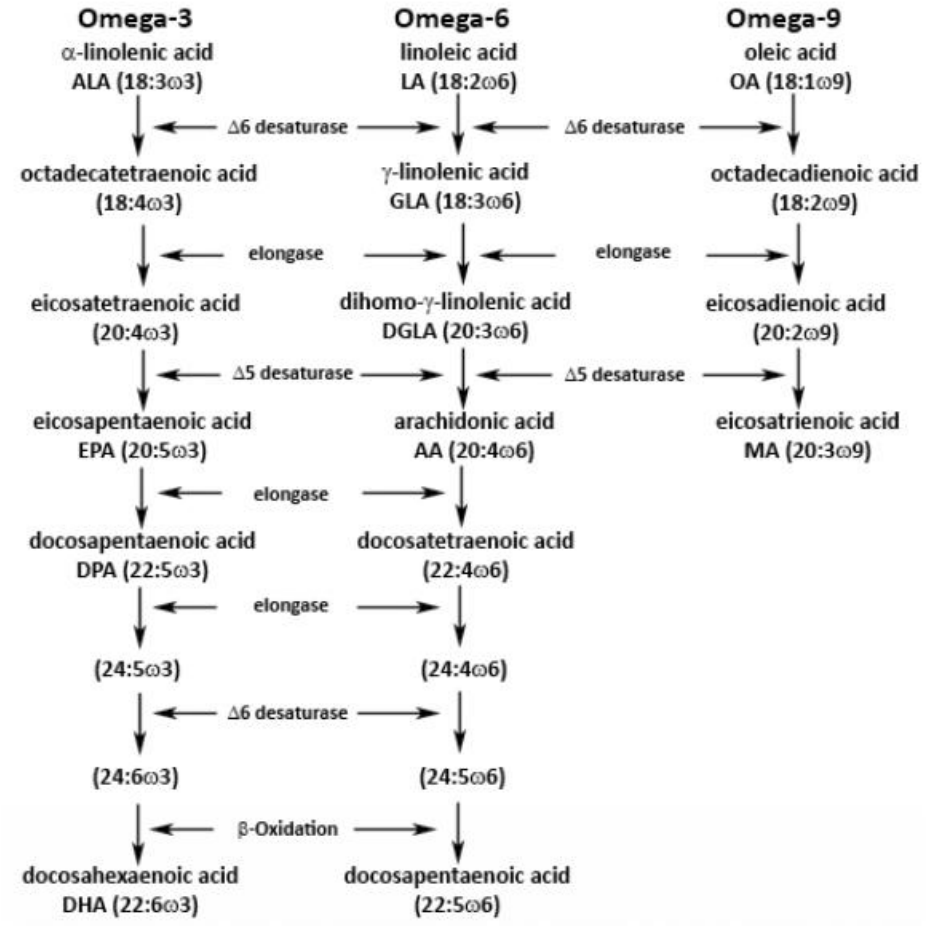

Figure 1-2: Pathway of metabolism and synthesis of n-3, n-6, and n-9 Long-Chain Polyunsaturated Fatty Acids (from Le et al. (2009))

Likewise, an insufficient intake of DHA, if n-6 fatty acids are not limiting, leads to a decrease in DHA and a simultaneous increase in n-6 docosapentaenoic acid (22:5n-6) synthesized from n-6 docosatetraenoic acid (22:4n-6). Because of this, the ratios of 22:5n- 6/22:4n-6 and DHA/22:5n-6 are regarded as reliable DHA markers of status.

1.3.7 Dietary Requirements of Long-Chain Polyunsaturated Fatty Acids

The minimum intake values for essential fatty acids to prevent deficiency symptoms are estimated to be 2.5%E LA plus 0.5%E ALA. Based on epidemiologic studies and randomized controlled trials of CHD events, the minimum recommended value of total PUFA consumption for lowering LDL and total cholesterol concentrations, increasing HDL cholesterol concentrations and decreasing the risk of CHD events is 6%E. In similar experimental studies, the risk of lipid peroxidation may increase with high (>11%E) PUFA consumption, particularly when tocopherol intake is low. Therefore, the acceptable range for total PUFA (n-6 and n-3 fatty acids) can range between 6 and 11%E. The adequate intake to prevent deficiency is 2.5–3.5%E. Thus, according to the 2008 Joint FAO/WHO Expert Consultation (2009), the recommended range (ADMR) for PUFA is 6–11%E.

Because LA is abundantly available in the human diet, the amount of AA almost always exceeds the level needed to maintain the metabolic needs of n-6 fatty acids, which are abundantly present in liquid vegetable oils. In rodents, AA alone has been shown to be as effective as LA in preventing symptoms of essential fatty acids deficiency (EFAD) (Thomasson, 1962, Hansen et al., 1986) demonstrating that AA can replace LA as the sole source of dietary omega-6 fatty acids (Le et al., 2009).

Unlike n-6 fatty acids, however, n-3 fatty acids do not occur naturally in plants (and the western diet) in amounts necessary to meet metabolic needs. Moreover, the ALA conversion process to EPA and DHA in humans is not efficient, as only 5-10% are converted to EPA, and a mere 2-5% to DHA (Arterburn et al., 2006). However, n-3 fatty acids are abundantly present in fish, shellfish and other seafood; and fish-oil supplements typically contain 30-50% of n-3 fatty acids (Russo, 2009).

The current adequate intake (AI) of ALA is 1.6g/ day for men 19-47 years and 1.1 g/ day for women 19-47 years (Institute of Medicine of the National Academies, 2005). The acceptable macronutrient distribution range (AMDR) for ALA is 0.6-1.2% of energy, approximately 10% of which can be consumed as EPA and/or DHA. The Institute of Medicine's dietary guidelines (2005) also note that consumption of

approximately two servings of fish per week (about 224 g) may reduce the risk of mortality from coronary heart disease. However, since the physiological potency of EPA and DHA is greater than ALA, and in light the growing evidence of the health benefits of omega-3 fatty acids (Mozaffarian and Rimm, 2006), the International Society for the Study of Fatty Acids and Lipids (ISSFAL) recommends a minimum DHA and EPA intake of 500 mg/day (ISSFAL, 2004).

Another important, although controversial, aspect in LCPUFA dietary intake is the appropriate n-6/ n-3 fatty acid ratio for optimal health (Crawford, 2000, Griffin, 2008, Simopoulos, 2009). Nevertheless, it can be stated that an adequate intake of both n-3 and n-6 fatty acids is essential for good health, although it remains unclear whether the ratio between the two is of crucial importance, or not (Willett, 2007).

1.3.8 The Biomedical Importance of n-6 and n-3 LCPUFAs

Polyunsaturated fatty acids play an important role in the composition of cell membranes as they maintain homeostasis for proper membrane protein function and help maintain the membrane fluidity that regulates cell signalling processes, cellular functions and gene expression (Das, 2006).

The n-6 fatty acid Arachidonic Acid (AA) is present in all biological membranes and represents up to 15% of the total fatty acids in phospholipids. Studies have shown that low AA in maternal and cord blood is associated with low birth weight, reduced head circumference (Crawford et al., 1989, Leaf et al., 1992), intrauterine growth retardation (Vilbergsson et al., 1994) and impaired growth in preterm infants (Carlson et al., 1993). AA is a precursor in the production of eicosanoids, particularly prostaglandins, thromboxanes, leukotrienes and lipoxins, which, if formed in large amounts, contribute to the inflammatory state, allergic reactions, and the formation of thrombus. Thus a high n-6/n-3 ration may shift the physiological state to one that is prothrombotic and proaggregatory, with increases in blood viscosity, vasospasm, and vasoconstriction (Ferrucci et al., 2006, Simopoulos, 2009).

Eicosapentaenoic Acid (EPA) and Docosahexaenoic Acid (DHA) play important roles in various physiological processes that impact normal health and chronic diseases (Benatti et al., 2004), such as the regulation of gene function and metabolism (Sampath and Ntambi, 2005), cardiovascular and immune function (Cottin et al., 2011), and neuronal and visual development (Haag, 2003, Crawford et al., 1976a). DHA is involved in the expression of several hundred genes in the brain (Kitajka et al., 2004). The

genomic evidence suggests that an abundant dietary source of preformed DHA, actually stimulated the evolution of the brain, and that a lack of DHA would have been restrictive (Brenna et al., 2009, Broadhurst et al., 2002, Crawford et al., 1999, Kitajka et al., 2004, Morgan, 1997). Since DHA is a major constituent of the signalling membranes of the brain and visual system, the superabundance of DHA with its irreplaceable role in neural cell signalling, allowed for the synaptic evolution of self-awareness and symbolic thinking and behaviour (Crawford et al., 2013).

Between 50%-60% of the brain's dry weight is lipid, and approximately 35% of these lipids are LCPUFAs, particularly DHA. In the outer segments of photoreceptor cells, DHA constitutes 60% of total fatty acids (Jeffrey et al., 2001). Evidence from animal studies suggests that DHA deficiency can decrease brain DHA levels, increase the n-6/n-3 ratio in nerve membranes and result in poor functioning (Auestad and Innis, 2000). Martinez (2001) has provided compelling evidence about the fundamental role of DHA in the brain by showing that DHA supplements to patients with Zellweger syndrome (generalized peroxisomal disorders) improved myelination, vision, liver function, muscle tone, and social contact. In addition, studies have shown enhanced visual development and cognitive performance due to increased intakes of DHA (Moriguchi et al., 2000, Neuringer, 2000, Helland et al., 2003).

The cardio-protective effects of DHA and EPA supplementation have been studied extensively since their importance was first highlighted by Dyerberg and Bang (1979). It is now widely accepted that DHA and EPA supplementation decreases the risk of cardiovascular diseases (von Schacky and Harris, 2007), such as fatal Coronary heart disease (Hu and Willett, 2002), and stroke (He et al., 2004). These cardio-protective effects of DHA and EPA have been attributed to their anti- inflammatory properties, anti-arrhythmic and anti-aggregatory action, as well as their beneficial effect on vascular and endothelial functions. DHA and EPA supplementation have also been beneficial in atopic diseases (Calder, 2003), chronic inflammatory states such as arthritis (Calder and Zurier, 2001), and inflammatory bowel disease (Calder, 2008).

In addition, both EPA and DHA are precursors of a novel class of lipid mediators involved in the resolution of inflammation (Serhan and Chiang, 2008). Anti-thrombotic properties of fish oils were initially attributed to EPA, however both animal and human studies suggest that DHA is a more potent anti-aggregatory agent than EPA at high doses (Adan et al., 1999, Woodman et al., 2003, Cottin et al., 2011). DHA and EPA supplementation have also been beneficial in atopic diseases (Calder, 2003), chronic

inflammatory states such as arthritis (Calder and Zurier, 2001), and inflammatory bowel disease (Calder, 2008).

Although the role of individual fatty acids in (human) cancer risk has been poorly investigated, epidemiological and experimental data have linked a high dietary intake of n-6 PUFA – especially in association with a low intake of n-3 PUFA – to an increased risk for cancers of the breast, colon, and possibly prostate (Benatti et al., 2004).

Eicosanoids are signalling molecules derived from 20-carbon essential fatty acids and which play a variety of roles in human physiology, in both health and disease. Eicosanoids include the prostanoids: prostaglandins, thromboxanes, prostacyclin, leukotrienes and lipoxins (Cook, 2005, Miller, 2006, Wang and Dubois, 2010). The eicosanoides contribute significantly to the regulation of inflammation (Dobrian et al., 2011), renal function (Imig, 2006, Harris, 2008), vascular function (Feletou et al., 2011), insulin secretion (Luo and Wang, 2011), and reproduction (Olson and Ammann, 2007, Roldan and Shi, 2007).

1.4 Health Effects of Omega-3 and Omega-6 Fatty Acids

1.4.1 The Ratio of Omega-3 to Omega-6 Fatty Acids

As noted above, the changing Western diet has drastically altered the omega-6 to omega-3 fatty acid ratio. In an effort to reduce cholesterol levels and lead healthier lifestyles, many Americans have substituted vegetable oils, which are high in omega-6 fatty acids, in place of saturated fat from animals. This change in diet has led to an enormous increase in omega-6 fatty acid consumption and has elevated the typical omega-6 to omega-3 fatty acid ratio from 2:1 to 25-50:1. The ratio LA:LnA, calculated from food balance sheets, is roughly 10:1 in the UK (Taylor et al., 1979) and other western countries (Budowski and Crawford, 1985). Actual analysis seems to yield a higher ratio (e.g. 14:1) in a French farming community (Renaud et al., 1980). Cordain et al. (2005a) have also concluded that the current Western diet has adversely impacted the ω-3:ω-6 ratio.

In ancient hunter-gatherer societies, the ratio of ω-3:ω-6 was closer to 2:1 or 3:1 (Simopoulos, 2004). Other researchers have reported ω-3:ω-6 values ranging from 2: I to 4:1 in muscle phospholipids of wild animals (Crawford et al., 1969, Crawford et al., 1970b, Crawford et al., 1970a, Crawford and Woodford, 1971). The wild plants and animals which provided food for prehistoric man were not only low in fat, but their lipids

were also rich in PUFA (Crawford and Stevens, 1981). An analytical survey of thirty-two wild animal species in Africa yielded average ratios of 1:1 in brain ethanolamine phosphoglycerides (EPG), the major phospholipid receptacle for PUFA in brain grey matter, and 1:1 in liver (Crawford et al., 1976a). LnA predominates in the chloroplasts of green, leafy plants, while seeds are richer in LA (Hitchcock and Nichols, 1971). Simopoulos (2002a) suggests that cereal grains have become the predominant food source since the Agricultural Revolution, which contain high levels of carbohydrate and ω-6 but little ω-3. Furthermore, technological innovations and advancement in crop production and processing has changed the ratio of n3 and n6 fatty acids (Budowski, 1984).

The dietary increase in the omega-6 fatty acid ratio can have profound effects on an individual's health since omega-6 fatty acids do not provide the same health benefits as omega-3 fatty acids. Although omega-6 fatty acids are an important part of the cell membrane, replacing phospholipids EPA and DHA (derivatives of omega-3 fatty acids) with arachidonic acid (derivative of omega-6 fatty acids).

The balance between ω-3 and ω-6 is therefore quite important as these two types of unsaturated fatty acids are in direct competition to be metabolized by cyclooxygenase (COX). COX is also the enzyme that catalyses arachidonic acid (AA), which is a ω-6 fatty acid, into the precursor molecule responsible for inflammatory reactions in the body (Lee, 2013). These ω-6 fatty acids create a physiological state which is prothrombotic, proaggregatory, increases blood viscosity, vasospasm, vasoconstriction and decreases bleeding time. This decrease in bleeding time is associated with several aspects of CVD including myocardial infarction, hypercholesterolemia, atherosclerotic disease as well as diabetes (Simopoulos, 2002a, Brox et al., 1983).

Whelan (1996) summarizes some of the most important differences in health effects between omega-3 and omega-6 fatty acids as follows:

1. Omega-3 fatty acids reduce inflammation; omega-6 fatty acids increase inflammation.
2. Omega-3 fatty acids are antithrombotic, omega-6 fatty acids increase blood clotting.
3. Omega-3 fatty acids are non-immunoreactive; omega-6 fatty acids are immunoreactive.

These differences have profound implications for heart diseases, cancer, arthritis, allergies and other chronic diseases. The current scientific consensus is that the ratio of omega-6 to omega-3 fatty acids should be less than 5:1 (Sugano, 2001).

1.4.2 Omega-3 Fatty Acids and Brain and Retinal Function

The dry weight of the human brain is composed predominantly of lipids: 22% of the cerebral cortex and 24% of white matter consist of phospholipids. It therefore requires a regular intake of "good fats" such as Omega-3s for normal neurogenesis and synaptogenesis. DHA accounts for 40% of all PUFAs in the brain and is considered to be the most important fatty acid for brain function and development (Singh, 2005, Haag, 2003).

Thus, DHA is essential for normal neurological development. Low DHA levels have been linked to low brain serotonin levels which are connected to an increased tendency to depression, suicide, and violence (Hamazaki et al., 1996, Hibbeln, 1998). DHA concentrated mainly in serine and ethanolamine phosphoglycerides (Svennerholm, 1968) and predominantly found in retina (Benolken et al., 1973) and cerebral cortex (Breckenreidge et al., 1971). Early studies have reported that a low concentration of DHA results in impaired retinal function (Neuringer and Connor, 1986, Neuringer et al., 1984, Weisinger et al., 1999) and altered cognitive function (Neuringer et al., 1994). The majority of DHA studies have focused on its role in the cerebral cortex and only a few have focused on DHA concentrations in the most deep CNS structures, but no studies about DHA concentrations in the basal ganglia has been done so far, even though these complex structures are involved in a wide array of integrative functions such as motor coordination, integration of visual signals, and psychiatric and personality phenomena (Ring and Serra-Mestres, 2002). DHA and AA concentrations in the CNS are highly region-specific and high amount of DHA is found in the deep CNS regions embedded in white matter of much lower DHA and AA concentration (Diau et al., 2005).

Furthermore, deficiency of this fatty acid is associated with a loss of discriminative learning ability, while intake of DHA may restore lost learning ability (Yamamoto et al., 1987). Consistent with these findings, it was demonstrated that chronic administration of DHA enhances long-term memory in both the young and old (Gamoh et al., 1999). Daily oral supplementation of 100-600 mg DHA improves the neurological condition in Zellweger's syndrome, in which there is serious mental

retardation and damage to the protective covering (myelin) around the nerves (Martinez et al., 1993).

Disorders such as ADHD and Autism Spectrum Disorder (ASD) have both been associated with reduced blood levels of PUFAs (Vancassel et al., 2001, Sinn and Bryan, 2007). Some researchers have suggested that both behavioural and learning problems associated with ADHD can be reduced by supplementing ω-3 fatty acid (Richardson and Puri, 2002, Sinn and Bryan, 2007). In their systematic review of the effects of omega-3 on ADHD, Bloch and Qawasmi (2011) found that omega-3 fatty acids, but specifically EPA, was comparable to pharmacological treatment of ADHD. Richardson and Puri (2002) found that children with symptoms of ADHD secondary to learning disabilities (primarily dyslexia) scored much higher for attention, anxiety and disruptive behaviour (than the control group) after receiving ω-3/ ω-6 supplements.

As already noted, DHA represents a small percentage of the fatty acids in most tissues of the human body, it reaches levels of 30-40% of total fatty acids in rod photoreceptor outer segments of the retina (Menon and Dhopeshwarkar, 1982). DHA influences retinal photoreceptor structural development and function, thereby increasing retinal light sensitivity. A deficiency in DHA can result in decreased visual acuity and an abnormal electroretinogram (Rotstein et al., 1998). In one study, researchers found that more frequent consumption of fish (which contain DHA) appeared to protect against late age-related macular degeneration. Only a moderate intake of fish was necessary for this protective effect (Levine, 1997).

In rhesus monkeys, diets deficient in omega-3 fatty acid induced profound functional changes such as reduced vision, abnormal electroretinograms, impaired visual evoked potential, more stereotypic behaviour (e.g., pacing) and probable disturbances of cognition (Neuringer et al., 1986).

1.4.3 Omega-3 Fatty Acids and Foetal Development

Two essential fatty acids, lenoleic acid (C18:2, n- 6) and lenolenic acids (C18:3, n- 3), derived from plants, do not present in brain tissues. After elongation and desaturation in the liver, they form long chain fatty acids including arechidonic acid (AA, C20:4, n- 6) and docosahexaenoic acid (DHA, C22:4, n-3). These two fatty acids are essential, structural and functional constituents of cell membranes (Crawford et al., 1976b) and are required for the growth and function of the brain and vascular systems which are the primary biofocus of human foetal growth. The foetal brain can accumulate

AA and DHA during cell division. It is observed that very preterm babies are born with minimal fat stores and suboptimal circulating levels of these nutrients. Postnatally, they lose the biomagnification of the proportions of AA and DHA provided by the placenta for the foetus. No current nutritional management repairs these deficits. The resultant foetal FA profile closely resembles that of the vascular endothelium and not the brain. Without this nourishment, cell membrane abnormalities would be predicted (Crawford et al., 2003).

Omega-3 fatty acids (DHA and EPA) from fish oils are of major importance for proper nutrition during pregnancy, not only for foetal development, but for the mother's health, as well. There are 2 critical periods for the acquisition of these essential omega-3 fatty acids: during foetal development itself and then after birth until the biochemical development of the brain and retina is completed. A deficiency or excess of any number of nutrients can lead to birth defects or complications for the mother (Allen and Harris, 2001).

DHA is brain food for a developing baby. It constitutes more than half of a newborn’s brain mass, and during the first three months of life, the DHA content of the infant’s brain increases threefold (Barrett et al., 2014). The fatty acid accretion increases as gestation progresses, reaching a maximum rate of accretion toward the end of gestation. DHA as a percentage of total fatty acids increases, whereas AA decreases in both the cerebrum and liver during the last trimester of gestation. The higher concentration of brain DHA is consistent with the rapid formation of synapses and dendritic spines taking place during this period (Martinez and Ballabriga, 1978, Pupura, 1975). An increase in the percentage of DHA can be due to the rapid development of the photoreceptor cells during the last half of gestation. Furthermore, n-3 fatty acids do not stop increasing after birth. The very rapid prenatal increase becomes more moderate but is still quite significant until at least 2 years of age (Martinez, 1992).

Since developing foetuses cannot make their own omega-3 fatty acids, they depend upon their mothers to meet their nutritional needs. Therefore, DHA and other essential nutrients should be obtained by the mother through her diet or supplementation, which can then be passed along to the foetus (Carlson, 1999). This vital nutrient is particularly important during the third trimester, as this is when much of the foetus' neurological, visual and nervous system development occurs (Carlson, 1999, Valenzuela and Nieto, 2001).

Human milk is the best and only time-proven source of DHA in the infant's diet. In well-nourished mothers, approximately 6% of total calories in human milk take the form of essential fatty acids and their metabolites. The conversion efficiency of dietary EFA into milk fatty acids is not clear; however, an additional 1 to 2% of calories in the form of EFA is recommended during the first 3 months of a mother's lactation. Another 2 to 4% of calories above the basic requirement is recommended thereafter (Makrides and Gibson, 2000).

Studies show that breast-fed babies have IQ advantages over babies fed formula without DHA. Unfortunately, DHA levels in the breast milk of U.S. women are among the lowest in the world. In addition, the United States is the only country in the world where infant formula is generally not fortified with DHA despite a 1995 WHO recommendation that all baby formulas should provide 40 mg of DHA per kilogram of infant body weight. Scientists believe that postpartum depression, attention deficit disorder (ADD), and low IQs are all linked to the low DHA intake commonly found in the U.S. Furthermore, several studies have shown that infants with an adequate supply of DHA developed better visual acuity and retinal response to light and scored higher when evaluated for mental development (Cunnane et al., 2000, Birch, 1999, Birch et al., 1998).

The constant drain on a mother's DHA reserves can easily lead to a deficiency. Some researchers believe that pre-eclampsia (pregnancy-related high blood pressure) and postpartum depression could be linked to such DHA deficiency (Chiu et al., 2004). Deficiency of DHA in the foetus has also been linked to premature births and abnormally low birth weights (Olsen et al., 2003).

Fish and fish oil consumption during pregnancy has been shown to affect the mental development of the child. Maternal ω-3 at delivery predicted better attention in infants during the first 2 years of life and better hand-eye coordination at 2.5 years (Dunstan et al., 2008, Colombo et al., 2004). Infants with higher DHA at birth and at 4 months also demonstrated better visual development (Malcolm et al., 2003, Lauritzen et al., 2004). At 4 years of age, children born to mothers who took cod liver oil during pregnancy and lactation had a higher score on the Mental Processing Scale for the Kaufmann ABC test, although this effect was not present at 7 years of age (Helland et al., 2008b, Helland et al., 2003).

Researchers have also identified other benefits associated with omega-3 fatty acids:

- Omega-3 fatty acids may promote an easier birth, and prevent preterm delivery.
- Omega-3 intake is associated with more mature neonatal sleep-state patterning (the baby sleeps longer through the night in early life).
- Omega-3 fatty acid supplemented infants show higher levels of cognitive function.
- Omega-3 intake can reduce the chances of a child developing allergies.
- Omega-3 intake is associated with increased foetal development, specifically as it relates to the brain and vision.
- Children are less likely to have behavioural and learning problems (Olsen et al., 2003, Cheruku et al., 2002, Prescott and Calder, 2004, Birch et al., 2000).

1.4.4 Omega-3 Fatty Acids and Cardiac Disease

There has been significant promotion of fish intake in recent years since it is a good source of high-quality protein, low fat, vitamins and minerals, but particularly omega-3 fatty acids which have been associated with cardiovascular health benefits. Nowadays, nutritionists recommend at least two servings of fish per week to achieve cardio-protective effects (Chan and Egeland, 2004, Nordoy et al., 2001).

For the last two decades, many studies have reported the beneficial effects of seafood consumption for reducing the risk of coronary heart disease mortality (Kromhout et al., 1985, Daviglus et al., 1997, He et al., 2004, Whelton et al., 2004). Intake of fish and fish oil is also thought to decrease the risk of other cardiovascular diseases, such as hypertension, stroke and cardiac arrhythmias (Sidhu, 2003).

The protective effects of omega-3 fatty acids on coronary heart disease have been demonstrated in hundreds of experiments in animals, humans, tissue culture studies, and clinical trials. Omega-3 fatty acids from fish have been shown to be protective of heart disease and are also capable of preventing deaths from coronary disease, particularly cardiac arrest (Paganelli et al., 2001, Shekell et al., 1985, De Caterina and Madonna, 2002, Norell et al., 1986, Kromhout et al., 1985, He et al., 2004, GISSI-Prevenzione Investigators, 2000, Kris-Etherton et al., 2003).

The unique properties of these fatty acids in coronary heart disease first became apparent in investigations into the health of Greenland Eskimos who consumed diets very high in fat content, and yet had a low rate of coronary heart disease. Further studies clarified this paradox: the fat consumed by the Eskimos contained large quantities of the very-long-chain and highly polyunsaturated fatty acids of EPA and DHA, which are

naturally abundant in fish, shellfish, and sea mammals but which are quite scarce or absent in land animals and plants. EPA and DHA are synthesized by phytoplankton, aquatic plants at the base of the food chain for marine life (Bang et al., 1976).

The American Heart Association identifies the cardiovascular benefits of DHA as follows:

- Prevents arrhythmias (ventricular tachycardia and fibrillation).
- Serves as a prostaglandin and leukotriene precursor.
- Has an anti-inflammatory property.
- Inhibits synthesis of cytokines and mitogens.
- Stimulates endothelial-derived nitric oxide.
- Has an antithrombotic role.
- Inhibits atherosclerosis.
- Protects against plaque fat ruptures leading to strokes and heart attacks.
- Relaxes blood vessels (vasodilatation).
- Lowers blood pressure, and lessens heart stress (Kris-Etherton et al., 2003).

ω-3 fatty acids are crucial in the development of a CVD. Firstly, ω-3 is involved in decreasing the body's inflammatory response by increasing the production of anti-inflammatory molecules and decreasing the production of inflammatory molecules (Calder, 2006). This anti-inflammatory effect is implicated in stabilizing arterial plaques, thereby decreasing the risk of CVD events (Thies et al., 2003).

Blood pressure has also been found to be reduced by ingesting only 3.7 g/d of fish oil (Geleijnse et al., 2002), and serum triglycerides, a risk factor for the development of CVDs, have been reduced by up to 30% by the use of ω-3 fatty acids supplements (Austin, 1991, Harris, 1997). Atherosclerotic plaque formation may also be lessened by the reduction in growth factors after fish-oil consumption (Wijendran and Hayes, 2004).

Dietary studies in which the effects of a diet rich in salmon oil were compared with those of a vegetable oil and a diet high in saturated fat. Fish oil in particular was shown to lower plasma cholesterol and triglyceride concentrations (Connor, 2000).

Based on the findings of two large scale reviews, the American Heart Association has recommended that adult patients without documented CHD eat a variety of (preferably oily) fish at least twice a week and include oils and foods rich in alpha-linolenic acid (flaxseed, canola and soybean oils, flaxseeds and walnuts). This is equivalent to 0.3 to 0.5 g/d of EPA and DHA which is essential for healthy individuals to

reap specific heart health benefits. For those with documented CHD, the AHA recommends consuming 1 g/d of EPA and DHA, preferably from oily fish, although supplements may be considered advisable upon consulting a physician. The AHA reports that consumption of one fatty fish meal (85 g portion) per day (or the equivalent fish oil supplement) could result in EPA and DHA intakes of approximately 0.9g/d, which researchers have shown to reduce CHD mortality rates in patients with coronary disease (Nigel et al., 2007). Similarly, König et al. (2005) has found that even a small quantity of fish consumed regularly was associated with a 17% reduction in CVD mortality and each additional serving of fish increased the reduction in CVD mortality by 3.9%.

On the other hand, some researchers have cautioned against overstating the benefits of omega-3 fatty acids. For example, Kwak et al. (2012) did not observe any effect of omega-3 supplements on the prevention of CVD events or mortality in those who already had a history of CVD. Similarly, the meta-analysis by Hooper et al. (2006) found no effect of omega-3 on total mortality, strokes or CVD events.

1.4.5 Omega-3 Fatty Acids and Other Diseases

1.4.5.1 Cancer

Researchers have not yet reached any concrete conclusions about the effects of ω-3 fatty acids for the prevention and treatment of cancer. Recent studies have not found any positive effect of ω-3 fatty acids in reducing cancer mortality (MacLean et al., 2006, Hooper et al., 2006). However, low levels of any type of fatty acid can promote cell growth in the prostate while high levels of EPA inhibits this growth (Pandalai et al., 1995). In another study, men who consumed higher levels of EPA and DHA through dietary ω-3 consumption had a lower risk of prostate cancer (Norrish et al., 1999), while Kimura et al. (2007) found a non-significant but inverse relationship between dietary ω-3 and colorectal cancer, especially distal colon cancer.

On the other hand, Cave (1986) has suggested that fish oil consumption can delay or reduce tumour development in breast cancer Studies have also shown that a high blood level of omega-3 fatty acids, when combined with a low level of omega-6 acids, reduces the risk of developing this disease (Simonsen et al., 1998). In a similar vein, daily supplementation with as little as 2.5 grams of fish oils has been found effective in preventing the progression from benign polyps to colon cancer (Yang et al., 1999). Gonzalez and Riboli (2006) suggest that fish consumption may decrease the risk of

colorectal cancer. Other researchers have found that fish oil supplementation improves survival and quality of life in terminally ill cancer patients.

1.4.5.2 Overweight and Obesity

Omega-3 fatty acids have a profound effect on obesity. It has been found that obese individuals have lower concentration of ω-3 fatty acids in their blood when compared to healthy, non-obese controls (Micallef et al., 2009). Couet et al. (1997) found that a fish oil diet corresponded to a 0.88 kg reduction of body fat when compared a control diet. Kabir et al. (2007) found that postmenopausal overweight and obese female subjects with type 2 diabetes also experienced a reduction in their total body fat after adding 3 g/d of fish oil (1.08 g EPA + 0.72 g DHA) for two months.

In a similar study, Thorsdottir et al. (2007) placed men and women on one of four types of energy restricted diets: a control diet with no fish, with lean fish, with fatty fish or with fish oil. They found that after four weeks, men had lost approximately 1 kg more after eating lean or fatty fish or taking fish oil supplements.

Epidemiological studies have also shown that fish consumption within a healthy eating pattern is associated with lower body weight (Shubair et al., 2005, Schulze et al., 2006). However, less is known about the health impact of fish consumption and fish oil supplementation, when paired with physical activity, on the nutritional status of school children, body composition, blood biochemistry and mental and physical abilities. Dietary intervention studies which included fish and fish oil in a weight loss diet are also limited (Thorsdottir et al., 2009, Mori et al., 1999).

The recently conducted randomized dietary intervention study SEAFOOD plus YOUNG showed promising results: lean and fatty fish consumption three times a week for eight weeks was associated with significantly lower body weight in humans compared to an isocaloric control diet without seafood.

1.4.5.3 Diabetes

Fish intake might also increase insulin sensitivity (Ramel et al., 2008) and decrease the risk of non-insulin-dependent (type II) diabetes (Kromann and Green, 1980, Nkondjock and Receveur, 2003).

Some data are available in the literate that show a positive impact of ω-3 fatty acids on diabetes. Norris et al. (2007) found an inverse relationship between higher

intake of ω-3 fatty acids and the risk of developing islet autoimmunity, the destruction of insulin-producing beta cells in the islets of the pancreas. Similarly, in another study, children who ingested cod liver oil were found to be at a significantly lower risk of developing type 1 diabetes (Stene and Joner, 2003). It has also been demonstrated that ω-3 is effective in decreasing the level of triglycerides in Type 2 diabetes, although no comparable effect on the fasting glucose level or glycaemia was found (Montori et al., 2000).

1.4.6 Omega-3 Fatty Acids: Sources and Dosage

The best source of DHA is seafood, especially coldwater fish. Omega-3 fatty acids are nature's antifreeze: in general, the colder the fish's natural environment, the higher the omega-3 content in the fish oil. Popular sources of DHA are wild salmon (not farm raised), sardines, tuna (especially blue fin tuna), mackerel, shellfish, herring, black cod and anchovies. The fish meats with the highest ω-3 content that fulfil the ω-3 criteria of the American Heart Association are salmon, mackerel, red mullet and, to a lesser extent, squid and hake (Domingo et al., 2007). Eggs and some organ meats (liver and brain) have a small amount of DHA, but the healthiest source of dietary DHA is seafood (Holub, 2001).

Despite the known benefits of regular fish consumption, the risks must be considered, as well. Fish are known to contain chemical pollutants which may be dangerous to consume regularly or at the frequency suggested by the AHA (Kris-Etherton et al., 2002a). Domingo et al. (2007) analysed the ω-3 content and the chemical pollutants present in 14 types of fish, and found that, when consumed according to the AHA guidelines, most marine specifies did not pose a risk. On the other hand, swordfish and tuna contained high levels of methylmercury; clam, mussels and shrimp contained high levels of the carcinogen polycyclic aromatic hydrograms (PAB); and red mullet contained high levels of polychlorinated dibenzodioxins and furans (PCDD/F). On this basis, it would appear that the safest fish to consume at the level suggested by the AHA – with the most ω-3 – would be salmon and mackerel.

Besides fish oils, vegetable oils (primarily flaxseed, soy, walnuts and canola) are also rich sources of omega 3 fatty acids, with flaxseed oil being the best. The main component of flaxseed and walnut oils is alpha-linolenic acid (ALA) while the predominant fatty acids found in fatty fish and fish oils are eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). The most beneficial and active of these fatty acids are

EPA and DHA. Alpha-linolenic acid (ALA) can be converted to EPA and DHA in the body, but the conversion process is inefficient, especially in older people. The two F's – fish and flax – are the top brain-building foods for growing children, and adults (Holub, 2001, Conquer and Holub, 1996). Certain microalgae also contain DHA and are used as a vegetarian source of this nutrient in some supplements. For infants, breast milk contains significant amounts of DHA, while infant formula often has none (Cunnane et al., 2000).

People without a CHD should eat fatty, oily fish twice a week and include oil and foods that have a high amount of alpha linoleic acid (Kris-Etherton et al., 2003), whereas people with CHD should ingest 1.0g of EPA+DHA every day from oily fish. In patients who need to lower their triglyceride levels, they recommend 2-4 grams of EPA+DHA per day, taken in capsule form (Kris-Etherton et al., 2003).

1.5 Genesis and Prevention of NCDs in Childhood

1.5.1 Children and Adolescents are Heavily Impacted by NCDs

Childhood NCDs are on the rise globally. The following identify some of the most significant ways children and adolescents are affected:

- 1.2 million children and youth under the age 20 died of NCDs in 2002 (Mathers, 2009).
- More than 25% of obese adolescents have signs of diabetes by age 15 (Goran et al., 2003). According to Mathers (2009), this accounts for approximately 486,000 children under 15 years of age.
- Despite improvements in the survival rate for some childhood cancers, this rate is much lower in resource-poor countries (Proimos and Klein, 2012).
- Approximately 90% of the 1 million children born each year with congenital heart disease live in areas without adequate medical care (Cancer Research UK, 2002).
- Tobacco smoke causes asthma, otitis, and respiratory infections in children (Tchervenkov et al., 2008).

- Mental health disorders (Cancer Research UK, 2002) motor vehicle trauma, homicide, and suicide (Gore et al., 2011) cause significant morbidity and mortality in children and youth.

It has been suggested that when risk behaviours begin in childhood and continue into adulthood, there is an increased risk of developing disease (Law, 2000), and the risks increase as the individual ages (World Health Organization, 2013a).

In one longitudinal study, Porkka et al. (1994) tracked children between 3-18 years of age for 12 years, and found that serum lipids (such as HDL, LDL and total cholesterol) tracked into adulthood and that 50% of those in the extreme ranges for these measures remained unchanged. They also found that men tracked these factors into adulthood more consistently than women. Similar results were found in a study following children in Louisiana, finding that the same pattern held at the other extreme: 42% of those in the lower range for HDL cholesterol remained in the lower range (Webber et al., 1991).

Blood pressure and BMI have also been found to track into adulthood from childhood, and that these measures are related to adult blood pressure, fasting insulin and lipid levels (Juhola et al., 2011, Sinaiko et al., 1999). McGill et al. (2008b) suggest that a high risk of developing advanced coronary artery lesions continues to increase with age. It has also been found that risk factors for cardiovascular disease in childhood predicts cardiovascular pathologies in adulthood, probably due to the changes in the cardiovascular system caused by the presence of risk factors in childhood (Raitakari et al., 2003).

The PDAY risk score in young people has been found to predict coronary artery calcium and carotid intima-media thickness into later adulthood (Gidding et al., 2006, McMahan et al., 2007), just as coronary artery calcium has been shown to be a reliable predictor of adult coronary heart disease (Pletcher et al., 2004). Jenkins et al. (1981) examined 35 people post-mortem who died at the average age of 18 and found that fatty streaks were related to total and LDL cholesterol, that coronary artery fatty streaks were correlated with very LDL cholesterol, and that fatty streaks were inversely related to the ratio of HDL to LDL and VLDL cholesterol. McGill et al. (2008) suggest that the prevention of risk factors will likely yield the maximum benefit in terms of cardiovascular disease prevention.

Not surprisingly, obese adolescents are at an increased risk of developing an NCD later in life (Reilly and Kelly, 2010). This is particularly problematic since 43 million children globally are obese and 92 million are at risk of being overweight. Furthermore, the rate of childhood obesity has increased from 4.2% in 1990 to 6.7% in 2010 (De Onis et al., 2010).

The Middle East is one of the regions with the highest prevalence of obesity in the world (James, 2004, Han et al., 2010). These overweight or obese children and adolescents are susceptible to becoming overweight or obese adults. This is especially true if the child has a higher BMI or if the child had an obese parent (Guo and Chumlea, 1999, Whitaker et al., 1997). The increase in weight among children and adolescents may be due to increased snack and fast food consumption (McConahy et al., 2004, Bowman et al., 2004).

It has been suggested that the dietary behaviours of children are shaped by food preferences that are developed prenatally and post-natally, where both taste and olfaction are important determining factors. (Bradley and Stern, 1967) found that taste cells are developed before twenty weeks of gestation and fully functional by 13-15 weeks, while olfactory function has been found to be developed in utero (Schaal et al., 1998), responding to the foods eaten by the pregnant mother (Birch, 1999). Studies have demonstrated that premature infants have already acquired clearly defined taste preferences (Tatzer et al., 1985, Ventura and Worobey, 2013a).

Children's food preferences can also be modulated by parental restriction or coercion. It has been found that children who are offered contingencies for eating foods (reward or punishment based) may send the message to the child that a food is not desirable, which may actually result in a decreased preference (Birch et al., 1982). Food restriction in an experimental setting has also been shown to result in higher intakes and selection of the restricted food despite calorically equivalent free access alternatives (Fisher and Birch, 1999). It has also been suggested that the foods made available by parents, and parental intake predicts the types of foods children consume (Wardle et al., 2005, Hanson et al., 2005, Young et al., 2004).

An important influence on the programming phenomena is foetal nutrition, which is a consequence of maternal nutrition during pregnancy. An imbalance of macronutrients, specifically protein and carbohydrates, have been found to be associated with a low birth-weight and higher blood pressure in children (Shiell et al., 2001). A

positive association has also been found between a maternal diet that includes green vegetables and fruits, and higher birth-weight and better glucose tolerance in the child. Belizan et al. (1997), Yajnik (2004), and Rao et al. (2001) have similarly found an association between a maternal diet that includes higher calcium intake with lower blood pressure in the child. Children of mothers with diabetes have also been found to be at an increased risk of glucose intolerance and type 2 diabetes. These are all physiological conditions that may occur due to maternal nutrition and/or low birth-weight which are known risk factors for NCDs later in life.

This pattern has been explained by the thrifty gene hypothesis, which suggests that the child's physiology will adapt to the undernourished environment in the womb. The result of the child's adaptation is a physiology unsuited to the over-nourished postnatal environment, thereby increasing the child's susceptibility to obesity and other NCDs. In the case of diabetes, it has been suggested that the foetus will direct glucose supply to vital organs when confronted with a glucose deficiency in the womb. As a result, the body adapts to low glucose environments and these children become more susceptible to glucose intolerance and type 2 diabetes later in life (Hales and Barker, 2013).

1.5.2 Nutritional Intervention at Childhood as a Method to Tackle Behavioural Abnormalities

Numerous studies have shown an association between nutrition and lifestyle factors to cognitive functioning and mental health in children. Sjöberg et al. (2005), for example, found that overweight children between 15 and 18 years old had depressive symptoms, while children in the higher BMI groups had major depressive symptoms, as defined by the DSM-IV. Luppino et al. (2010) also found a relationship between depression and obesity in their systematic review and meta-analysis.

Dreyfus (1993) examined the mental health issues in obese children and found that 15% of obese children had a personality disorder and 2% had psychotic features while 58% showed no severe personality disorder. Adolescents with obesity or weight gain displayed more psychopathology or psychiatric morbidity and higher levels of depression than those with a normal weight, although the sample only included those who were seeking treatment for weight related issues (Hammar et al., 1972, Buddeberg-Fischer et al., 1999). Vila et al. (2004) examined obese children who were patients at a nutrition outpatient centre in Paris and found that 58% had a DSM-IV psychiatric

diagnosis, 32% had a DSM-IV anxiety disorder, 12% had affective disorders, 16% had disruptive behaviour disorders; in some cases, a single individual had multiple diagnoses. Despite these pervasive associations, it has been demonstrated that mental health issues such as depression and schizophrenia in children improved with treatment of ω-3 fatty acids (EPA) (Nemets et al., 2006, Emsley et al., 2003).

Cognitive functioning has also been shown to be affected by poor dietary habits. The main metabolic factor involved in brain function is glucose and thus the effect of glucose on uninterrupted brain function cannot be understated. It has been also been suggested that poor nutrition can affect the brain function (Bellisle, 2004). (The important role of fatty-acids has already been discussed above.)

The effect of glucose ingestion on memory and cognition has been investigated by several researchers. It has been found that the ingestion of glucose in children produced beneficial effects on short-term memory, rapid information processing, focussed and sustained attention, arithmetic ability, long-term free and cued recall tasks. The rise in blood glucose after ingesting a glucose drink resulted in faster information processing, word recall and improvement on cognitive conflict and reaction time tasks. It has also been suggested that the latter phases of long and difficult mental tasks are improved with the ingestion of glucose, although this effect does not apply to the earlier phases of long and difficult mental tasks or shorter duration that are less demanding (Benton et al., 1987, Benton and Owens, 1993, Foster et al., 1998). This demonstrates the brain's sensitivity to short-term fluctuations in glucose levels (Bellisle, 2004).

Benton et al. (2003) found that low-glycaemic index food facilitated mental performance hours after being ingested, since they do not severely disrupt blood glucose levels. Schoenthaler and Bier (1998) found that low-dose vitamin mineral supplements improved performance on tests of intelligence in children with poor diets; the same result was not found in children with adequate diets.

1.6 The Sultanate of Oman, NCDs, Risk Factors & Epidemiology

The Arab World, identified in the literature as the Eastern Mediterranean, Western Asia, North Africa and the Northern Gulf are certainly not immune to the effects of NCDs. In 2004, the WHO Mediterranean Region had a 47% disease burden due to NCDs and this number is predicted to rise to 60% by 2020 (Khatib, 2004). WHO also predicts that the mortality rate due to NCDs in the region will increase by 25% (Alwan, 2008). In some of these countries, the number of deaths below the age of 60 due

to NCDs is at 40% (Alwan, 2014) with more than 1.2 million Arabs dying from NCDs in 2008, which accounted for 60% of total deaths in the region (Rahim et al., 2014b).

The Sultanate of Oman is a WHO member state situated in the Eastern Mediterranean region. This developing, high-income country has a population of 3.3 million people. Similar to other countries in the region, Oman's population also suffers from NCDs and the resulting burden of disease placed on the national healthcare system (World Health Organization, 2014a). In 2008, NCDs accounted for 83% of deaths in Oman, with the under 60 mortality rate at 44.5% for men and 32.6% for women (World Health Organization, 2011b). In 2012, 70% of the YLL in Oman was due to NCDs or injuries. In Oman, the rates of death by each NCD are listed as follows:

- CVD, 49% of total mortality
- Diabetes, 7%
- All Cancers, 11% and
- CRD, 3%.

These proportions are particularly worrying, since only 3% of the Omani population in 2004 was aged 60 or older (World Health Organization, 2011b).

The prevalence of overweight or obese and physically inactive is high in Arab region. Kim et al. (2011) found that in, in the Arabian Gulf, 66-75% of the adult population (above age 18) and 25-40% of children (below age 18) were either overweight or obese. In Oman, 30% of the population is overweight and 20%-21.5% are obese (Al-Lawati et al., 2008). Al-Lawati and Jousilahti (2004) found that this trend appears to be shifting, with more men and fewer women are becoming overweight and obese.

Rahim et al. (2014b) found that the Arab region, but particularly high-income GCC countries, had the highest level of physical inactivity in the world. It has been suggested that this is due to urbanization and its impact on recreational and lifestyle activities, as well as a shift to more sedentary occupations. Additionally, extreme climatic conditions and lack of public transport in many of these countries has created a reliance on personal automobiles, and people are also becoming more dependent on mechanization to complete household chores as well as technology for leisure activities (Rahim et al., 2014b).

Between 1961 and 2007, the Arab Region experienced an increase in sugars and sweeteners, meats, milks and dairy products, changes that are characteristic of the

nutrition transition associated with an increased burden of NCDs (Golzarand et al., 2012). The nutrition transition taking place in Oman is at stage 2, 'Degenerative Diseases,' where the intake of food has shifted to a Western diet. This usually occurs in societies where there is an accompanying shift in technology, especially in both work and leisure activities (Popkin, 1993). The other two diet types, as characterized by Jacka et al. (2010), are 'Traditional' and 'Modern' diets. The 'Traditional' dietary pattern is defined as consisting of vegetables and fruits, whole-grains, meats and fish. The 'Modern' pattern consists of fruits, salad, and more beans, yogurt, nuts, fish and tofu. Rahim et al. (2014b) suggest that the Arab Region is moving away from the traditional diet towards the westernised diet, while the developed world is moving away from the western diet towards the modern diet.

The unhealthy dietary habits resultant from rapid urbanization in the region has produced a largely 'Western diet' that is characterized by high-fat, calorie dense foods, refined sugars and salt, as well as high intakes of fast foods and carbonated drinks (Musaiger et al., 2011b, Mahmood et al., 2008). Undoubtedly, this shift partly accounts for the fact that, in GCC countries, 25–40% of children below 18 years of age are overweight or obese (Kim et al., 2011). When examining overweight and obesity in children aged 0–5 years old, De Onis et al. (2010) found that 14.7% of preschool children were overweight or obese in the Western Asia region (the Arabian Peninsula). Using the data trends, the researchers suggested that this rate could increase to 21.5% by 2015 and predicted that 29.1% of children would be overweight or obese in 2020.

Similarly, Osman et al. (2004) tracked a cohort of 550 Omani students, both male and female, and found that the incidence of overweight and obesity was 7.3% at 6–7 years, and increased to 16% at 12–13 years and increased yet again to 23.3% at 15–16 years. The authors concluded that Omani school children tend to become increasingly overweight and obese as they age, may be largely due to the more sedentary activities and socialized more by eating energy-dense nutrient poor foods as they grew older.

1.7 Aim and Objective of the Study

Like many other developed countries, Oman is facing a rapidly escalating burden of non-communicable diseases (NCDs), i.e., obesity, diabetes, high blood pressure, heart disease, strokes, cancers and some chronic respiratory disease .The NCD rates are high and markedly amplified because many, if not most, adults 30–60 years ago were born to relatively poorly fed mothers and frequently experience mild to moderate malnutrition in

childhood. It is now recognised that malnourished children are highly susceptible to NCDs when confronted with a high fat, sugar and salty diet in later life. As a result, the adult Omani population already displays greater rates of abdominal obesity and its associated NCDs, particularly diabetes, than adults in Western Europe. Therefore, a much more incisive and radical public health approach is needed to produce a better environment conducive to routine physical activity and higher quality food choices, and it is especially important to target earlier stages of school-aged children.

In addition, behavioural disorders including attention deficit hyperactivity disorders (ADHD) are also on the rise. In a cross-sectional study of Omani school children, hyperactivity was found in 7.8% of boys (Al-Sharbati et al., 2008) and 5.1% girls (Al-Sharbati et al., 2004). Furthermore, a study on 5,409 Omani adolescents found 17% (boys 14.7%, girls 19.4%) of them suffer from some sort of mild depressive symptoms (Afifi, 2006). The link between omega-3 fatty acids, mainly DHA and psychiatric disorder was proposed from several studies (Antalis et al., 2006, Burgess et al., 2000, Colquhoun and Bunday, 1981, Colter et al., 2008, Mitchell et al., 1987, Stevens et al., 1996); a similar link has been found with depression (Pottala et al., 2012).

It has been suggested that increased long-chain omega-3 fatty acids intake might help pupils to study more effectively and potentially help to tackle ADHD and depression. In 2008, Aberg et al. (2009) reported a positive association between the number of times having fish meals per week at age 15 and cognitive performance measured 3 years later. Fish consumption of more than once per week compared to less than once per week was associated with higher Stanine scores in combined intelligence (0.58 units; 95% C.I. 0.39, 0.76), verbal (0.45; 0.27, 0.63) and visuospatial performance (0.50; C.I. 0.31, 0.69). The association between fish consumption and the three intelligence scores was the same in lowly and highly educated groups.

Despite growing interest in role of omega-3 fatty acid in human health and development worldwide, very little research has been carried out in Oman. Oman is a marine nation and fish has been a part of the traditional diet. Yet, more people are adapting a so-called “Western style diet” (high in sugar and fat) and fast food, making them vulnerable to chronic diseases such as obesity, diabetes and cardio-vascular disease. However, these are preventable diseases - through changes in diet and lifestyle - and this can be achieved by educating people. In order to establish guidelines and policy, it is important to carry out scientifically sound basic research which will provide informative data. Since no data is currently available on the omega-3 fatty acids status of

Omani school children, the current study, the first of its type to be conducted in Oman, was planned to fill this gap.

A lot of studies have been conducted on the beneficial effects of omega-3 fatty acids in complicated and uncomplicated pregnancy, preterm and term babies (Martinez et al., 1993, Crawford et al., 2003), children with behavioural abnormalities acid (Richardson and Puri, 2002, Sinn and Bryan, 2007, Bloch and Qawasmi, 2011), adults with symptoms of mental health disorders (Gamoh et al., 1999, Hashimoto et al., 2002), adults with non-communicable chronic disorders (type 2 diabetes, hypertension and cardiovascular and cerebrovascular disease) (Shubair et al., 2005, Schulze et al., 2006, Norris et al., 2007, He and Daviglus, 2005). In contrast, there is a paucity of studies on the beneficial impact of omega-3 fatty acids in healthy school children. Indeed, because of the scarcity of data in this age group, the International Society for the Study of Lipids and Fatty Acids in its 9th Congress which was held in Maastricht (The Netherlands) in 2010 has called for more research in healthy children. The proposed investigation, which we believe is the first of its kind in the Middle East, will contribute significantly to knowledge because it is well-powered, involves homogenous groups of children and compares efficacy of fish and capsule-derived omega-3 fatty acids.

There is very limited published data on the nutritional status, body composition, blood lipids, fat-soluble vitamins, red blood cell fatty acid profile and behavioural status of Omani school children. Moreover, the effect of regular fish consumption or fish oil supplementation on red blood cell omega 3 fatty acid index have never been investigated for this population. Therefore, the current study was necessary to generate original data which could be vital for nutritional and health policy and management in Oman.

There is little knowledge - and certain discrepancies - in the literature regarding the possible impact of fish consumption on health, especially as it is applicable to Oman. There has been no research designed to investigate the effect of the fatty acid profile of local Omani fish, nor the effect of Omani marine foods on local population health. Thus, this study aims to examine local fish consumption and fatty acids supplementation impact on school children's nutritional status and biochemical parameters. The results of this study will contribute to the promotion of healthy school feeding and a reconsideration of the relevance of Omani Fish products.

In the short term, this intervention will establish whether the consumption of fish has a beneficial effect on the health of school children. If positive effects of fish on the

children's health parameters are found, then guidelines may be developed in conjunction with the Ministry of Health and Ministry of Education to encourage increased consumption of fish and/or fish oils in the population's diet.

1.7.1 Hypotheses

- Healthy Oman school children do not have nutritional deficiency, blood lipid disorder or abnormal body composition.
- Healthy Omani school children display no behavioural abnormalities in the classroom that would be classified as evidence of ADHD
- Healthy Omani school children have normal plasma vitamin A, D , E, and B-carotene concentrations, and these levels are not influenced by omega 3 fatty acid supplementation
- Healthy Omani school children have an optimal level of red blood cell omega 3 fatty acid, and this level does not change by increased oily fish consumption or with fish oil supplementation.

The genesis of NCDs starts from the uterine stage if the pregnant mother is underfed: undernutrition at early life determines disease in later life (Barker, 1995b). Numerous animal experiments have shown that undernutrition *in utero* leads to persisting changes in blood pressure, cholesterol metabolism, insulin response to glucose, and a range of other metabolic, endocrine and immune functions (Barker, 1998, Lucas, 1994). An undernourished foetus consumes its own substrates to provide energy (Harding and Johnston, 1995), whereas prolonged undernutrition slows growth, resulting in disproportionate organ size since organs and tissues grow rapidly at this stage. Undernutrition in late gestation may reduce the growth of the kidney which develops rapidly at that time (Hinchliffe et al., 1992, Widdowson et al., 1974). Likewise, foetal insulin, IGF and glucose concentrations fall, probably the effect of decreased maternal IGF in an under nourished mother. This leads to reduced transfer of amino acids and glucose from mother to foetus, and eventually reduced rates of foetal growth (Oliver et al., 1993). Foetal insulin and the insulin-like growth factors (IGFs) are thought to have a central role in the regulation of growth and respond rapidly to changes in foetal nutrition (Fowden, 1989), which leads to a rise in cortisol, which affects cell differentiation (Fowden, 1995).

Great progress has been made in preventing and managing communicable diseases worldwide. Risk factors such as high blood pressure, raised cholesterol, tobacco use, alcohol consumption, and overweight, coupled with poor economic and social conditions, create the perfect storm for many of the world's chronic diseases. If left unchecked, NCDs will continue to reduce global productivity, threaten quality of life, and cost trillions of dollars. Thankfully, systematic efforts to prevent NCDs, and ameliorate their burden, have now become part of a global health strategy (World Health Organization, 2008).

The development of atherosclerosis, which is an important risk factor in the development of cardiovascular disease, has also been found to begin in childhood and adolescence (McGill et al., 2000b), as do fatty streaks, although this progression is affected by several local mechanical forces on the blood vessel wall (Stary et al., 1994). As noted previously, these fatty streaks can become fibrous plaque as lipids accumulate into the streak. The fibrous plaque can then rupture, which causes thrombosis and cardiovascular disease or mortality. It has been found that all children have aortic fatty streaks, although fatty streaks themselves are not a clinical event (Holman et al., 1958b). McGill et al. (2008b) have argued that no level of risk factor control in adults will contribute to a 90% overall eradication of coronary heart disease, and this may be possible only by managing risk factors from childhood. Tejada et al. (1968) showed that the fatty streaks that developed in childhood became fibrous plaques and complicated lesions during the third and fourth decades of life. Another issue that is of particular importance to NCD risk factors in childhood is low birth weight. The Barker Hypothesis posits that children born with low birth-weight are at a greater risk for developing CHD (Barker and Osmond, 1986). More recent research has found that low birth-weight is a risk factor not only for CHD, but also for hypertension, increased insulin resistance, high fasting insulin levels and type 2 diabetes (Curhan et al., 1996a, Curhan et al., 1996b, Barker and Osmond, 1986). Researchers suggest this is due to 'programming' whereby a stimulus that occurs at critical developmental periods has permanent effects on the foetus throughout its postnatal life (De Boo and Harding, 2006).

1.7.2 Aim of the study

- To assess at baseline the omega-3 fatty acid, blood biochemistry and nutritional status of Omani school children and, whether supplementation of either fish or fish

oil capsules improves the omega-3 fatty acid status of children and their blood biochemistry.

1.7.3 Specific objectives

To test the above stated hypotheses:

a) Macro- and micro-nutrient intake, body weight, height, body mass index, fat and muscle mass, fat-free mass, plasma triglycerides, plasma total cholesterol, LDL Cholesterol, HDL Cholesterol, blood pressure will be assessed.

b) Behavioural abnormalities, specifically attention deficit hyperactivity disorder and its subtypes (predominantly inattentive, predominantly hyperactive/impulsive and/or ADHD combined inattention/hyperactivity) and associated risk factors such as birth weight, gestational age, parental consanguinity, age, educational level, occupation, income and will be examined.

c) Plasma vitamin A, E and D and B- carotene concentrations will be determined before and after intervention with oily fish or docosahexaenoic acid enriched fish oil capsules for 12 weeks.

d) Levels of red blood fatty acids, particularly omega-3 fatty acid index (docosahexaenoic and eicopentaenoic acids), will be analysed before and after intervention with oily fish or docosahexaenoic acid enriched fish oil capsules for 12 weeks.

CHAPTER 2:
Methods

2.1 Subjects and Recruitment

2.1.1 Subjects and Sampling Strategy

Study area: The study was carried out in Muscat Governorate, Sultanate of Oman. The data were collected in the period from December 2012 till May 2013.

Target population: Male and female children aged 9-10 years in Grade 4.

Sampling frame: Following consultation with a statistician, a three stage sampling procedure was used to ensure representative samples of 9 and 10 year old children in Muscat Governorate. In the first stage, three (n=3) schools were randomly selected from the 39 schools in the Governorate. Next, the three schools were then randomly assigned to 'Fish Meal', 'Omega-3 capsule' or control group. Finally, in each of the selected schools, three classes of 9 and 10 year old children were randomly selected to receive the assigned intervention.

The three schools randomly selected for participation in this study were Waha School, Mashareq School and Ula School, which were randomly assigned interventions as follows:

- Students from Waha School were randomly assigned to receive the fish meal.
- Students from Mashareq School received the omega-3 fish oil capsule.
- The Ula School children did not receive fish meal or omega-3 fish oil capsule.

Of the population of 6,855 children aged 9 and 10 enrolled in the 39 schools in the Muscat Governorate, 354 (5.2%) were included in the study.

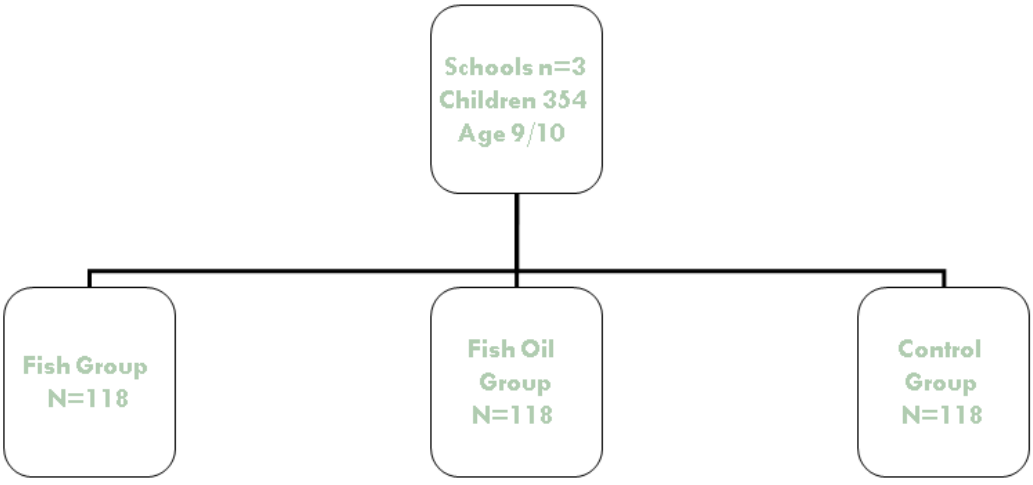

Figure 2-1: Subjects and Methodological Framework

2.1.2 Sample Size Calculation

Since there is no established data on the blood (red cell or plasma) fatty acids of Omani children, our calculation uses the red cell DHA of UK children which is 2.0±0.70 (Matsudaira, 2010, Gow, 2012). We anticipate that:

- The consumption of fish or the provision of omega-3 fatty acid capsules four times a week for 12 weeks will enhance the DHA status of the children.
- The increase will vary due to absorption and metabolic differences between individual children.
- The mean DHA values of both groups (omega-3 supplement and fish meals) to increase to 2.4±0.70.

Based on these expectations, the sample size required to detect the increase with 80% power and a 95% (two-sided) confidence interval is forty-nine (n=49). However, since there is an indication that boys and girls metabolise fatty acids differently, it was necessary to enrol 49 boys and 49 girls. This raised the total number of children required to assess the effect of fish feeding on DHA status to ninety-eight (n=98). Similarly, another 49 boys and 49 girls (n=98) was required to test the efficacy of the omega-3 fatty acid capsules on the DHA status of the school children. With the addition of another 49 boys and 49 girls for the control group, the total required sample size was 294.

The research literature indicates that the rate of compliance of school children in nutritional studies is low. There is also evidence that some children may develop a strong aversion to fish after a few weeks of exposure to fishy foods. To compensate for these possibilities, we increased the number of subjects by 20% (n=60). Hence, the total number of children needed for the study was raised to three hundred and fifty four (n=354).

- *Inclusion criteria*: Male and female children aged 9-10 years who do not have any known hereditary or chronic medical conditions.
- *Exclusion criteria*: Children with a known hereditary or chronic medical condition that requires medication or who suffer from a fish or shell fish allergy.

2.2 Ethical Approval and Consent

Ethical approval was obtained from the Ministry of Health of Oman (Ref. MH/DGP/R&S/Proposal_Approved/8/2012) (Appendix 4), UK National Health Service Ethics Committee and London Metropolitan University Ethics Committee.

A written informed consent was obtained from the parents or guardians of all the children who participated in the study. Participating children and their parents were also assured that withdrawal at any stage of the study was permissible and would not carry any negative consequence. The consent forms explained the details of the study, as directed by the Ethical Committee of the Ministry of Health in Oman (see Annex 3). Each eligible and willing child was then invited by the author and school nurse to the school's clinic – to be accompanied by at least one parent – where the author explained the study in more detail, including the mode and duration of the intervention. A thorough history and clinical examination, for the collection of baseline measurements, were also made at this time (see Annex 4).

2.3 Intervention

Fish or fish oil capsule was given to the children at lunch time in school.

1. ***Fish lunch:*** Fish were selected from the local markets depending upon their availability and popularity among Omanis, such as Emperor, Grouper, King Fish, Red Snapper and Yellowfin Tuna. Fish meals were prepared by various methods, either grilled or steamed to enhance compliance and were provided to the pupils at school once daily (mid-day break) four days a week for 3 months (12 weeks). Food was prepared by one of the selected caterers in Muscat and in accordance with the Muscat Municipality or Consumer Protection Agency regulations and HACCP standards. Each serving consisted of 100-150g of fish. This amount was estimated to provide 200-250 mg omega-3 fatty acids, depending on the species of fish.
2. ***Omega-3 oil capsule:*** One omega-3 oil capsule containing 200-250mg omega-3 fatty acid (docosahexaenoic acid) was given to the school children once daily, four days a week for 12 weeks.

2.3.1 Determination of DHA Content in the Fish

Fish were selected from the local markets depending upon their availability and popularity among Omanis. The quantity of DHA in the fish was then determined in order to select fish best suited for the study. These were Emperor, Red Sea Bream, Striped Bonito, Grouper, Mackerel, Sardine, King Fish and Long Tail Tuna, which are all commonly found in local markets and consumed in Oman.

Figure 2-2: Quantity of DHA (mg) in 100 gram of uncooked fish with and without skin

The concentration of DHA ranged between 135 mg and 572 mg per 100 grams of uncooked fish without skin (Figure 2-3). Of the eight fish analysed, the varieties found to contain the most significant levels of DHA were Striped Bonito, Mackerel, Long Tail Tuna and particularly King Fish. The amount of DHA in skinned fish (raw) was slightly higher than in un-skinned fish (raw), which suggests that eating fish with skin would provide more DHA.

Similarly, 100 gram of grilled fish would provide 200–1200 mg of DHA depending on the type of fish, due to the loss of water (Figure 2-3).

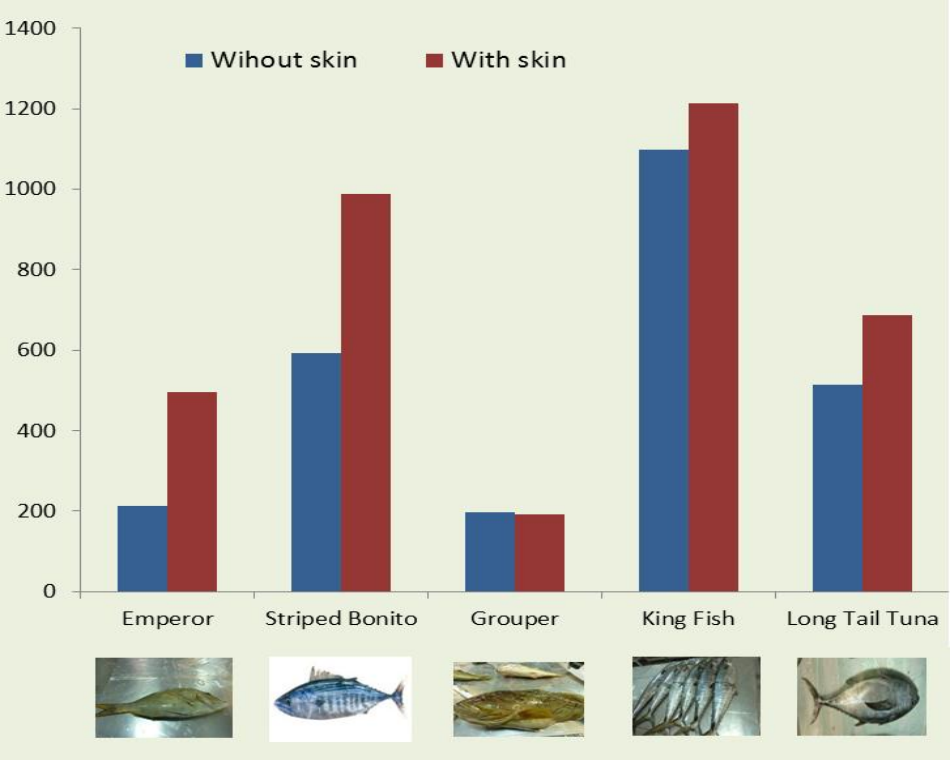

Figure 2-3: Quantity of DHA (mg) in 100 gram of grilled fish with and without skin

2.3.2 Preparation of the Fish Meals

The fish were filleted and grilled with a minimal use of salt, cooking oil and other condiments. 100 mg of grilled fish fillet was used in each meal. Trial recipes were tested by fifty children from the three schools.

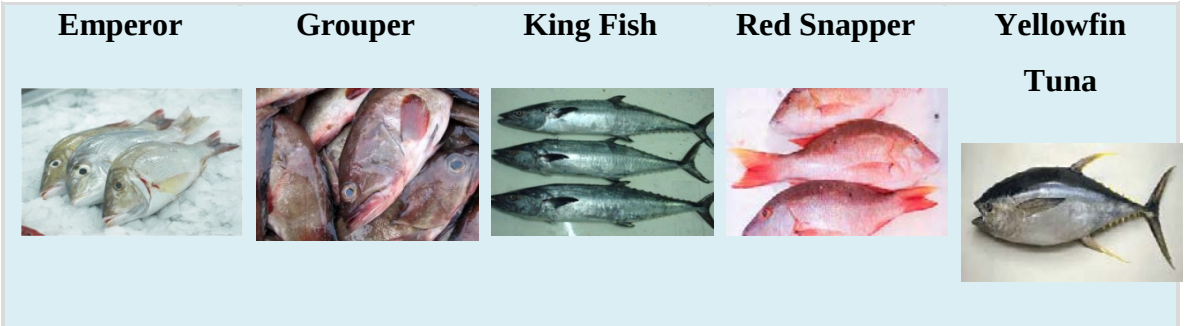

Figure 2-4: Fish used in the study

2.3.3 Omega-3 Fish Oil Capsule

The omega-3 fish oil capsules used for study were provided by Efamol Limited (14 The Mole Business Park, Leatherhead, Surrey KT22 7BA, UK). One capsule contained 403 mg of DHA and 53 mg of EPA.

Company website: www.efamol.com

2.4 Assessment of Habitual Diet, Blood Profile, Anthropometric and Body Composition, and Cognitive Function

Before the intervention, baseline measures were assessed for dietary intake, body composition, cognitive, and behavioural function of the participating children. In addition, fasting blood samples were obtained for various biochemical analyses.

2.4.1 Habitual Diet

A food frequency questionnaire and a 24-hour dietary recall was developed in close coordination with the Ministry of Health and London Metropolitan University to measure fish consumption and other food items commonly used in the Omani diet. Children or their parents were asked to recall detailed information about everything they had to eat and drink over the past 24-hour period. Quantities consumed were estimated using calibrated cups and other standard units of weight or volume (e.g., 1 apple, a packet of biscuits, a can of soda). Questionnaires were completed during work days to avoid including data from the weekends. The Food Processor software version 10.2 (ESHA Research, Salem, OR, USA) was used to calculate the means of daily nutrient intakes (carbohydrates, protein, fats and total energy intake).

2.4.2 Anthropometric and Body Composition

Measurements of weight, height, waist circumference and percentage body fat were taken by the author and two dieticians from the Ministry of Health. The standard operating procedure of the Ministry of Health was followed for all measurements.

Weight was measured to the nearest 100g using a UNISCALE, with the subject in light clothing without shoes. Height was measured using Shorr measuring boards (C.M.S. Weighing Equipments Ltd. London). The subject was measured with socks and shoes removed, standing upright with feet together in the centre of the base plate.

Height (m) was measured to the nearest 0.1 cm. Values of weight and height were then used to calculate BMI (Kg/m^2) values. BMI z-scores were extracted using BMI, decimal age, and gender, allowing for a comparison of BMI with WHO's 2007 standard (overweight: z score >1 SD, and obesity : z-score >2 SD) (de Onis et al., 2007).

Waist circumference was measured using a flexible, inelastic tape measure on the horizontal plane 4 cm above the umbilicus with the abdominal muscle relaxed and the subject breathing shallowly (Rudolf et al., 2007). Waist circumference is a measurement of central fat mass which contributes to the development of impaired lipid profile, high blood pressure, and metabolic complications (Reilly et al., 2010, Reilly and Kelly, 2010, McCarthy et al., 2005).

Skin-fold thickness was measured in triplicate at the left side of the body to the nearest 0.1 mm with Harpenden skin-fold calliper.

Body composition (fat-, muscle-, and bone-mass) was measured by using a Body Composition Analyser (Tanita, SC-331S) with subjects in light clothing without shoes.

2.4.3 Socio-Demographic Characteristics

Socio-demographic characteristics including age, gender, residential status, medical family history, vitamins or nutritional supplements, monthly income, parental occupation, and parental educational level were collected during personal interviews with the children's parent. In addition, birth weight, length, gestational age and medical history for all enrolled children were compiled from their health cards.

2.5 Collection of Biological Samples

For each school, the nearest Primary Health Centre or Polyclinic was identified as responsible for sample processing.

2.5.1 Blood sampling

The author was responsible for collecting all blood samples, and also responsible for ensuring their proper transport to the processing laboratory within 2-3 hours. The supplies needed for field collection of biological specimens were assembled and prepared in advance. For each field day, a total of 23-25 kits were prepared in advance.

School children of 9-10 years of age (grade 4) were asked to come after fasting overnight (about 10 hours).

A paediatric tourniquet was applied and a vacutainer device was used to collect about 17 ml blood from each student: 5 ml on a 5ml red capped plain gel-separating tube, and 12 ml whole anti-coagulated blood divided in 3 EDTA tubes (purple-capped) each having 4 ml blood. The EDTA blood was immediately mixed by repeated inversion to prevent clotting by mixture with the anticoagulant; blood in the plain tube was left to clot for about 10 minutes, then centrifuged for 5 min at a speed of 3,000 rpm until the gel separated the serum (above) from the clotted blood (below).

The data for each student was entered into the computer system including Full name, age, date of birth, sex, nationality, and any relevant past medical history. Blood samples of each student were labelled with a sticker that included all relevant personal data and then put into a single collection bag.

All collection bags for blood were then placed in an envelope which was then put in a cool box with an ice pack and immediately delivered to Royal Hospital Lab for further processing.

The blood collection took place on a clean absorbent pad, and standard laboratory safety and hygiene procedures were followed. The blood was collected and transferred into vacutainer tubes and immediately labelled.

2.5.2 Transport and Storage of Samples

To ensure the proper transport of human biological products, the following cold chain was maintained (Table 2-1):

Table 2-1: Cold Chain to ensure the proper transport of human biological products

	Venues in the Cold Chain				
	Polyclinic/ Health Centre	Vehicle	Royal Hospital	Laboratories	Shipment via DHL
Procedures	Blood drawing; centrifuge to separate serum Storage until shipped to Lab	Transport to Royal Hospital		Analyses	Some samples sent to London Metropolitan University Laboratory
Packaging	Cool boxes or Styrofoam, with frozen cool packs	Styrofoam boxes with frozen cool packs	Freezer	Freezers	Cool boxes and dry ice
Temp.	Less or equal to 10°C	Less than or equal to 10°C	-20°C to-40°C	-20 to -40°C	Less than or equal to -20°C
Duration	2-3 hours	20 minutes	3 months	Until all analyses completed	24-48 hours

2.5.3 The Royal Hospital Laboratories

The blood samples were processed at the Royal Hospital laboratories as follows (Table 2-2) by the author who was supervised by a specialised lab technician :

Table 2-2: Procedure for Blood Sample Processing

	Procedure for Separating Red Blood Cells and Plasma
Step 1	Spin whole blood as follows; ▪ Speed: 1500 g ▪ Duration: 10 min ▪ Temp.: 4°C
Step 2	Transfer 1.0 ml supernatant (**Plasma**) into 1.5 ml (or 2 ml) Eppendorf tubes (labelled). Prepare as many aliquots as possible without discarding any sample.
Step 3	Add equal volume of normal saline (0.9%) into the remaining red blood cells and repeat STEP 1.
Step 4	Discard supernatant and repeat STEP 3.
Step 5	Discard supernatant and then transfer 1.0ml of **red blood cells** into 1.5 ml (or 2 ml) Eppendorf tubes (labelled). Prepare as many aliquots as possible without discarding any sample.
Step 6	Store the samples at -20°C freezer until transport to London Metropolitan University (UK).

2.5.4 Blood Lipid Profile and Vitamins

A validated method approved by the Ministry of Health was used to determine triacylglycerol, total-, HDL, LDL and VLDL-cholesterol, and vitamin D. The analysis was carried out at the Royal Hospital.

Plasma vitamin A and vitamin E and beta carotene analyses – An aliquot of 200 μL of plasma in duplicate was used for analysis. The plasma was deproteinised with 4 ml of absolute ethanol and vortexing thoroughly for three minutes. Subsequently, 10 ml of hexane was added to the plasma-ethanol mixture, vortexed for three minutes and then centrifuged at 1200 g, 4ºC, for ten minutes. The top organic layer containing the required analytes was carefully transferred to another tube, dried at 30º C under a gentle stream of nitrogen, suspended in 1000 μL of methanol containing 0.01% butylated hydroxytoluene. An aliquot of 50 μL was then taken for analysis. The target analytes (retinol, alpha-tocopherol and beta-carotene) were separated by an Agilent 1100 high performance liquid chromatography (HPLC) system (Agilent Technologies, Waldbronn, Germany) with the use of a 5 micron C18 reverse-phase column, 150 X 4.6 mm (HiChrom Limited UK). The analytes were eluted with 100% HPLC grade methanol at a flow rate of 2 ml/min and detected with a diode array UV/Vis detector (Agilent Technologies, Waldbronn, Germany). Vitamin A, vitamin E and beta-carotene were detected at 325 nm (1.5 min), 292 nm (4.8 min) and 453 nm (30 min). Concentrations were determined from a standard curve computed with the use of ChemStation (Agilent Technologies, Waldbronn, Germany).

Plasma triglycerides – Concentration of plasma triglycerides was determined enzymatically (Glycerol phosphate oxidase assay) based on the method described by Fossati and Prencipe (1982) and McGowan et al. (1983) with the use of a reagent kit supplied by Abbot Laboratories (Ref: 7D74-21, 304350/R1, Abbott, Max-Planck-Ring 2, 65205 Wiesbaden, Germany).

Plasma cholesterol – The enzymatic method (cholesterol esterase-cholesterol oxidase-eroxidase) described by Roeschlau and Allain (Roeschlau et al., 1974, Allain et al., 1974) with a reagent kit obtained from Abbott Laboratories (Ref: 7D62-21, 304342/R1, Abbott, Max-Planck-Ring 2, 65205 Wiesbaden, Germany) was used to analyse total cholesterol.

Vitamin D (25-hydroxy vitamin D) - Plasma total vitamin D, 25-hydroxylated cholecalciferol (vitamin D3) and ergocalciferol (vitamin D2) was determined with a

competitive electrochemiluminescence (ecl) protein binding assay (Abdel-Wareth et al., 2013) using the Cobas e 601 immunoassay auto-analyser and reagents obtained from Roche Diagnostics (Sandhoferstrasse, Mannheim, Germany).

Parathyroid Hormone (PTH) – Intact plasma PTH was quantified by Architect Intact PTH assay, a two-step chemiluminescent microparticle immunoassay (cmia) using the automatic immunoassay analyser ARCHITECT i2000SR (Abbott, Abbott Park, IL, USA) and reagents from Abbott Diagnostics (Ref: 8K25, 84-6434/R5, Abbott, Max-Planck-Ring 2, 65205 Wiesbaden, Germany).

Alkaline Phosphatase (ALP) – ALP was measured on an Architect c8000 analyser (Abbot Diagnostics, Abbot Park, Il, USA) with a reagent kit supplied by Abbott Diagnostics (Ref: 7D61-20, 30-3979/RS, Abbott, Max-Planck-Ring 2, 65205 Wiesbaden, Germany).

Calcium **-** Plasma total calcium was determined with the use of an Architect c8000 analyser (Abbot Diagnostics, Abbot Park, Il, USA) with the Arsenazo III dye binding method and a reagent kit from Abbott Diagnostics (Ref: 7D61-20, 30-3979/RS, Abbott, Max-Planck-Ring 2, 65205 Wiesbaden, Germany).

Phosphate – Plasma inorganic phosphate was analysed based on the Molybdenum blue colorimetric method with a reagent kit obtained from Abbott Laboratories (Ref: 7D71-20 and 7D71-30, 30-3926//R5, Abbott, Max-Planck-Ring 2, 65205 Wiesbaden, Germany) using the ARCHITECT c8000 auto-analyser (Abbott, Abbot Park, IL. USA).

2.5.5 Red Blood Cell Fatty Acid

Blood samples were separated into plasma and red blood cells by cold (4°C) centrifugation at 1500g for 10 min. After removing supernatant (plasma) to a 1.5 ml eppendorf tube, the remaining red cells were washed with saline (0.9%) twice and transferred to another tube. This initial stage of sample preparation was carried out at the Royal Hospital, Oman. The prepared plasma and red blood cells were then transported to the LNRC laboratory and kept in a -70°C freezer until analysis.

For the analysis at LNRC, the total red cell lipid was extracted by the method of Folch et al. (1957a) and fatty acid methyl esters were separated using a gas-liquid chromatograph (HRGC MEGA 2 Series; Fisons Instruments, Milan, Italy) fitted with a BP20 capillary column (25m x 0.32 mm i.d., 0.25μm film). Hydrogen was used as a

carrier gas and the injector, oven, and detector temperatures were maintained at 250, 200, and 280°C, respectively. The fatty acid methyl esters were identified by comparing retention time with authentic standards. Peak areas were quantified by a computer chromatography data system (EZChrom Chromatography Data System; Scientific Software, Inc., San Ramon, CA).

2.6 Cognitive, Emotional, and Behavioural Assessment Methods

2.6.1 The Vanderbilt Test

An Arabic version of the National Initiative for Children's Health Quality Vanderbilt Assessment Scales-Teacher Assessment Scale (NICHQ Vanderbilt Assessment Scales) was used (American Academy of Pediatrics, 2008, Pliszka and AACAP Work Group on Quality Issues, 2007). The Teacher Assessment Scale of the NICHQ Vanderbilt Assessment Scales has 55 questions divided into two sections soliciting information about 'symptoms' and 'performance'. The SYMPTOMS section contains 47 items divided into various sub-sections: items 1-18 tap into the symptoms of ADHD, items 19-26 tap into symptoms of oppositional defiant disorder, items 27-40 quantify the presence of Oppositional-Defiant/Conduct disorders and items 41-47 solicit the presence of Anxiety/Depression. Symptoms scales are rated as follows: never = 0, occasionally = 1, often = 2, very often = 3. The teacher is instructed to circle only one of the numbers on the scale.

The PERFORMANCE section measures the level of impairment regarding Academic Performance (reading, mathematics and written expression) and Classroom Behavioural Performance (relationships with peers, following directions/rules, disrupting class, assignment completion and organizational skills). Performance scales are rated as: excellent = 1, above average = 2, average = 3, somewhat of a problem = 4, problematic = 5. The formula for scoring NICHQ Vanderbilt Assessment Scales has been detailed elsewhere (Wamithi et al., 2015).

The following symptoms were the focus of the present study: the predominantly inattentive subtype of ADHD (PIS), Predominantly Hyperactive/Impulsive subtype (PHIS), ADHD Combined Inattention/Hyperactivity (ADHDCIH), Oppositional-Defiant/Conduct Disorders and Anxiety/Depression. The research team explained to teachers how to complete the NICHQ Vanderbilt Assessment Scales, and were explicitly instructed to base their answers in reference to the child's behaviour over a six month period (see Appendix 2).

2.7 Quality Assurance Methods and Procedures

To ensure the quality of the data and resulting analysis, the data were checked during the process of data collection; during the data entry phase, a double entry verification process was followed; and once entered, the data were managed and cleaned by the author. The questionnaires were validated during the pilot phase of this research.

2.7.1 Quality Assurance and Data Management after the data analysis

To ensure the quality of data collection, team members were provided with the field manual, and were advised to follow it strictly. The field supervisor of each team was responsible for reviewing the questionnaires immediately after the interview in the school. All questionnaires were checked for consistency and accuracy by the author.

Data entry files that included consistency checks were prepared on EPI6, and the data of all questionnaires were entered twice by two separate data entry personnel. The duplicate files were run on the validate module of EPI6 software and the errors as well as the missing values were corrected by referring back to the hardcopy questionnaires.

The frequencies and cross tabulations of all relevant variables were then run, in order to detect any inconsistencies and corrected from the initial interview questionnaires.

2.8 Data Analyses

All statistical analyses were performed using SPSSS version 21 by the author with assistance of a statistician. Data were checked for normality, and all data were expressed as “mean and standard deviation” or “median and range”.

Continuous variable data collected at baseline and at the end of the intervention period (for all three groups: Fish meal, Omega 3 and Control) were evaluated using analysis of variance (ANOVA) followed by a post hoc analysis. Chi-square (χ^2) tests was used for comparing categorical variables, while non-parametric variables was assessed with the Kruskal-Wallis test or Fisher’s exact test. $P < 0.05$ was used as a measure of statistical significance.

Intervention effects was investigated with the Analysis of Covariance Model (ANCOVA). Associations between red blood cell DHA and the other assessed (measured) variables including cognitive function and learning scores will be evaluated using Pearson or Spearman correlations, depending on the normality of the variables.

Variable that are not normally distributed was transformed before statistical analysis is undertaken, and corrections will be made for multiple testing except when it is inappropriate to do so. The analyses was conducted on intention-to-treat basis and multiple imputation was used to correct for missing data.

The data are expressed as mean and standard deviation (S.D.). Independent (unpaired) and paired t-tests, respectively, were used to determine statistical significance between the genders at baseline and between pre- and post-intervention within gender. Group comparison was performed with a one-way ANOVA, and Boneferroni post hoc test when a significant difference is indicated. Differences were considered significant if the p value was less than 0.05. All analyses were carried out with SPSS version 21 (IBM SPSS, IBM Corporation, Armonk, NY, USA).

CHAPTER 3:
Dietary Intake and Body Composition of Preadolescent Children in Oman

3.1 Introduction

Over the last four decades, the Gulf Countries have undergone a drastic socio-economic transformation. In Oman, the per-capita GDP rose 30-fold between 1970 and 2005, from 158 Omani Rials (OMR) to 4,712 OMR, bringing with it all the promises of modern civilization. This 35-year span marked a period of remarkable growth and changes in Omani society accompanied by transitions in demography, epidemiology, and nutrition.

The demographic changes have been profound. The population more than quadrupled, increasing from 732,000 in 1970 to 3.2 million in 2013. During the same period, the Total Fertility Rate (by UN Estimates) dropped from 7.41 to 2.52, while life expectancy at birth rose from 51 years in 1970 to 73 years in 2011. These massive changes were due in large part to a significant reduction in the mortality rates of under five year old children (U5MR) from 48 deaths of under-five year olds per 1000 live births in 1990, to 22 in 2000, and 9 in 2011. Predictably, with this change in life expectancy, the demographic profile of Oman has changed, as well: in 1970, 46.4% of the population was under the age of 15 years; in 2010 only 27.2% was in this young age group.

This dramatic shift has led to the emergence of a double burden of disease: diarrheal disease, maternal complications, and several communicable diseases still remain a problem, but cardiovascular disease, hypertension, diabetes, cancers and chronic kidney disease are all on the rise. The burden of non-communicable diseases has now become quite substantial as shown in Figure 3-1: among the most affluent Arab Countries, Oman has the second highest disease burden and a significant problem with diabetes. Infectious diseases are no longer dominant. Increasingly, chronic NCDs characterize Oman's major health problems as the population now lives long enough to contract them (Rahim et al., 2014a).

The double burden of disease that characterizes this epidemiological transition is mirrored in the double burden of malnutrition that is key to the nutritional transition: during this period of development, evidence of undernutrition (in the form of stunting, underweight, wasting or micronutrient deficiency) now coexists with measures of over-nutrition (in the form of overweight or obesity).

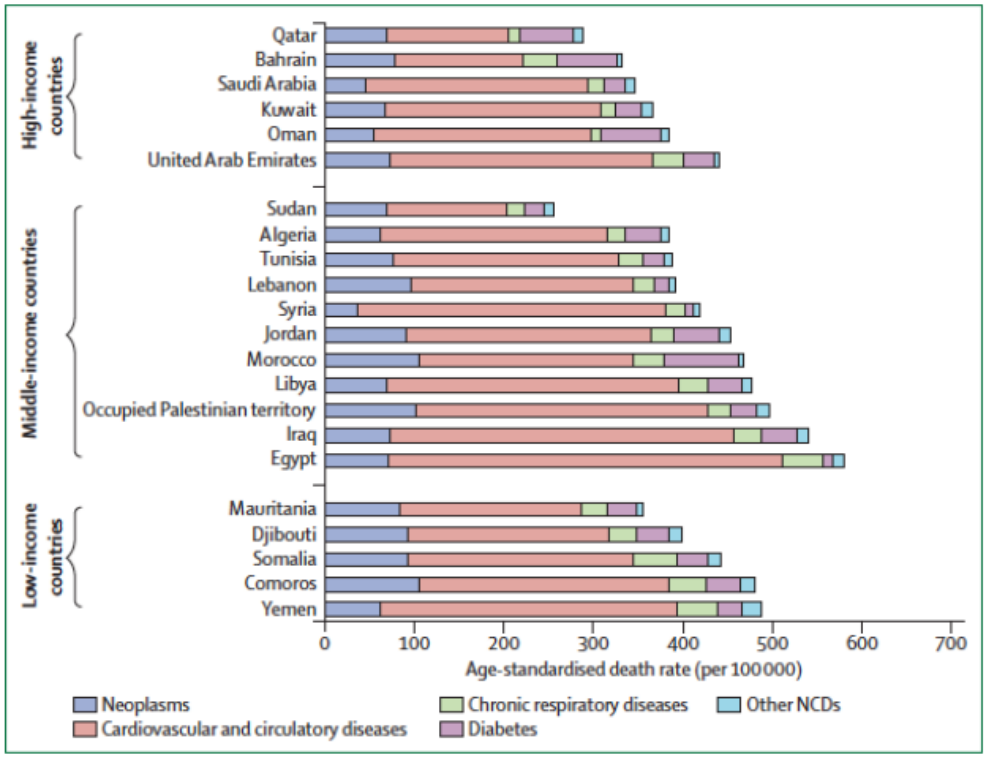

Figure 3-1: Death Rates from NCDs in Arab Countries

In other words, the drastic socio-economic changes, accompanied by rapid urbanization, have also witnessed an increase in a sedentary lifestyle and the adoption of a Western diet. Regrettably, this pattern of physical inactivity and the adoption of a Western diet, and perhaps genetic susceptibility, is in large part responsible for the exponential increase in the prevalence of non-communicable diseases (NCDs), such as coronary heart disease, stroke and type-2 diabetes in adults, as well as obesity in children, adolescents and adults (Rahim et al., 2014a, Kilpi et al., 2014, Al-Lawati et al., 2012). Consistent with the aforementioned reports, a comprehensive Oman-wide community household survey conducted in 2008 (Al Riyami et al., 2012) found a prevalence of 40.3% hypertension, 12.3% diabetes, 21.4% obesity and 33.6% elevated blood cholesterol.

The factors behind the rapid globalisation of the Western diet are diverse and complex (Pingali, 2007). However, in the case of Oman, the liberalisation of food imports from developed countries to meet the rising demand associated with the spectacular increase in income and wealth, the proliferation of hypermarkets and fast food restaurants, creative food product marketing and promotional strategies, and a general lack of awareness of the health problems associated with a high calorie density

with elevated levels of saturated fats and refined sugars seems to have contributed significantly to the widespread consumption of Western foods. Although a comprehensive study has not yet been conducted to evaluate the frequency of fast food consumption by Omani children and adolescents, anecdotal evidence and casual observations and consistent with the reports from other parts of the Arab world and other countries (Musaiger, 1987a, Chakar and Salameh, 2006, Al-Hazzaa et al., 2011, Musaiger et al., 2011a, Allafi et al., 2014, Al-Haifi et al., 2013). Pingali (2007) suggests that fast food meals are more popular among younger age groups than in adults, and there is evidence that childhood dietary habits persist into adult life (Mikkilä et al., 2004, Ventura and Worobey, 2013b); furthermore, non-communicable chronic diseases have also been demonstrated to originate in early life (Holman, 1961, McNamara et al., 1971, Newman et al., 1986, Barker, 1995a, McGill et al., 2009a).

The typical Western diet is composed of calorie dense foods that are high in glycaemic index carbohydrates, total fat and saturated, trans- and omega-6 fatty acids, and low in omega-3 fatty acids and essential vitamins and trace elements (Cordain et al., 2005a, Hintze et al., 2012, Myles, 2014, USDA, 2002). Hence, the propensity of Omani children to develop Western food habits should be of concern due to the potential negative impact of such habits should be of concern due to the potential negative impact of such foods on growth and development, cognitive ability and behavioural competence (Nyaradi et al., 2013, Nyaradi et al., 2014) and the manifestation of NCDs in later life (Popkin, 2006, Cordain et al., 2005a, Moghaddam et al., 2007, Misra et al., 2010, Carrera-Bastos et al., 2011b). Numerous studies have also assessed the relationship between energy and nutrient intake and adiposity in children (Jennings et al., 2012, Kovalskys et al., 2013, Campbell et al., 2006, Walton et al., 2015, Tsiountsioura et al., 2014, Maffeis et al., 2000); a number of such studies have also been conducted in the region (bin Zaal et al., 2009, Musaiger et al., 2011a, Washi and Ageib, 2010).

Until recently, the focus of nutritional research in Oman has been the prevention of maternal and infant undernutrition, malnutrition and the deficiency of nutrients - such as protein, calcium, iron vitamin A, iodine and folate - which were once prevalent in the Country. As such, there are no comprehensive published data pertaining to the critical role of a balanced diet for optimal cognitive, emotional and physical growth of children and the prevention of NCDs in adults. Also, there is no comprehensive data assessed the dietary habits and intake of the pre-school children. As such, the current study was

conducted to assess the dietary intake, body composition and blood lipid profile of preadolescent children.

3.2 The Current Nutritional Situation in Oman

Oman has experienced remarkable improvements in health and nutrition indicators, especially for women and children, such that WHO ranked it among the top 10 member countries in its 2000 World Health Report (WHO, 2000). UNICEF has also reported on the significance of Oman's progress, noting that the under-five mortality rate (U5MR) has decreased from 48 (1990), to 22 (2000) and 9 (2011), representing a reduction of 82% since 1990 and 60% since 2000. The progress marked by these indicators are matched by a rise in life expectancy rates from 51 years (1970) to 76 years (2012) (Ministry of Health, 2012). Despite these signs of remarkable progress, however, there are other markers that suggest that these improvements are far from uniform or complete. Rates of anaemia illustrate this, although reportedly only in a mild form: 42.7% in pregnant women, 34% in non-pregnant women, and 50.5% in preschool children (DoN-DGHA, 2009).

In light of the radical and abrupt demographic and nutritional transitions in Oman during the past thirty-five years, and these measures of uneven progress, it is especially important to maintain an up-to-date and comprehensive portrait of the population's current nutritional status, particularly as it relates to the increased disease burden associated with NCDs. The following provides an overview of the most important features of such a portrait.

Monitoring of malnutrition among Omani school children was first initiated in 2002 (Abdou et al., 2010). Since then, students in Grades 1, 7 and 10 have been screened as part of the annual school health examination. The proportion of underweight children in grade 1 has shown a steady decline from 16.5% in 2002 to 10.8% in 2007, which is consistent with data from health centres for younger children (ages 0-5 years old). The proportion of underweight children in grade 7 follows the same pattern. Adolescents in grade 10 seem to have less underweight children, although there was also a counter-trend towards an increasing proportion of students who are overweight or obese (Abdou et al., 2010).

3.2.1 Non-Communicable Diseases (NCDs)

The same conditions of an improved socio-economic status, and accompanying changes in lifestyle to a more sedentary existence, the importation of high caloric density processed foods, an urban environment with poor access to parks or other areas for exercise that contribute to a lack of physical activity, etc., are conditions found in many of the Arab countries, particularly member states of the Gulf Cooperation Council (UNICEF, 2010). The recent *Lancet* series on the health of Arab countries places Oman as second only to the United Arab Emirates in deaths from non-communicable diseases.

The planning section of the Ministry of Health has produced evidence which confirms that Oman now has one of the highest rates of death from cardiac disease among the more affluent Middle East countries, and indeed the world. This problem is predicted to escalate along with an increase in diabetes and other co-morbidities of the metabolic syndrome (Mokdad et al., 2014). Cancer rates are also predicted to increase, as highlighted by the International Agency in their report for World Cancer Day (Falkner et al., 1994). In addition, the societal burden associated with NCDs will continue to grow as the demographic transition continues, and as life expectancy increases. Other countries facing similar trends have experienced a decline in work efficiency from absenteeism due to disease, while premature deaths from coronary heart disease and diabetes contribute to greater DALYs. This increasing trend is a major concern in Oman where cardiovascular diseases and cancer are the two leading causes of hospital deaths, totalling 32.5% and 9.9%, respectively. The prevalence of diabetes among adults has increased by nearly 50% since 1991 and now stands at 12.3% (World Health Organization, 2011b).

3.2.2 Physical Activity and Dietary Behaviours

A large portion of NCDs are preventable through the reduction of four key behavioural risk factors, namely: unhealthy diet, physical inactivity, tobacco use, and alcohol abuse. The prevalence of the first three of these key risks is of primary concern. Nearly 70% (69.8%) of Omani adults eat less than 5 servings of fruit and vegetables per day and 40% are physically inactive; in addition, 14.7% of men smoke. Low daily fruit and vegetable intake and physical inactivity are also a concern for younger populations: 75.3% and 84.3%, respectively, among 13-15 year-old students and 87.6% and 50%, respectively, among college students. In addition, tobacco use among male college students is higher than among men in general; 17.3% smoke cigarettes and 13.2% use shisha.

The Oman Global School Based Student Health Survey (2010) showed that 41.6% of the sample usually ate fruit two or more times per day, while 17.9% usually ate vegetables three or more times per day. Nearly half of the sample ate breakfast most of the time, while nearly one half of students consumed carbonated soft drinks one or more times per day. Almost one quarter of surveyed students (24.1%) ate fast food. As for physical activity, 22.7% of the students in the sample were physically active five or more days per week for a total of 60 minutes. This behaviour was more predominant in males than females (Abdou et al., 2010).

Along similar lines, a health survey of adolescents, conducted by the government in 2004, found that only 45% of 13-15 year olds had breakfast on a regular basis. Furthermore, the Global Health Survey (2004) identified a number of additional behaviours among this age group that could lead to overweight and obesity: the consumption of fast foods, sugary drinks, high consumption of crisps and carbonated drinks. The 2010 Global School-Health Student Survey reported similar findings: of the students included in the sample, 45.1% ate breakfast most of the time, with a significant difference between boys (55.8%) and girls (35.8%). The survey also found that 18.2% ate vegetables three or more times a day (boys 19.6%; girls 16.5%), and 42% ate fruit two or more times a day (boys 46.6%, girls 38.5%) (Abdou et al., 2010).

The Global School-Health Student Survey, in both 2005 and 2010, identified the importance of physical activity throughout the lifespan to maintain normal weight and to prevent the onset of chronic disease, also noting that habits formed in youth continue through to adulthood. In 2010, however, only 22.7% of all students were physically active for a total of at least 60 minutes per day on five or more days in a week. This represented a significant decrease from the survey's 2005 results, where that measure was 75.5%. According to the same survey, girls (15.9%) were half as active as boys (29.0%). The survey also found that two-thirds of the students did not walk or ride a bicycle to school the previous week (Abdou et al., 2010).

Preliminary results of a 2009 Knowledge, Attitudes and Practices (KAP) study conducted among students in Universities, College and Higher Institutes showed a noticeable gap between knowledge and behaviour related to diet: knowledge about the importance of breakfast, and about increasing the proportion of vegetables and fruits in the diet, was quite high, while behaviour consistent with that knowledge was very low. Furthermore, 45% of the sample mentioned eating fast food 3 or more days during the previous week and 66% ate fast food 1-2 times per day (MOH, 2009). The reasons

underlying this gap between knowledge and healthy dietary behaviour were as follows: lack of time (44%); unavailability of healthy food (32%); insufficient knowledge (31%); social pressure (27.6%); insufficient skills to buy and prepare healthy foods (24%); do not enjoy healthy food (19.2%) and high cost of health foods (17.8%).

The same gap between knowledge and practice was found in regard to the importance of physical activity, with the percentage of females who demonstrated adequate levels of physical activity being half of that found in males. On the other hand, it was found that the percentage of students who walk was high (83.5%) when compared with the proportion that is sedentary for more than two hours a day (28.7%). The main challenges and difficulties for not practicing physical activity were: lack of time (53.5%), accessibility of places to practice (48.7%), weather conditions (46.8%) and social network support (34.2%).

3.3 Methods and Analysis

Sample: A total of 354 school children aged 9 and 10 in the Muscat Governorate were included in the study's sample using a three-stage sampling procedure, and only 222 of them were completed their dietary intake data.

Measurements: baseline measures were assessed for dietary intake, body composition, and cognitive/behavioural function of the participating children. In addition, fasting blood samples were obtained for various biochemical analyses. Dietary intake was assessed using a food frequency and a 24-hour dietary recall questionnaire. Both the instrument and procedure is described in Chapter 2 section 2.4.1. The procedures used to assess and analyse the blood profile, anthropometric and body composition of students is described in Chapter 2 sections 2.4.2 - 2.7.1.

Analysis: Continuous variable data collected at baseline and at the end of the intervention period (for all three groups) were evaluated using analysis of variance (ANOVA) followed by a post hoc analysis. Chi-square (χ^2) tests were used for categorical variables, while non-parametric variables were assessed with the Kruskal-Wallis test or Fisher's exact test. Statistical significance was established using $P < 0.05$. The procedures used are described more fully in Chapter 2 section 2.8.

3.4 Research Findings

3.4.1 Birth Characteristics of Children and their Families

The foetal birth measures of the children and the socio-demographic characteristics of their parents are presented in Table 3-1. Of the total sample of children, 11% were delivered by caesarean section and 3% and 1% of them were low birth weight and pre-term delivery children, respectively. Among these measures, there is no appreciable difference by gender, either clinically or epidemiologically. With respect to antenatal history of the mothers, 11% were diagnosed with gestational diabetes while 0.6%, 7% and 5% were diagnosed with Type 2 Diabetes, hypertension and iron deficiency anaemia, respectively. In all, 70% of the mothers were absent of any illness during their antenatal period.

On average, the children's birth weight was 3.1 (±0.5) kg and their birth length was 50 (±5) cm. Of all the children, 58% had parents who were unrelated, 28% were of first degree consanguineous marriage, while the rest (15%) were of second degree consanguineous marriage. In terms of education, 42% of the mothers were high school graduates while 23% studied up to primary school; among the fathers, 55% were high school graduates and 16% studied up to primary school. In terms of employment, 55% of the mothers were housewives, while 29% and 10% worked in the public and private sectors, respectively. Among the fathers, 34% and 31% worked in the public and private sectors, respectively. Overall, 40% of the children were from low income families while 20% were from high income families.

3.4.2 Macronutrients

Table 3-2 presents the mean (sd) of baseline daily macronutrient intake as compared to the daily recommended intake (DRI) (Institute of Medicine of the National Academies, 2005). In terms of daily caloric intake, both boys and girls fall below the DRI, although their intake levels remain within one standard deviation of the mean. The daily consumption of calories from fat, however, falls well below the recommended range of 25-35% of total recommended calories (550-750 Kcal), with a sample average of 389.5 ± 157.9. Daily Recommended Intake levels for unsaturated and saturated fats, trans fatty acid and other fats were not available for purposes of comparison.

In contrast, data for the intake of protein and carbohydrates indicate that students in the sample consumed more than the minimal daily recommended levels. For protein,

the DRI is 136 Kcals, which is significantly lower than found in our study sample (231.0 ± 68.5). Similarly, the DRI for carbohydrates is 520 Kcals, which is also significantly lower than the level of daily carbohydrate intake found in our sample (790.4 ± 327.4). Total sugar intake was much lower than the recommended maximum, which should be no more than 25% of the total recommended number of calories consumed per day (540 Kcal). In our sample, the mean intake of sugar was measured at 313.5 ± 197.0 Kcal.

The most important measures for this study, however, relate to the intake of omega-3 and omega-6 fatty acids. The DRI for omega-3 fatty acids is between 108-207 Kcal or 5-10% of total recommended calories consumed per day. In our study's sample, the average daily intake of omega-3 fatty acids was 4.2 ± 0.2 Kcal. The DRI for omega-6 fatty acids, on the other hand, is between 13-26 Kcal, or 0.6-1.2% of total calories, significantly lower than the recommended level. In our study's sample, the average daily intake of omega-6 fatty acids was 27.0 ± 1.4 Kcal. In other words, the consumption of fatty acids by the students in our sample was more adequate for omega-6 than for omega-3 fatty acids.

Table 3-1: Foetal birth dimension and parental socioeconomic characteristics

		Male (86)	Female (136)	Total (222)
Natal history (%)	Caesarean Section	13	9	11
	Low Birth Weight	5	2	3
	Preterm Baby	0.00	2	1
	Normal	78	85	82
Antenatal history (%)	Gestational Diabetes	10	12	11
	Diabetes type 2	0.00	1.00	0.60
	Hypertension	12	4	7
	Iron Defeciency Anemia	5	5	5
	Other	5	8	7
	Normal	67	71	70
Birth weight (kg)		3.1±0.5	3.1±0.5	3.1±0.5
Birth length (cm)		50±5	50±5	50±5
Consanguinity (%)	First degree	33	25	28
	Second degree	15	14	15
	No relationship	52	61	58
Mother Education(%)	Primary	27	20	23
	Secondary	29	39	35
	Graduate	44	41	42
Father Education(%)	Primary	16	16	16
	Secondary	34	26	29
	Graduate	50	58	55
Mother Occupation (%)	Public sector	31	27	29
	Private sector	12	8	10
	Military sector	1	4	3
	Freelancers	1	0.70	0.90
	Retired	0.00	4	3
	Housewife	55	55	55
Father Occupation (%)	Public sector	30	36	34
	Private sector	37	27	31
	Military sector	17	19	18
	Freelancers	2	5	4
	Retired	11	11	11
	Do not work	2	3	3
Family Income(%)	Low Income	39	40	40
	Medium Income	44	38	40
	High Income	17	22	20

Table 3-2: Sample Mean (sd) of Macronutrient Intake and Recommended Daily Intake (DRI)

Variables	Mean ± SD	DRI (9- 13 Years)
Calories (kcal)	1761.4 ± 401.5 (B) 1709.0 ± 380.4 (G)	2279 (B*) 2071 (G*)
Calories from Fat (kcal)	389.5 ± 157.9	550-750 Kcal (25- 35% of total)
Fat (Kcal)	315.3 ± 131.2	ND
Saturated Fat (kcal)	129.0 ± 62.5	As low as possible while consuming a nutritionally adequate diet
Unsaturated Fat (Kcal)	184.6 ± 87.5	-
Trans Fatty Acid (kcal)	1.8 ± 2.8	As low as possible
Other Fat (Kcal)	4.3 ± 3.9	-
Protein (kcal)	231.0 ± 68.5	136
Carbohydrates (Kcal)	790.4 ± 327.4	520
Total Sugars (Kcal)	313.5 ± 197.0	< 540 Kcal (no more than 25% of total)
Monosaccharides (Kcal)	20.5 ± 65.6	-
Disaccharides (Kcal)	36.3 ± 34.2	-
Other Carbs (Kcal)	420.1 ± 201.0	-
Dietary Fiber (g)	19.6 ± 9.4	31(B), 26 (G)
Soluble Fiber (g)	1.4 ± 1.3	-
Cholesterol kcal	11.9 ± 0.6	As low as possible
Poly fat kcal	78.3 ± 2.8	
Omega-3 Fatty Acid (Kcal)	4.2 ± 0.2	108 - 217 Kcal) (5- 10% of total Kcal)
Omega-6 Fatty Acid (Kcal)	27.0 ± 1.4	13 - 26 Kcal (0.6- 1.2 % of total Kcal)

Table 3-3 presents the mean (sd) of macronutrients by gender. For all macronutrients except Omega-3 fatty acid and Omega-6 fatty acid, the means are nearly identical for boys and girls. However, the mean (sd) of saturated fat (kcal) intake was 134.5 (65.7) in girls, which was higher than the mean (sd) in boys 120.2 (56.3); the difference was tending towards significance (p=.085). The mean (sd) of Omega-3 fatty acid intake was 4.8 (2.9) for boys, significantly higher than for girls 3.9 (2.0) (p=.012). Similarly, the mean (sd) of Omega-6 fatty acid was significantly higher in boys as compared to girls (p=.044).

Table 3-3: Sample Mean of Macronutrient Intake by Gender

Variables	Boys n= 86 mean ± SD	Girls n=136 mean ± SD	Total N=222 mean ± SD	P value
Calories (kcal)	1761.4 ± 401.5	1709.0 ± 380.4	1729.3 ± 388.7	0.335
Calories from Fat (kcal)	391.2 ± 156.5	388.4 ± 159.3	389.5 ± 157.9	0.897
Fat (Kcal)	309.6 ± 129.1	318.9 ± 132.9	315.3 ± 131.2	0.605
Saturated Fat (kcal)	120.2 ± 56.3	134.5 ± 65.7	129.0 ± 62.5	0.012
Unsaturated Fat (Kcal)	187.5 ± 88.0	182.7 ± 87.4	184.6 ± 87.5	0.691
Trans Fatty Acid (kcal)	1.9 ± 3.8	1.7 ± 1.9	1.8 ± 2.8	0.651
Other Fat (Kcal)	4.6 ± 4.3	4.1 ± 3.5	4.3 ± 3.9	0.366
Protein (kcal)	235.2 ± 70.0	228.3 ± 67.7	231.0 ± 68.5	0.469
Carbohydrates (Kcal)	811.0 ± 356.2	777.3 ± 308.5	790.4 ± 327.4	0.471
Total Sugars (Kcal)	333.4 ± 215.1	300.9 ± 184.4	313.5 ± 197.0	0.248
Monosaccharides (Kcal)	21.7 ± 74.6	19.8 ± 59.4	20.5 ± 65.6	0.842
Disaccharides (Kcal)	31.9 ± 30.5	39.0 ± 36.2	36.3 ± 34.2	0.118
Other Carbs (Kcal)	424.0 ± 210.9	417.7 ± 195.2	420.1 ± 201.0	0.823
Dietary Fibre (g)	20.3 ± 9.3	19.2 ± 9.5	19.6 ± 9.4	0.395
Soluble Fibre (g)	1.5 ± 1.3	1.4 ± 1.2	1.4 ± 1.3	0.566
Cholesterol kcal	12.6 ± 10.2	11.6 ± 8.3	11.9 ± 0.6	0.446
Poly fat kcal	78.9 ± 40.9	77.7 ± 42.1	78.3 ± 2.8	0.833
Omega-3 Fatty Acid Kcal	4.8 ± 2.9	3.9 ± 2.0	4.2 ± 0.2	0.012
Omega-6 Fatty Acid Kcal	30.3 ± 21.6	24.6 ± 18.4	27.0 ± 1.4	0.044

Table 3-4 presents the observed distribution of nutrient intake according to Omani recommended intake levels for various nutrients by gender (Department of Nutrition, 2007). The Omani Ministry of Health, specifically, its Nutrition Department, developed the Omani Guide to Healthy Eating in 2009 (Department of Nutrition, 2009). The guidelines target the general population above the age of 2 years and focus on adequate nutrition (see Appendix 5); and the prevention of obesity and chronic diseases such as diabetes, hypertension, and hyper-lipidemia through diet and physical activity. Patients with special dietary requirements and complicated cases are advised to consult professional dietitians. Emerging issues were taken into consideration in the development of these guidelines; the most important among these were issues related to trans fats and omega-3 and omega-6 fatty acids.

The recommended cut-offs vary by nutrient, presented as a range, such as the total energy (Kcal) intake for boys (2000-2300) and girls (1900-2200). In our sample, the mean intake of total energy for both boys (1761) and girls (1709) fell below the recommended range. In terms of percentages, 65.1% of boys and 64.7% of girls fell below the Omani DRI for total energy consumption. The mean daily intake of carbohydrates for both boys (202.8g) and girls (194.3g) also fell below the recommended levels (for boys, 275-175g; for girls, 261-356g). In terms of our sample, 88.4% of boys and 83.8% of girls fell below the DRI for daily carbohydrate consumption.

Table 3-4: Distribution of Sample Macronutrient intake versus Omani Recommended Daily Intake (DRI) by gender

Nutrients	DRIs (9-13 y)		Boys	Girls
	Boys (n=86)	Girls (n=136)	% (n)	% (n)
Energy (Kcal)	<2000 2000-2300 >2300	<1900 1900-2200 >2200	65.1% (56) 20.9% (18) 14.0% (12) [m = 1761]	64.7% (88) 25.0% (34) 10.3% (14) [m = 1709]
Protein (g)	<40 40-50 >50	<38 38-47.5 >47.5	15.1% (13) 18.6% (16) 66.3% (57) [m = 58.8]	12.5% (17) 19.9% (27) 67.6% (92) [m = 57.1]
CHO (g)	<275 275-375 >375	<261 261-356 >356	88.4% (76) 8.1% (7) 3.5% (3) [m = 202.8]	83.8% (114) 11.8% (16) 4.4% (6) [m = 194.3]
Fat (g)	<33.3 33.3-66.7 >66.7	<31.7 31.7-63.3 >63.3	52.3% (45) 45.3% (39) 2.3% (2) [m = 34.4]	41.2% (56) 54.4% (74) 4.4% (6) [m = 35.4]
Saturated Fat (g)	<22 ≥22	<20.9 ≥20.9	93.0% (80) 7.0% (6) [m = 13.4]	80.9% (110) 19.1% (26) [m = 14.9]
Trans Fatty Acid (g)	<0.04 ≥0.04	<0.04 ≥0.04	40.7% (35) 59.3% (51) [m = 0.21]	36.0% (36) 64.0% (87) [m = 0.19]
Fibre (g)	< 16 16-40 >40	<15 15-38 >38	34.9% (30) 65.1% (56) 0% (0) [m = 20.3]	37.5% (51) 59.6% (81) 2.9% (4) [m = 19.2]

On the other hand, as already noted above, the sample's average daily intake of protein exceeded the daily recommended level. For boys, the DRI is 40-50g, while the mean intake of protein for the boys in the sample was 58.8g; for girls, the DRI is 38-47.5g, while the mean actual intake for the girls in the sample was 57.1g. In terms of the study's sample, 66.3% of boys and 67.6% of girls exceeded the DRI, while 15.1% of boys and 12.5% of girls fell below the DRI level.

With regard to dietary fibre, both boys (20.3g) and girls (19.2g) in the sample fell within the DRI range defined by the Department of Nutrition, but only marginally so, since both means fell at the lower end of range (16-40g, for boys; 15-38g, for girls). More than a third of students fell below the recommended range (34.9% for boys, 37.5% for girls). The average daily intake of fat was also at the lower end of the DRI range for both boys and girls, with 52.3% of boys and 41.2% of girls falling below the lower cut-off for the daily intake of fat.

The average intake of saturated fat also fell below the recommended range, with 93% of boys and 80.9% of girls falling below the lower cut-off point. On the other hand, the level of consumption of trans fatty acids in the sample far exceeded the recommended levels of 0.04g per day: while the average intake of trans fatty acids for boys was 0.21g and for girls was 0.19g.

Figure 3-3 depicts the distribution of macronutrient consumption across and between meals; complete summary measures are provided in Table 3-5. The overall distribution indicates that the two largest sources of calories comes from the morning snack (m=501.93) and from dinner (m=486.18). In terms of total energy, breakfast and lunch are next, each providing approximately 300 Kcal intake, with the afternoon snack coming next (246.17), and finally the evening snack (173.46). In general, the distribution of energy, protein, carbohydrate and fat intake for boys and girls was not significantly different, except for the following:

The mean (sd) intake of energy at the morning snack was significantly higher in boys 542.9 (251.2) as compared to girls 475.8 (212.7) (p=.036). The mean (sd) intake of energy for dinner, on the other hand, was not significantly different between boys and girls. The difference in the consumption of carbohydrates was significant, however: the boys consumed significantly more carbohydrate 53.61 (60.88) when compared to girls 38.95 (38.79). For the morning snack, carbohydrate intake was significantly higher in boys 55.65 as compared to girls 47.74 (p=.057).

Similarly, the mean (sd) consumption of fat during the evening snack was significantly higher in boys than girls (p=.068). In sum, the boys consumed significantly more carbohydrate and fat when compared to girls.

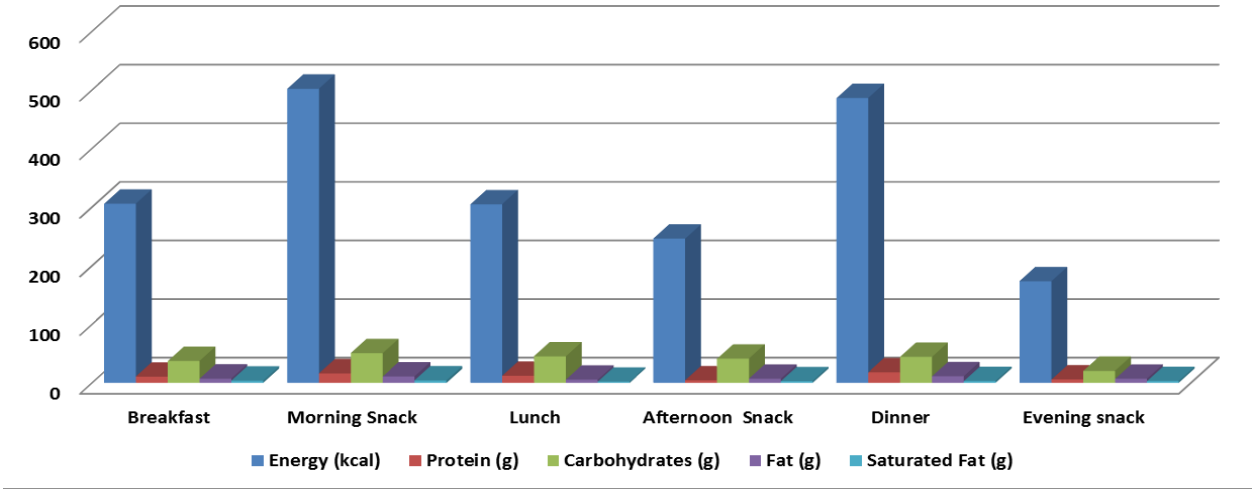

Figure 3-2: Distribution of Macronutrient Consumption between Meals

Table 3-5: Distribution of Energy between Meals by Gender

	Total (n=222)	Males (n=86) (38.7%)	Females (n=136) (61.3%)	P-value[b]
	Mean ± SD			
Breakfast				
Energy	305.71±210.60	291.97±222.18	314.27±203.52	0.47
Fat	7.26±5.90	7.61±7.32	7.05±4.85	0.524
Carbohydrate	37.3±30.55	34.39±23.60	39.11±34.14	0.291
Protein	10.63±8.00	10.78±9.54	10.55±6.94	0.845
Morning Snack				
Energy	501.93±230.27	542.97±251.25	475.82±212.75	0.036*
Fat	10.92±8.82	11.51±9.61	10.54±8.29	0.429
Carbohydrate	50.74±28.58	55.65±33.81	47.74±24.50	0.057
Protein	16.19±10.11	17.31±10.15	15.48±10.05	0.196
Lunch				
Energy	304.51±202.69	297.62±191.73	308.87±209.95	0.693
Fat	5.38±6.32	5.16±6.38	5.52±6.30	0.685
Carbohydrate	45.27±38.12	44.39±27.88	45.82±43.47	0.789
Protein	12.12±7.33	11.72±7.80	12.38±7.04	0.527
Afternoon snack				
Energy	246.17±168.57	241.51±159.97	248.83±173.94	0.782
Fat	7.18±6.80	6.91±6.74	7.34±6.87	0.691
Carbohydrate	41.26±31.46	39.35±28.70	42.37±33.03	0.543
Protein	4.45±4.39	4.09±4.26	4.68±4.46	0.399
Dinner				
Energy	486.18±311.43	516.52±322.30	467.50±304.30	0.269
Fat	11.36±10.33	11.08±9.84	11.53±10.66	0.76
Carbohydrate	44.54±48.79	53.61±60.88	38.95±38.79	0.038*
Protein	18.11±12.86	19.24±13.99	17.42±12.13	0.323
Evening snack				
Energy	173.46±131.64	181.80±129.80	167.04±137.95	0.797
Fat	7.01±5.13	9.60±6.20	5.42±3.78	0.068
Carbohydrate	20.46±17.18	24.08±17.05	17.95±17.50	0.424
Protein	5.81±3.53	5.78±2.86	5.82±3.99	0.979

[a] Selected population: Energy: 1000-2500 Kcal

3.4.3 Micronutrients

Table 3-6 presents the mean (m±sd) of daily micronutrient intake as compared to the daily recommended intake (DRI) (Institute of Medicine of the National Academies, 2005), from which it becomes clear that the students in our sample fall far short of recommended levels for a number of micronutrients. For calcium, the DRI for children in this age group is 1300mg, while the mean for our sample was only 465.4mg (sd=263.3). Similarly, the DRI for potassium for this age group is 4500 mg, while the mean intake in our sample was only 2068mg (sd=634.3).

The daily intake levels of other micronutrients also fell short of the DRI, but not to the same extreme. Among these was phosphorous, with a DRI of 1250mg, compared with the sample mean daily intake of 845.2mg (sd=316.7). Also in this category was Vitamin A, with a DRI of 600µg, as compared with the mean daily intake in our sample of 348.8µg (sd=232.7). Also notable is the level of intake for Vitamin D, with a DRI of 15µg, compared with the intake level in our sample at 4.9µg; a standard deviation of 23.1 suggests a large variability among students for this measure. The daily intake of the remaining micronutrients in the study sample all appear to conform to the DRI levels recommended for this age group.

Table 3-7 presents the observed distribution of micronutrient intake and the Omani recommended intake levels for various nutrients by gender (Department of Nutrition, 2007). The recommended cut-offs vary by nutrient and, for the most part, are presented as a range rather than a single number. Thus, the recommended daily intake of Calcium is 500-800mg for boys and 475-760mg for girls. In our sample, however, 64% of boys and 56% of girls fell below this recommended range, while 36.1% of boys and 44.1% girls met or exceeded it. Similarly, 52.3% of boys and 76.5% of girls fell below the recommended intake level for Folate, while only 22.1% of boys and 22.8% of girls exceeded the recommended range. A similar pattern was found in terms of the intake of Iodine, where 80.2% of boys and 76.5% of girls failed to meet the minimal daily intake level recommended by the Omani Department of Nutrition.

Table 3-6: Sample Mean of Micronutrient Intake and Recommended Daily Intake (DRI)

Nutrients	Total (N=222) Mean ± SD	DRI (9-13 years)
Calcium (mg)	465.4 ± 263.3	1300
Copper (mg)	0.8 ± 0.3	0.7
Folate (mcg)	297.7 ± 151.1	250
Iodine (mcg)	97.3 ± 65.1	73
Iron (mg)	12.0 ± 6.6	8
Magnesium (mg)	206.6 ± 89.7	240
Manganese (mg)	3.9 ± 2.5	1.9 (B) 1.6 (G)
Phosphorus (mg)	845.2 ± 316.7	1250
Potassium (mg)	2068. ± 634.3	4500
Selenium (mcg)	51.9 ± 26.1	40
Sodium (mg)	1532. ± 638.7	1500
Vitamin A (µg RE)	348.8±232.7	600
Vitamin D (µg)	4.9±23.1	15
Zinc (mg)	6.7 ± 2.9	8

A more extreme pattern is evident with Sodium and Zinc, where 100% of both boys and girls consumed less than the recommended daily amount: for sodium, 5g for boys and 4.8g for girls; for zinc, 20mg for boys and 19mg for girls. The daily intake levels of Vitamins A and D were also deficient: in the case of Vitamin A, 89.5% of boys and 83.1% of girls did not consume sufficient quantities to meet the minimal daily requirement; in the case of Vitamin D, 91.9% of boys and 89.7% of girls consumed less than the lower end of the recommended range.

In the case of Iron, approximately half of the sample fell below the recommended daily intake (11mg for boys, 10.5mg for girls), while the other half of the sample met or exceeded the minimum requirement.

Table 3-7: Distribution of Micronutrient Intake versus Omani Recommended Daily Intake (DRI) by gender

Nutrients	DRIs (9-13 y)		Boys	Girls	P value
	Boys (n=86)	Girls (n=136)	% (n)	% (n)	
Ca (mg)	<500 500-800 >800	<475 475-760 >760	64.0% (55) 29.1% (25) 7.0 % (6)	55.9% (76) 30.9% (42) 13.2% (18)	0.28
Folate (µg)	<300 300-400 >400	<285 285-380 >380	52.3% (45) 25.6% (22) 22.1% (19)	76.5% (104) 0.7% (1) 22.8% (31)	0.000
Iodine (mcg)	<150 ≥150	<142 ≥142	80.2% (69) 19.8% (17)	76.5% (104) 23.5% (32)	0.51
Iron (mg)	<11 ≥11	<10.5 ≥10.5	53.5% (46) 46.5% (40)	50.7% (69) 49.3% (67)	0.0689
Sodium (g)	<5.0 ≥5.0	<4.8 ≥4.8	100% (86) 0.0%	100% (136) 0.0%	NA
Vitamin A (µg RE)	<700 700-1000 >1000	<665 665-950 >950	89.5% (77) 10.5% (9) 0% (0)	83.1% (113) 11.8% (16) 5.1% (7)	0.092
Vitamin D (µg)	<5 5.0-10.0 >10	<4.8 4.8-9.5 >9.5	91.9% (79) 7.0% (6) 1.2% (1)	89.7% (122) 9.6% (13) 0.7% (1)	0.762
Zinc (mg)	<20 ≥20	<19 ≥19	100% (86) 0.0%	100% (136) 0.0%	NA

Table 3-7 also provides evidence of the gender differences in the intake of these micronutrients which, overall, point to the significance of folate, iron and vitamin A. As for the gender differences, for Vitamin A intake, 89.5% of the boys consumed less than the recommended level compared to girls (83.1%), although the difference was marginally significant (p=.09). Iron intake was significantly higher for boys (53.5%) as compared with girls (50.7%) (p<0.068), although both fell short of the recommended daily level. In contrast, Folate intake was significantly higher in girls (76.5%) when compared to boys (52.3%) (p<.001), although both were also lower than the

recommended level. The rates of consumption of the other remaining nutrients did not vary by gender.

The following Table 3-8 presents the mean (sd) intake of micronutrients by gender. Overall, the mean (sd) level of micronutrient intake was nearly identical by gender; there was no statistically significant difference between boys and girls on these measures.

Table 3-8: Mean (sd) Micronutrient Intake by gender

Nutrients	Total (N=222) Mean ± SD	Boys (n= 86) Mean ± SD	Girls (n=136) Mean ± SD	P value
Calcium (mg)	465.4 ± 263.3	450.1 ± 252.1	475.1 ± 270.7	0.485
Copper (mg)	0.8 ± 0.3	0.8 ± 0.3	0.8 ± 0.3	1.000
Folate (mcg)	297.7 ± 151.1	300.4 ± 138.3	296.0 ± 159.1	0.827
Iodine (mcg)	97.3 ± 65.1	93.0 ± 66.3	99.9 ± 64.4	0.446
Iron (mg)	12.0 ± 6.6	11.9 ± 5.6	12.0 ± 7.1	0.907
Magnesium (mg)	206.6 ± 89.7	208.8 ± 86.5	205.2 ± 92.0	0.768
Manganese (mg)	3.9 ± 2.5	3.9 ± 2.5	3.9 ± 2.4	1.000
Phosphorus (mg)	845.2 ± 316.7	844.2 ± 325.8	845.8 ± 312.1	0.971
Potassium (mg)	2068. ± 634.3	2072.0± 619.2	2065. ± 645.9	0.935
Selenium (mcg)	51.9 ± 26.1	53.8 ± 27.6	50.6 ± 25.2	0.385
Sodium (mg)	1532. ± 638.7	1538.2± 667.6	1528.9 ± 622.2	0.917
Vitamin A (µg RE)	348.8±232.7	382.3±278.1	369.3±261.4	0.334
Vitamin D (µg)	4.9±23.1	2.4±2.1	3.4±14.3	0.319
Zinc (mg)	6.7 ± 2.9	6.8 ± 3.0	6.7 ± 2.9	0.806

3.4.4 Anthropometric, Body Composition, Blood Pressure & Blood Sugar Profile

Table 3-9 presents the anthropometric, body composition, blood pressure and blood sugar levels of the children included in the study by gender.

The mean weight of the students in the sample was 30.2kg (sd=8.0), with girls weighing slightly more (30.2±8.0) than boys (30.1±7.6). The mean height was 133.6cm, with girls measuring slightly taller (133.7±6.6) than boys (133.6±5.0). The differential for waist circumference was slightly larger, with boys measuring at 60.9cm (sd=8.8) and girls at 60.2 (sd=8.8). The measures for mean body mass index, on the other hand, were virtually identical (m=16.8±3.4), with boys at 16.8 (sd=3.3) and girls at 16.8 (sd=3.4). No statistically significant difference was obtained for any of these measures.

However, the mean (sd) body fat (%) for girls was significantly higher at 19.5 (7.8) when compared to the boys' measure at 17.3 (7.8) (p=.048), although there was no significant difference in body fat (Kg), with boys average (5.9±4.6) slightly lower than girls (6.4±4.6). Inversely, the mean (sd) of muscle mass (kg) was significantly higher for boys than girls: 23.6 (3.9) versus 22.5 (3.7) (p=0.038). The difference in muscle mass (%) was marginally significant (p=0.061), with the boys' average slightly higher (78.2±7.3) than the average for girls (76.3±7.4). The mean (sd) of impedance for boys was 598.99 (67.1), significantly lower when compared to the mean impedance for girls 649.8 (72.7) (p<.001).

The fasting glucose was higher in boys 5.1 (0.4) as compared to girls 5.0 (0.4) (p=.071), as was the mean (sd) of HbA1, which was also significantly higher in boys 5.2 (0.6) than girls 4.98 (0.6) (p=.008). Measures of systolic (m=109, sd=10) and diastolic (m=65, sd=10) were not significantly different between boys and girls.

Table 3-9: Anthropometric, Body composition, Blood Pressure and Blood Sugar Profile by Gender

Variables	Male N=86	Female N=136	Total N=222	p-value
	Mean ± sd	Mean ± sd	Mean ± sd	
Weight (kg)	30.1 ± 7.6	30.2 ± 8	30.2 ± 8	0.925
Height (cm)	133.6 ± 5	133.7 ± 6.6	133.6 ± 6.0	0.893
Waist circumference (cm)	60.9 ± 8.8	60.2 ± 8.8	60.5 ± 8.7	0.564
Mean Body Mass Index (Wt/Ht2)	16.8 ± 3.3	16.8 ± 3.4	16.8 ± 3.4	1.000
Body Fat (%)*	17.3 ± 7.8	19.5 ± 7.8	18.60 ± 7.9	0.042
Body Fat (Kg)	5.9 ± 4.6	6.4 ± 4.6	6.20 ± 4.6	0.431
Muscular Mass (%)	78.2 ± 7.3	76.3 ± 7.4	77.0 ± 7.4	0.061
Muscle Mass (Kg)	23.6 ± 3.9	22.5 ± 3.7	22.90 ± 3.8	0.038
Impedance*	598.99 ± 67.1	649.8 ± 72.7	630.1 ± 74.6	<0.001
Systolic (mmhg)	109 ± 10	108 ± 11	109 ± 10	0.486
Diastolic (mmhg)	65.5 ± 10	65 ± 11	65 ± 10	0.727
HB (g/dl)	12.7 ± 1.1	12.8 ± 0.96	12.8 ± 1,00	0.489
Fasting glucose *(mmol/L)	5.1 ± 0.4	5.00 ± 0.4	5.04 ± 0.4	0.071
HbA1*(mmol/L)	5.2 ± 0.6	4.98 ± 0.6	5.1 ± 0.6	0.008

Using BMI-for-age z-scores, the prevalence of overweight or obesity in our study was 28.2% for boys and 22.6% for girls; obesity and overweight for the entire sample was 24.3% (see Figure 3-4). At the other extreme, while nearly one fourth of the adolescent school going children in Oman are overweight or obese, the prevalence of underweight from our study was about 12% and 8% in the males and females of our sample. In terms of sample distribution, 9.0% of the sample was thin, 7.7% of the sample was moderately thin, and 1.4% of the sample was severely thin.

These data have seldom been reported from other studies.

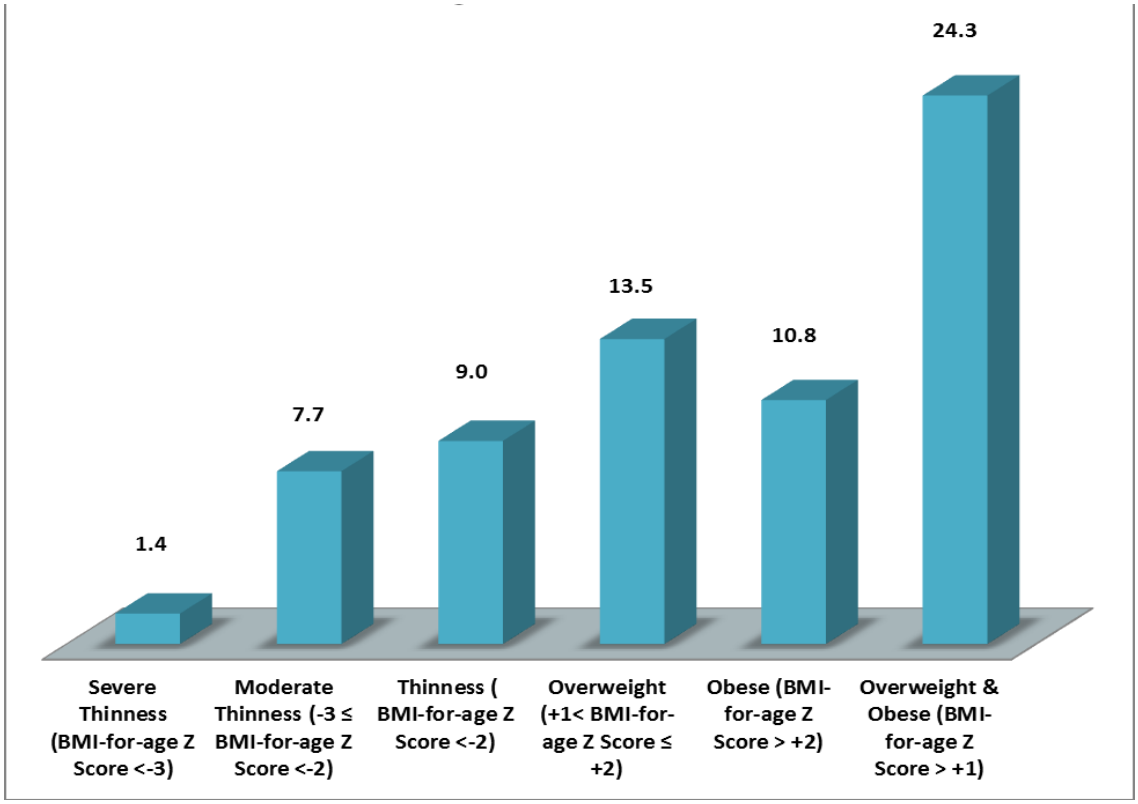

Figure 3-3: Prevalence of Thinness, Overweight and Obesity among Omani Children

3.4.5 Blood Lipids

Table 3-10 summarizes the mean (sd) blood lipids levels (mmml/L) of boys and girls in our sample. The average HDL for the sample was 1.4 (0.33), with the boys' average slightly higher 1.41 (0.36) than the girls' 1.4 (0.30). This difference was not found to be significant. The mean LDL for the sample was 2.72 (0.62), with the girls' average higher 2.78 (0.61) than the boys' 2.63 (0.62). This was found to be significant at the 0.078 level.

More significant than this was the difference in TGS between boys and girls. While the sample average was 0.63 (0.30), the average measure for girls was found to be higher 0.7 (0.30) than for boys 0.6 (0.30) (p=0.016). The difference in CHOL measures was not statistically significant: the average sample measure was 4.4 (0.7), with girls averaging slightly higher 4.45 (0.7) when compared to the boys 4.3 (0.8).

Table 3-10: Blood Lipids by Gender

Variables	Male N=86	Female N=136	Total N=222	p-value
	Mean ± sd	Mean ± sd	Mean ± sd	
HDL(mmol/L)	1.41 ± 0.36	1.4 ± 0.30	1.4 ± 0.33	0.830
LDL(mmol/L)	2.63 ± 0.62	2.78 ± 0.61	2.72 ± 0.62	0.078
TGS*(mmol/L)	0.6 ± 0.30	0.7 ± 0.30	0.63 ± 0.30	0.016
CHOL(mmol/L)	4.3 ± 0.8	4.45 ± 0.7	4.4 ± 0.7	0.155

3.5 Summary and Discussion

The sample of children included in this study were identified using a two-stage random sampling procedure from schools in the Muscat Governorate; it is believed that these children and their dietary behaviour would represent the population of similarly aged school children in Oman. Moreover, the instruments used to measure anthropometry were well calibrated. It seems reasonable to conclude, then, that the results from this study could be generalisable to children's dietary behaviour in other Gulf countries, at the minimum. This is the first study in the region to incorporate micro- and macro-nutrient levels, in addition to extensive anthropometry, such as body fat and muscular mass, etc. in school-going children. The study's main aim was to assess at the micro- and macro-nutrients intakes, anthropometry, body composition and lipid profiles for Omani school children.

Compared to the Daily Recommended Intake levels, the students in our sample fell below established standards when it came to total calories, fat, sugar, and omega-3 and omega-6 fatty acids (Table 3-2). Both boys and girls fell below the DRI for total calories, although the average level of consumption remained within one standard deviation of the recommended norm. The recommended intake of fat, on the other hand, was even lower with a sample average of 389.5kcal, compared to the recommended range (25-35% of total calories) of 550-750kcals. The average consumption of sugar in our sample (313kcal) also fell below the recommended level (540kcal). In terms of fatty acids, it was found that the students' normal diet provided adequate levels of omega-6 fatty acids while, in sharp contrast, the consumption of omega-3 fatty acids (4.2kcal) was woefully inadequate to meet the recommended level (108-207kcal). In terms of the

intake of protein and carbohydrates, the students in our sample exceeded the DRI levels: the DRI for protein is 136kcal, compared to the sample average of 231kcal, while the DRI for carbohydrates is 520kcal, compared to the sample average of 790kcal.

Similar but slightly different patterns were found when comparing intake levels in our sample with the Omani DRI levels (Table 3-4). Here, too, both boys (1761kcal) and girls (1709kcal) fell below the DRI for total energy consumption. The mean level of calories from fat also fell below the Omani DRI, with 93% of boys and 80.9% of girls falling below the lower end of the recommended range. The same pattern was found for carbohydrates, where 88.4% of boys and 83.8% of girls fell below the recommended levels. In contrast, students exceeded the recommended levels of calories from protein and trans fatty acids: regarding the former, 66.3% of boys and 67.6% of girls exceeded the recommended range; with regards to calories from trans fatty acids, both boys (0.21g) and girls (0.19g) far exceeded the established DRI of 0.04g/day.

There were also a number of significant differences in levels of macronutrient intake by gender (Table 3-3). On average, the girls in the sample were found to consume more calories from saturated fat (134.5kcal) as compared to boys (120.2kcal), while boys were found to consume more calories from omega-3 fatty acids (4.8kcal) when compared to girls (3.9kcal). The same pattern was found for calories from omega-6 fatty acids.

In terms of micronutrient consumption (Table 3-6), the students' diets were found to be most deficient in calcium and potassium: whereas the DRI for calcium was 1300mg, the mean for the students in our sample was only 465mg; and compared to the DRI for potassium (4500mg), the mean for the students was only 2068mg. The students' level of consumption of phosphorus, Vitamin A and Vitamin D were also found to fall short of the DRI levels, although not to the same degree as calcium and potassium. Consumption levels for all other micronutrients were found to fall within the recommended DRI range.

Similar, but slightly different, patterns were found in relation to the Omani DRIs (Table 3-7). For both sodium and zinc, 100 per cent of boys and girls fell below the recommended levels. For Vitamin A, 89.5% of boys and 83.1% of girls fell below the Omani DRI levels, whereas for Vitamin D, 91.9% of boys and 89.7% of girls consumed less than the lower end of the range recommended by the Omani Department of Nutrition. Less severe shortfalls in micronutrient intake were found for Calcium, Folate, and Iodine.

In terms of gender, no significant differences were found in the levels of micronutrients consumed by boys and girls. However, when compared with the gender-differentiated DRI levels set by the Omani government, significant gender differences were found for Folate, Iron and Vitamin A. In terms of blood lipids, the only significant difference was found for TGS. While the sample average was 0.63, the girls were found to have a significantly higher level (0.7) when compared to boys (0.6) (p=0.016).

The mean (sd) body fat (%) and TSG measures were significantly higher among girls as compared to boys, while muscle mass, omega-3 and omega-6, and fasting glucose levels were significantly higher in boys. The prevalence of overweight or obesity was 28.2% and 22.6% in boys and girls, respectively. Data such as these, and on the above mentioned micro- and macro-nutrients, blood pressure and lipid profiles are scanty for Gulf countries.

However, it has been reported that the rate of obesity among adolescents in Bahrain is between 12%-25% (Musaiger, 2004). Over time, the study participants generally showed a higher rate of obesity, ranging from 15% to 45%; and in adulthood, women showed a higher prevalence (35%-75%) when compared with men (30%-60%). The common risk factors, such as change in dietary habits, socioeconomic factors, inactivity and multiparity (among women) were all shown to be significantly associated with these trends in Bahrain. Similarly, in Saudi Arabia, the prevalence of obesity was reported to be 46% amongst adolescents in Jeddah (Washi and Ageib, 2010). Increased weight status of 13- to 18-year-old Saudi adolescents was also demonstrated to be related to their dietary habits.

Thus, while the prevalence of overweight or obesity was lower in Oman compared to these other countries in Gulf, nearly one-fourth of the adolescent school-going children in Oman can be said to be overweight or obese. In contrast, the prevalence of underweight from our study was about 12% and 8% in males and females adolescent children, respectively. These data have seldom been reported in other similar studies.

In addition, our study found that higher calorie and protein intake was significantly associated with overweight or obesity. In the same vein, it has also been reported that changes in dietary habits and inactivity were associated with obesity in Bahrain (Musaiger, 2004); just as obesity in Jeddah has been reported to be associated with higher intake of carbohydrates, proteins and fat.

In 2010, an extensive school-based study covering 1606 8th to 10th standard Omani students from 49 schools was conducted in collaboration with WHO and the CDC, USA (Joshi et al., 2006, Abdou and Al-Murzahmi, 2012). According to that study, one in five students (18.7%) described themselves as slightly overweight or overweight, in contrast to our study which reported the actual prevalence of obesity as 28% and 23% in males and females, respectively. Thus, our study highlights an important discrepancy between these figures, signalling the potential inaccuracy of self-reported measures; there may have also been a significant increase in the prevalence of obesity among older Omani school children since the GSHS study was conducted. This (apparent) increase is of great concern.

The authors of the Omani GSHS report also reported that nearly one third (35.6%) of students were trying to lose weight while only one in five students (18.7%) described themselves as slightly overweight or overweight. About 41.6% of students usually ate fruit two or more times per day while 17.9% of students usually ate vegetables three or more times per day during the past 30 days. About 45.1% of students ate breakfast most of the time or always during the past 30 days. Consistent with this study, many Omani students actually skip breakfast, which leaves dinner and other snacks as the main sources for their daily caloric intake. Traces of this pattern were apparent in our study, as well, since the two main sources of calories during the day were dinner (m=486kcal) and their morning snack (m=501kcal) (Table 3-5), and during the course of a single day, total snacks almost contributed the same number of calories (m=922kcal) as total meals (1096kcal). It was also found that there were significant gender differences: for morning snacks, the meaning intake of energy and carbohydrates was significantly higher for boys when compared to girls; the mean consumption of fat during the evening snack was significantly higher for boys than girls; and for the evening dinner, the consumption of carbohydrates was similarly higher for boys when compared to girls.

Kovalskys et al. (2013) report that the mean calorie intake of 5th grade students in Buenos Aires (average age, 10.9 years) was 2316 kcal/day, where the most frequently consumed high calorie density foods were soft drinks, juices, candies, sweet cookies and high fat seasonings and dressings. In contrast, the average calorie intake from our study was 1729 (kcal)/day.

In Buenos Aires, the prevalence of overweight and obesity was 21.3% and 14.3%, respectively. According to our study, the prevalence of overweight or obesity in

Oman was 28% and 23% for boys and girls, respectively. Thus, Omani children showed a significantly higher prevalence of overweight and obesity as compared to school children in Buenos Aires (Kovalskys et al., 2013). Drawing upon the Ireland National Children's Food Survey, Walton et al. (2015) reported that 16% of the total energy consumed in one day was provided from food eaten 'before school', 33% was provided from food eaten 'at school', and 53% was provided from food eaten 'after school'. Relative to the overall school-day, food eaten 'before school' was lower in saturated fat and sodium, and higher in DF and many micronutrients; food eaten 'at school' was relatively high in added sugars and sodium, lower in DF and micronutrients, and similar in saturated fat compared to the overall school-day; food eaten 'after school' was relatively high in DF and vitamin A, similar in saturated fat, magnesium and sodium, and lower in added sugars and other micronutrients compared to the overall school-day. Though we do not have similar data from Oman, it would be useful to conduct such a study to identify the main sources of energy for Omani school children.

Maffeis et al. (2000) reported the relationship between Italian children's adiposity and their parents' body mass index (BMI). The correlation between children's adiposity and their mother's and father's BMI was 0.12 and 0.13 ($p<.01$), respectively (Samadi et al., 2014). The correlation (however small) becomes significant when the size is small. Clinically or epidemiologically, the minimum should be above 4. Because the sample size in this study was 503, the small correlation was considered significant, which is not very useful.

3.6 Conclusion

Our study has established standards for most micro- and macro-level nutrients by gender for school-going children in Oman. In terms of macronutrients, the students fell below established standards when it came to total calories, fat, sugar, and omega-3 and omega-6 fatty acids; their intake of protein and carbohydrates, on the other hand, exceeded DRI levels. In terms of micronutrients, students in the sample were most deficient in calcium and potassium; their intakes of Vitamin A and Vitamin D were also found to fall short of the DRI levels. No significant gender differences were found, except in the case of calories from saturated fat (girls > boys) and calories from omega-3 fatty acids (boys > girls).

This data will provide a crucial reference for future studies but also an important estimate of the prevalence of micro- and macro-nutrient deficiencies in Oman. As such,

it provides a benchmark for the country and a roadmap for future planning for school health programs. In summary, the prevalence of overweight or obesity is comparable to other countries in the Gulf region and significantly lower than in more developed countries. Nevertheless, the prevalence rate of approximately 25% overweight and obesity for boys and girls is still too high. Therefore, health education that focuses on nutrients should start at the school level.

CHAPTER 4:
ADHD and Parental Factors in Omani School Children

4.1 Introduction

The global prevalence of Attention Deficit Hyperactivity Disorder (ADHD) is estimated to be approximately 5% to 13% (Faraone et al., 2003). The condition is defined by the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) (American Psychiatric Association, 2013) and also by the International Classification of Diseases (ICD-10) (World Health Organization, 1992) as including two distinct behavioural dimensions - inattentive and hyperactive-impulsive - which have been recognized to exist across cultures and in a variety of ethnic groups (Barkley, 2003).

Children who suffer from ADHD tend to have difficulties in following instructions or abiding by the rules (Taylor et al., 2004). They are also more likely to generally misbehave and more frequently interrupt and/or intrude on others' conversations and activities (de Boo and Prins, 2007). In addition, these children are more prone to risk-taking and rule-violating behavior. As a consequence, they are also more prone to offend norms of social modesty by their disruptive behavior. The net outcome of such conduct are negative responses from peers, teachers and parents (McQuade and Hoza, 2008, Solanto et al., 2009).

Symptoms of ADHD have been linked to higher risks of substance misuse, comorbid neurobehavioral disorders as well as becoming 'social misfits' with all the consequences this may entail, including a decreased quality of life (Frick and Dickens, 2006, Tapert et al., 2002, Tercyak et al., 2002). As the bulk of literature on ADHD has emerged from Euro-American populations, initial studies led to the view that ADHD might be a 'culture-bound syndrome' (Canino and Alegria, 2008). Although a systematic review of studies from different populations and ethnicities identified drastic variations in the magnitude of the disorder (Polanczyk et al., 2007), it cannot be denied that ADHD is a global challenge.

There is a dearth of studies from Arabian Gulf populations such as those of Oman, a country that lies at the tip of the Arabian Peninsula, adjacent to the continent of Africa and Asia. Oman has a pyramidal population structure with the bulk of the population consisting of children and adolescents (United Nations, 2010). Anecdotal evidence indicated that different regions are not immune to the vagaries of neuro-developmental disorders such as ADHD. In the instance of Qatar (Bener et al., 2006), teachers using the Conner's scale found that 16.7% males and 7.3% female students had a propensity to having ADHD. In the principality of Sharjah of the United Arab Emirates

(Bu-Haroon et al., 1999), 18.3%, of male and 11.4% of female students were also identified by their teachers as having symptoms of typical of ADHD. In Saudi Arabia, clinical notes at a tertiary care hospital indicated that 10.5% of attendees were marked by symptoms of ADHD (Al-Haidar, 2002). In Oman, Al-Sharbati et al. (2004) reported that 7.8% males and 5.1% females showed characteristic symptoms of ADHD.

Although these studies should be welcomed as useful beginnings in an emergent field of research, they have failed to include the risk factors or familiar aggregates for children with ADHD. Charting out socio-demographic factors has a potential to lay the groundwork for devising preventive measures and for designing relevant health educational programs. Furthermore, quantifying the risk factors for children with ADHD can help construct a theoretical model to discern whether ADHD is a global phenomenon or an artifact of socio-cultural factors. Thus, while genetic and neurological determinants have been shown to be critically associated with the development of ADHD in western countries, the range of social and economic indicators are seen to play an important role in the development of ADHD, as well (Russell et al., 2014, Pastor and Reuben, 2008, Akinbami et al., 2011, Froehlich et al., 2007, St Sauver et al., 2004, Ford et al., 2007, Boe et al., 2012, Hjern et al., 2010, Paananen et al., 2013, Hobcraft, 2004, Sciberras et al., 2011).

Within this context, the present study aims to achieve the following goals: first, to estimate the current rate of ADHD in school children aged 9-10 years in Oman, second, to examine the role of parental factors such as sex, educational level, occupation, income and consanguinity in the cognitive functioning and symptomatology of ADHD and, third, to identify the role of each subtype of ADHD (predominantly inattentive, predominantly hyperactive/impulsive and/or ADHD combined inattention/hyperactivity) in the expression of cognitive functioning.

4.2 Methods

4.2.1 Participants

The study was conducted between August 2012 and February 2013 in the Muscat Governorate, a region in Oman including the coterminous capital city of Muscat. It lies in the most populated part of the country and has a population reaching slightly above one million (National Centre for Statistics and Information, 2014). The Governorate is divided into 6 administrative divisions or *wilayat*s: Al Amerat, Bawshar, Muscat,

Mutrah, Qurayyat and As Seeb. All participants from the selected schools were invited to participate in the study during the academic year.

4.2.2 Sampling

According to statistics available from the Ministry of Education, in the 2012–2013 academic year there were 101,597 pupils in the Muscat Governorate enrolled in public schools (run by the state under the direction of the Ministry of Education). In total, there were 49,783 (49%) male and 51,814 (51%) female students. For the purpose of this study, all participating pupils were children who were enrolled for the second stage sampling of the 4^{th} grade (aged 9-10).

There is some debate whether children younger than 9-10 years can be said to manifest the symptoms of ADHD as outlined in International Classification of Disease (ICD-10) (World Health Organization, 1992) or the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) (American Psychiatric Association, 2013). In these and other manuals, the diagnosis symptoms such as those associated with ADHD are often attached to a specific age and must endure for a specific period of time. If the relevant symptomatology has appeared by the age of 9 years, however, it would appear that the condition has been firmly consolidated (Treyvaud et al., 2013). In the existing research literature, this age group has been identified as suitable for testing with the cognitive measures used in this study (Goodman et al., 2016). This age group was also deemed appropriate in light of the dietary intervention at the heart of this study since, at this age, the children will have developed independent food preferences and their eating habits (healthy, or otherwise) will have been established.

The participants were selected using stratified random selection. In the first stage, three schools in the catchment area of 39 schools were randomly selected with an equal representation of both genders. In the second stage, three Grade 4 classes from five were randomly selected, and inviting all students in those classes to participate in the study. All students were given letters of invitation addressed to their parents/guardians describing the rationale for the study. The parents/guardians were asked to sign consent forms indicating their consent to the study. In addition to this, the students themselves were also required to give consent before taking part in the study. The invitation was sent to 354 students, of whom 327 responded giving a response rate of 85.9%. After excluding those cases with missing socio-demographic data or incomplete questionnaires, a total of 304 students were included in the final sample, among whom

female students constituted 55%. These students account for 4.6% of the school children between 9 and 10 from the Muscat Governorate.

4.2.3 Sample Size

The objective of the current study is to estimate the prevalence of ADHD in school children and their risk factors. The prevalence of ADHD is reported in the literature to be about 9%. In order to estimate this with the precision of 3% with a 95% CI, nearly 350 children would need to be included in the study. Thus, the baseline data of the main study should provide enough precision to estimate the prevalence of ADHD.

4.2.4 Inclusion and Exclusion Criteria

Criteria of Inclusion: Male and female children aged 9-10 years without any hereditary or chronic medical condition or cognitive impairment that would warrant diagnosis of developmental disorder. Since the present cohort was derived from schools designed to serve the educational mainstream, the students were deemed likely to have adequate intellectual functioning since children with special needs, talents, learning disorders and mental disability do not attend 'mainstream' schools (Al-Lamki, 2012).

Criteria of Exclusion: Children receiving pharmacotherapy for behavioural, cognitive or emotional disorders, or with hearing or visual impairments.

4.2.5 Participant Consent

Informed and signed consent to participate was obtained from the parents/ guardians of the children.

4.2.6 Ethical Approval

The study was approved by the Research Ethics Committee of the Ministry of Health, Sultanate of Oman (Ref. MH/DGP/R&S/Proposal_Approved/8/2012), and the National Research Ethics Committee North West – Haydock, UK (REC reference no. 12/NW/0760).

4.3 Study Variables

4.3.1 Socio-Demographic Characteristics

Socio-demographic characteristics including age, gender, monthly income for socio-economic status, educational level of parents, occupational status of parents and

the consanguinity status of parents were collected by a trained researcher during face-face interviews.

4.3.2 Outcome Measures

An Arabic version of the National Initiative for Children's Health Quality Vanderbilt Assessment Scales-Teacher Assessment Scale (NICHQ Vanderbilt Assessment Scales) was used (American Academy of Pediatrics, 2008, Pliszka and AACAP Work Group on Quality Issues, 2007). The NICHQ Vanderbilt Assessment Scales has 55 questions divided into two sections: 'symptoms' and 'performance'. The SYMPTOMS section contains 47 items that are divided into various sub-sections: items 1-18 tap into the symptoms of ADHD, items 19-26 tap into oppositional defiant disorder symptoms, items 27-40 quantify the presence of Oppositional-Defiant/Conduct disorders and items 41-47 solicit the presence of Anxiety/Depression. Items are rated: never = 0, occasionally = 1, often = 2, very often = 3. The teacher is instructed to circle only one of the numbers on the scale.

The PERFORMANCE section taps into the level of impairment in Academic Performance (reading, mathematics and written expression) and Classroom Behavioral Performance (relationships with peers, following directions/rules, disrupting class, assignment completion and organizational skills). Performance scales are rated as: excellent = 1, above average = 2, average = 3, somewhat of a problem = 4, problematic = 5. The formula used for scoring the NICHQ Vanderbilt Assessment Scales has been detailed elsewhere (Wamithi et al., 2015).

The following symptoms were the focus of the present study: the predominantly inattentive subtype of ADHD (PIS), Predominantly Hyperactive/Impulsive subtype (PHIS), ADHD Combined Inattention/Hyperactivity (ADHDCIH), Oppositional-Defiant/Conduct Disorders and Anxiety/Depression. The research team explained to teachers how to fill out NICHQ Vanderbilt Assessment Scales. The teachers were then explicitly informed to base their answers in reference to the child's behaviour over a six month period.

4.4 Statistical Methods

The prevalence of PIS, PHIS and ADHD was measured using a 95% CI. In the unadjusted (bivariate) analysis, a chi-square test was used to measure the association between risk variables and the outcome variables: PIS, PHIS and ADHD (yes/no).

Logistic regression analysis was done as adjusted analysis to control for the effect of confounders and other risk variables. The odds ratio was presented with a 95% CI along with P value, where a P value < 0.05 was considered significant. The goodness of fit of the logistic regression analyses (model) was done using Hosmer-Lemeshow statistics. The assumptions were validated using Deviance chi-square statistics versus predicted probabilities graphs. Data was analysed using SPSS 21.0 software.

4.5 Results

A total of 328 children participated in the study. The prevalence of PIS, PHIS and ADHDCIH was 7.3% (95%CI: 4.5%, 10.1 %), 3% (1.2%, 4.8%) and 8.8% (5.7%, 11.8%), respectively. The prevalence of Opposition-Defiant/Conduct disorder and Anxiety/ Depression was 1.5% (0.2%, 2.8%) and 1.8% (0.4%, 3.2%), respectively. Male children had significantly higher prevalence of PIS, PHIS and ADHD as compared to female children ($p<0.05$).

4.5.1 Predominantly Inattentive Subtype (PIS)

The unadjusted (bivariate) and adjusted (multivariate) analyses results for the scale PIS according to the socio-demographic characteristics of parents and gender of children is presented in Table 4-1. Though the child's gender was statistically significant at the unadjusted (bivariate) analyses, after adjusting for parental characteristics it was no longer significant in the adjusted (multivariable) analyses. Children who had mothers that could not read or write had significantly higher odds for PIS as compared to children whose mothers were graduates ($p=0.06$). Similarly, fathers with occupations other than in public or military sectors had higher odds of their children having PIS 2.8 (0.9, 8.3) ($p=0.07$), although both of these relationships were only marginally significant.

4.5.2 Predominantly Hyperactive/Impulsive Subtype (PHIS)

The unadjusted and adjusted analyses results for the scale PHIS according to socio-demographic variables of the parents and gender of the children is presented in Table 4-2. The male children were 6.2 (0.9, 42.7) times more likely to have PHIS as compared to female children, although this relationship was only marginally significant ($p=0.06$). The children whose fathers studied up to the preparatory or secondary diplomas were 83% less likely to have PHIS as compared to the children of fathers who graduated with a degree; this relationship was also marginally significant ($p=0.08$). On the other hand, the mothers of children whose occupation was other than housewife, had

7.1 (1.1 , 50) times higher odds for PHIS as compared to housewives (p=03). Similarly, the children who came from low income families had 24 (1.7 , 341) times higher odds for PHIS as compared to children from medium or high income families (p=0.01). Thus, it appears that mother's occupation and family income were more powerful predictors of PHIS than father's education or gender of the child.

4.5.3 ADHD Combined Inattention/Hyperactivity (ADHDCIH)

The unadjusted and adjusted analyses results for the scale ADHDCIH according to socio-demographic variables of parents and the gender of children is presented in Table 4-3. The children of mothers who were non-literate, who could not write or who studied up to primary school were 9.5 (0.7, 125) times more likely to have ADHDCIH compared to children whose mothers who were degree holders, but this relationship was only marginally significant (p=0.08). The children of fathers who were employed in areas other than the public sector or the military had 4.2 (1.5, 12.5) times higher odds for ADHDCIH as compared to children of fathers who worked in those sectors; this relationship was highly significant (p=0.01). On the other hand, children from low income families had nearly 3 (0.9 , 10) times higher odds for ADHDCIH as compared to children from medium or higher income families, but this relationship was only marginally significant (p=0.08).

Table 4-1: Unadjusted and Adjusted analysis for Predominantly Inattentive subtype (PIS) with Socio demographic variables

Variables	Unadjusted Analysis of PIS				Adjusted Analysis of PIS		
	Total n (%)	Yes n (%)	No n (%)	P value	OR	95%CI	P value
Sex							
Male	142(43.3)	17(70.8)	125(41.1)	0.005	1.65	0.60– 4.58	0.334
Female	186(56.7)	7(29.2)	179(58.9)		1.00		
Mother Education							
Unread/Unwrite/Primary	49(15.4)	7(29.2)	42(14.3)	0.017	11.4	0.87– 150.70	0.064
Preparatory/Secondary/Diploma	196(61.6)	16(66.7)	180(61.2)		3.49	0.36 – 34.29	0.283
Ealorois/Graduate	73(23.0)	1(4.2)	72(24.5)		1.00		
Father Education							
Unread/Unwrite/Primary	22(6.9)	2(8.3)	20(6.8)	0.791	0.59	0.08– 4.18	0.596
Preparatory/Secondary/Diploma	177(55.8)	14(58.3)	163(55.6)		0.69	0.19 – 2.43	0.568
Ealorois/Graduate	118(37.2)	8(33.3)	110(37.5)		1.00		
Mother Occupation							
House-wife	180(56.6)	15(62.5)	165(56.1)	0.544	0.75	0.20 – 2.83	0.672
Others	138(43.4)	9(37.5)	129(43.9)		1.00		
Father Occupation							
Public/Military Sector	169(53.3)	9(37.5)	160(54.6)	0.106	1.00	0.9 - 8.3	
Others	148(46.7)	15(62.5)	133(45.4)		2.80		0.076
Family Income							
Low Income	137(54.4)	14(73.7)	123(52.8)	0.079	2.04	0.60 – 6.96	0.252
Medium/High Income	115(45.6)	5(26.3)	110(47.2)		1.00		
Consanguinity:							
Yes	128(40.5)	8(33.3)	120(41.1)	0.456	0.65	0.23 – 1.86	0.422
No	188(59.5)	16(66.7)	172(58.9)		1.00		

Table 4-2: Unadjusted and Adjusted analysis for Predominantly Hyperactive Impulsive subtype (PHIS) with Socio demographic variables

Variables	Unadjusted Analysis of PHIS				Adjusted Analysis of PHIS		
	Total n (%)	Yes n (%)	No n (%)	P value	OR	95%CI	P value
Sex							
Male	142(43.3)	8(80.0)	134(42.1)	0.023	6.24	0.91– 42.76	0.062
Female	186(56.7)	2(20.0)	184(57.9)		1.00		
Mother Education							
Unread/Unwrite/Primary	49(15.4)	2(20.0)	47(15.3)	0.722	6.89	0.25– 193.48	0.257
Preparatory/Secondary/Diploma	196(61.6)	7(70.0)	189(61.4)		1.74	0.14 – 22.47	0.669
Ealorois/Graduate	73(23.0)	1(10.0)	72(23.4)		1.00		
Father Education							
Unread/Unwrite/Primary	22(6.9)	1(10.0)	21(6.8)	0.675	0.29	0.01– 5.94	0.421
Preparatory/Secondary/Diploma	177(55.8)	5(50.0)	172(56.0)		0.17	0.02 – 1.27	0.084
Ealorois/Graduate	118(37.2)	4(40.0)	114(37.1)		1.00		
Mother Occupation							
House-wife	180(56.6)	5(50.0)	175(56.8)	0.751	1.00		
Others	138(43.4)	5(50.0)	133(43.2)		7.1	1.1 – 50.0	0.038
Father Occupation							
Public/Military Sector	169(53.3)	1(10.0)	168(54.7)	0.007	-	-	-
Others	148(46.7)	9(90.0)	139(45.3)				
Family Income							
Low Income	137(54.4)	7(87.5)	130(53.3)	0.074	24.09	1.70 –340.83	0.019
Medium/High Income	115(45.6)	1(12.5)	114(46.7)		1.00		
Consanguinity:							
Yes	128(40.5)	2(20.0)	126(41.2)	0.211	0.35	0.06 – 2.06	0.246
No	188(59.5)	8(80.0)	180(58.8)		1.00		

Table 4-3: Unadjusted and Adjusted analysis for ADHD Combined Inattention Hyperactivity with Socio demographic variables

Variables	Unadjusted Analysis of ADHD				Adjusted Analysis of ADHD		
	Total n (%)	Yes n (%)	No n (%)	P value	OR	95%CI	P value
Sex							
Male	142(43.3)	21(72.4)	121(40.5)	0.001	2.27	0.85 – 6.06	0.101
Female	186(56.7)	8(27.6)	178(59.5)		1.00		
Mother Education							
Unread/Unwrite/Primary	49(15.4)	7(24.1)	42(14.5)		9.49	0.72 – 124.61	0.087
Preparatory/Secondary/Diploma	196(61.6)	21(72.4)	175(60.6)	0.009	3.61	0.36 – 35.94	0.273
Ealorois/Graduate	73(23.0)	1(3.4)	72(24.9)		1.00		
Father Education							
Unread/Unwrite/Primary	22(6.9)	2(6.9)	20(6.9)		0.28	0.04 – 1.92	0.197
Preparatory/Secondary/Diploma	177(55.8)	15(51.7)	162(56.2)	0.864	0.39	0.13 – 1.19	0.098
Ealorois/Graduate	118(37.2)	12(41.4)	106(36.8)		1.00		
Mother Occupation							
House-wife	180(56.6)	19(65.5)	161(55.7)	0.310	0.98	0.27 – 3.55	0.971
Others	138(43.4)	10(34.5)	128(44.3)		1.00		
Father Occupation							
Public/Military Sector	169(53.3)	10(34.5)	159(55.2)	0.033	1.00		
Others	148(46.7)	19(65.5)	129(44.8)		4.2	1.4 - 12.5	0.012
Family Income							
Low Income	137(54.4)	18(78.3)	119(52.0)	0.016	2.96	0.86 – 10.15	0.084
Medium/High Income	115(45.6)	5(21.7)	110(48.0)		1.00		
Consanguinity:							
Yes	128(40.5)	13(44.8)	115(40.1)	0.619	1.06	0.42 – 2.71	0.899
No	188(59.5)	16(55.2)	172(59.9)		1.00		

4.6 Discussion

To our knowledge, this is the first study with robust methodology to highlight the prevalence rate of ADHD among school children in Oman. The study indicates that 8.8% of the cohort exhibited symptoms of ADHD as solicited by the NICHQ Vanderbilt Assessment Scales. In previous studies, most reports were based on the Conner's Scale (Bener et al., 2006, Bu-Haroon et al., 1999, Al-Haidar, 2002, Al-Sharbati et al., 2004). Unlike Conner's Scale, the NICHQ Vanderbilt Assessment Scales used in this study are more protracted, and appear to reflect the nomenclature as depicted in the DSM (Wamithi et al., 2015, Collett et al., 2003). Furthermore, the NICHQ Vanderbilt Assessment Scales are better equipped to detect a spectrum of ADHD including inattentive symptoms and hyperactivity/impulsivity, as well as a combination of these. The NICHQ Vanderbilt Assessment Scales are also equipped to tap into the core symptoms of ADHD, but also impairment as well as comorbidity, such as Oppositional-Defiant/Conduct Disorders and Anxiety/Depression (Wamithi et al., 2015).

The present study has therefore identified a different and, perhaps, more complete spectrum of ADHD. The study results indicate that 7.3% of children in the sample were identified by the teacher as having inattentive symptoms while 3% were identified as exhibiting predominately hyperactivity/impulsivity symptoms. On the whole, the present rate of 8.8% appears to echo the international range noted in the research literature (Faraone et al., 2003), although it appears in the lower range more typical when using questionnaires or a symptoms checklist (Faraone et al., 2003). On the other hand, when studies are conducted in the community using the 'gold standard' of semi-structured interview, the rate has been estimated to range between 6-7% of the targeted group (Faraone et al., 2003). The available literature also indicates that Arab populations generally show a lower rate of ADHD, as compared to Euro-American populations (Polanczyk et al., 2007).

On the whole, this study indicates that ADHD is relatively common among school-going children in Oman. As the present cohort is derived from school children residing in the area coterminous with the capital city of Muscat which, in essence, the urban region of the country where the bulk of the population in Oman is located (National Centre for Statistics and Information, 2013). Further studies are needed to render the study findings generalization to the rest of the population beyond the Muscat Governorate.

The second interrelated aim of this study was to highlight the risk factors, or specifically parental factors, associated with ADHD. Previous studies in the regions have focused only on establishing the rate of prevalence (Bener et al., 2006, Bu-Haroon et al., 1999, Al-Haidar, 2002, Al-Sharbati et al., 2004). Establishing the risk factors would lay the groundwork for developing preventative measures as well as for contemplating the most effective remedial services. This results of this study suggest that socio-economic status has a direct bearing on whether the children exhibit symptoms of ADHD or otherwise. Specifically, this study indicates that the higher income of the parent, the more likely that the children will be shielded from exhibiting ADHD, especially PHIS (Russell et al., 2014, Larsson et al., 2014).

This study also indicates that the parent`s place of work has strong links to whether a child has ADHD or not. Parents working in the government sectors, particularly fathers, have children with less risk for exhibiting symptoms of ADHDCIH compared to those working in private sectors. In Oman, government jobs tend to provide more holidays as well as higher salaries. In fact, studies have indicated that the most preferred jobs among the Omani labour force are in the government sector. Indeed, one study has indicated that those working in the private sector are more likely to have a lower level of education and are more like to suffer from an emotional disorder (Al-Salmani et al., 2015).

Finally, and somewhat surprisingly, the results of this study indicate that children of mothers who are not housewives have a significantly higher risk of showing symptoms of PHIS, even though the mother's level of education had no predictive value for this subtype of ADHD. This suggests that the operative factor relates to the mother's presence inside the home. This is consistent with socio-cultural teaching where mothers tend to play dominant role in socializing children (Frick and Dickens, 2006, Tercyak et al., 2002, Tapert et al., 2002). On the other hand, it seems to challenge previous findings that suggest that low parental education is predictive of ADHD (St Sauver et al., 2004).

It should be kept in mind, however, that the variables in question demonstrate different predictive patterns across the different types and measures of ADHD used in this study (PIS, PHIS, ADHDCIH). Thus, it provides a more nuanced portrait of the possible contributing factors for the development of ADHD symptomatology. On the other hand, the possible causative or contributory role of these variables cannot be divorced from the specific forms of impairment captured by these measures.

4.6.1 Study Limitations

The current study's objective to establish the prevalence of ADHD in Oman and identify the associated risk factors were addressed using a cross-sectional study design. The study's findings, therefore, rely upon a single measurement in time which is subject to change as the children become older. Therefore, the ideal design would be a longitudinal cohort study using 6 month intervals to measure ADHD. This would provide a more accurate measure of the incidence of ADHD as well.

The sample children in this study were from Muscat region alone, which is not necessarily representative of the national population. Therefore, the generalisability of these findings to children in other areas of the country may be limited. Consequently, a multicentre study using more than a single region would be appropriate to address this limitation.

In previous studies, familiar measures of ADHD have been strongly linked to IQ as well as parental factors. IQ levels were not explored in this study. Thus, based on the findings of this study, we are unable to explore the association between IQ and the spectrum of ADHD.

4.7 Conclusion

This study has measured the prevalence rate of PIS, PHIS and ADHD among Omani school children as 7.3% (95% CI: 4.5%, 10.1 %), 3% (1.2, 4.8%) and 8.8% (5.7%, 11.8%), respectively. Statistical analyses indicates that reduced family income, and non-government jobs were most strongly associated with an increased risk for ADHD: specifically, family income for PHIS (p=.019) and father's employment sector for ADHDCIH (p=.012). Childhood symptoms of PHIS were also significantly correlated with mother's occupations outside the home (p=.038). These associations remain the same even after controlling for other factors.

CHAPTER 5:

Vitamin D Deficiency Is Prevalent in Healthy Omani School Children: Omega-3 Fatty Acids Have a Mitigating Effect

5.1 Introduction

Oman has made a remarkable progress in socio-economic development in the last four decades (Musaiger, 1998, IBPUS, 2013). This advancement is reflected in dramatic reductions in maternal, child and infant mortality rates, common infectious diseases, extreme poverty, and a significant increase in life expectancy (UNICEF, 2009, Al-Lamki, 2010, UNDP, 2010). Conversely, the prevalence of obesity in adults and children, and non-communicable diseases, such as vascular and respiratory diseases, diabetes and cancer has reached epidemic proportions (Musaiger, 2002, Badran and Laher, 2011, Rahim et al., 2014a). The Oman World Health Survey, a country-wide community-based household survey involving about 5000 subjects conducted in 2008, revealed that 40.3% of those surveyed had hypertension, 12.3% diabetes, 21.4% obesity and 33.6% elevated blood cholesterol (Al Riyami et al., 2012).

It is plausible that genetic predisposition may be a factor for the rise in non-communicable diseases in Oman and the other Gulf countries. However, the fact that the rise occurred in a short time and coincided with a period of economic prosperity suggests that modifiable lifestyle factors, such as physical inactivity, smoking and unhealthy diets could be the main culprits. Indeed, it has been reported that the traditional diet of the Gulf Countries which comprises primarily of dates, milk, rice, brown bread, fish and vegetables (Musaiger, 1998, Galal, 2002) has changed to resemble a more Western diet which is high in vegetable oils and animal fat (~30% daily calorie), refined sugar (~51% daily calorie) and low fibre cereals (mainly highly extracted wheat flour and polished rice, 35-42% of daily energy) (Musaiger, 1998, Badran and Laher, 2011). The Western diet is high in calorie, high glycaemic index carbohydrates, total fat and saturated, trans and omega-6 fatty acids, and low in omega-3 fatty acids and essential vitamins and trace elements.

Childhood dietary habits tend to track to adult life (Mikkilä et al., 2004, Ventura and Worobey, 2013b) and some of the non-communicable chronic diseases are thought to begin in early life and progress to become clinical diseases in adulthood (Holman et al., 1958a, Holman, 1961, McNamara et al., 1971, Newman et al., 1986, Barker, 1995a, McGill et al., 2000a, McGill et al., 2008a, McGill et al., 2009a). Moreover, perhaps because of the impact of marketing strategy (Robinson et al., 2007, Andreyeva et al., 2011), fast food meals have become very popular among children and adolescents in the Arab countries (Musaiger, 1987b, Chakar and Salameh, 2006) and elsewhere. Therefore,

children and young adults must be an integral part of programmes for prevention and control of non-communicable diseases.

Recently, we conducted a comprehensive study designed to define health, physical fitness and cognitive ability of school children within the context of the rapid nutrition transition in Oman. This communication reports plasma fat-soluble micronutrient status at baseline and after intervention with fish-based menu or docosahexaenoic acid (DHA) enriched fish oil supplement.

It should be noted that there is conflicting evidence about the bioavailability of EPA and DHA from various forms of fish oil (el Boustani et al., 1987, Lawson and Hughes, 1988, Luley et al., 1990, Nordoy et al., 1991, Krokan et al., 1993, Hansen et al., 1993). El Boustani et al. (el Boustani et al., 1987) have reported a delayed and reduced incorporation of EPA into plasma triglycerides when administered as an ethyl ester, compared to the incorporation of EPA administered as natural triglycerides or as a free fatty acid. When Lawson and Hughes (Lawson and Hughes, 1988) compared the time course for the increase in concentration of EPA in plasma triglycerides relative to the maximal rise in a-linolenic acid, they found a nearly 100% absorption of EPA and DHA as free fatty acids, in contrast to the absorption of EPA as natural triglycerides (68%) or ethyl esters (20%).

Other research suggests an equal absorption of n-3 FA, either as triglycerides or ethyl esters (Luley et al., 1990, Nordoy et al., 1991). In comparing the absorption of EPA and DHA from natural fish oil triglycerides with that from ethyl esters at two different levels of EPA and DHA (54% and 35%), Luley et al. (1990) found no difference in absorption. Nordoy et al. (1991) compared the content of n-3 FA in chylomicron triglycerides and the increase in chylomicron triglycerides after a test meal with a large dose of n-3 FA, either as re-esterified triglycerides or as ethyl esters; they found a similar absorption of n-3 FA irrespective of whether the supplement was re-esterified triglycerides or ethyl esters, despite a lower rate of hydrolyses by intestinal lipase of fatty acids from ethyl esters than from triacylglycerols in vitro. The same pattern was found by Krokan et al. (1993), who demonstrated that the absorption of EPA and DHA from synthetic ethyl esters rich in EPA and DHA were fully comparable to that of natural triacylglycerols containing smaller amounts of these fatty acids.

Hansen et al. (1993) gave volunteers EPA and DHA, either as natural triglycerides or as ethyl esters, of approximately 3.5 g/day for 7 weeks. They found equal

incorporations of EPA and DHA into plasma phospholipids from their two formulations. The incorporation of EPA into plasma cholesterol esters from ethyl esters, on the other hand, was significantly lower than that from natural triglycerides.

5.2 Subjects and Methods

5.2.1 Subjects and Recruitment

Three hundred fourteen children (boys, n=139, girls, n=175) accounting for a 4.6% of the school pupils aged between 9 and 10 years from the Muscat Governorate were recruited using a two stage sampling procedure. In the first stage, three (n=3) of thirty nine (n=39) schools in the Governorate and in the second stage, three Grade 4 classes from five were randomly selected. The three schools were assigned to fish, fish oil or control group and the children were given for lunch a 100 gram lightly grilled fish sandwich with some vegetables (fish group), their habitual food or omega-3 fatty capsule containing 403 mg docosahexaenoic (DHA) and 53 mg eicosapentaenoic (EPA) acids. One hundred gram (100g) of the fish used in the study (Grouper, Sea bream, Kingfish, Emperor and Snapper) provided 150 to 200 mg omega-3 fatty acids and the dishes were prepared tastefully to enhance compliance by professional chefs at the Intercontinental City Hotel, Muscat. Body weight, height and body mass index were assessed baseline and a non-fasting blood sample, about 8 ml, obtained in EDTA at baseline and after 12 weeks of intervention.

The study was approved by the Research Ethics Committee of the Ministry of Health, Sultanate of Oman (Ref. MH/DGP/R&S/Proposal_Approved/8/2012), and the National Research Ethics Committee North West – Haydock, UK (REC reference no. 12/NW/0760) and registered with ISRCTN Register (Reg. No. ISRCTN93233285). Informed and signed consent was obtained from the parents/guardians of the children and the study was conducted in accordance with the provisions of the ethical approval of the two ethics committees and the principles of Helsinki Declaration.

5.2.2 Methods

Sample processing – Plasma and red blood cells were separated from whole blood specimen by centrifugation at 1200 g, 4ºC, for 10 minutes. The plasma was siphoned out carefully and transferred to another tube. The buffy coat was discarded and the red cell pellet washed three times by suspension in physiological saline (0.85%

NaCl) and cold centrifugation. The plasma and red blood cells were stored at -70ºC until analysis.

Anthropometry - Weight in kilogram and height in centimetre were assessed with a Seca Electronic Scale 890 (UNISCALE, Seca, Birmingham B5 5QB, UK) and a measuring board (Schorr, Weight and Measure, LLC, Olney, Maryland, USA) respectively.

The specific procedures used for each micronutrient included in this analysis are described in section 2.4.2 Blood Lipid Profile and Vitamins.

5.3 Results

5.3.1 Pre-intervention (baseline) gender comparison

Body weight, height, body max index and plasma vitamin A (all-trans retinol), beta carotene, vitamin E (alpha-tocopherol), total lipid (triglycerides and cholesterol), alpha-tocopherol and total lipid ratio, total vitamin D, parathryroid hormone, alkaline phosphatase, calcium and inorganic phosphate levels of the children are shown in Table 5-1. The male compared with the female students had higher vitamin D ($p<0.0001$) and lower parathyroid hormone ($p<0.0001$) and alkaline phosphatase ($p<0.01$) levels.

5.3.2 Post-intervention group comparison

Compared with the control group, the children (both male and female students) who were given fish oil supplement for twelve weeks had increased concentrations of B-carotene and vitamin D ($p<0.001$). Similarly, both carotene ($p<0.001$) and vitamin D ($p<0.05$) levels were higher in those who received fish meals (Table 5-2).

Table 5-1: Baseline weight, height, body mass index and plasma A, D and E, beta carotene, total lipid, parathyroid hormone, calcium and phosphate levels of Omani school children

Variables	Total students (n=314)	Male students (n=139)	Female students (n=175)
Weight (kg)		30.1 ± 7.8	29.9 ± 8.2
Height (cm)		133.1 ± 6.4	133.1 ± 6.6
Body mass index (kg/m^2)		16.8 ± 3.4	16.7 ± 3.5
Retinol (μmol/L)	2.7 ± 0.9	2.7 ± 0.8	2.6 ± 0.9
Beta carotene (μmol/L)	0.7 ± 0.5	0.7 ± 0.5	0.7 ± 0.5
α-tocopherol (μmol/L)	21.1 ± 4.8	20.9 ± 4.9	21.3 ± 4.7
Total lipid (mmol/L)	5.0 ± 0.8	4.9 ± 0.8	5.1 ± 0.8
α-tocopherol (μmol) / total lipid (mmol) ratio	4.3 ± 0.9	4.3 ± 0.9	4.3 ± 0.9
Vitamin D (25-hydroxy vitamin D) (nmol/L)	43.1 ± 17.1	49.3 ± 17.5	38.5 ± 15.3**
Parathyroid hormone (pmol/L)	5.5 ± 1.9	5.0 ± 1.7	5.8 ± 2.1**
Alkaline phosphatase (U/L)	237.2 ± 73.5	225.2 ± 66.6	247.8 ± 73.7*
Calcium (mmol/L)	2.5 ± 0.1	2.5 ± 0.1	2.5 ± 0.1
Phosphate (mmol/L)	1.6 ± 0.2	1.6 ± 0.2	1.6 ± 0.2

** $p<0.0001$, * $p<0.01$ - Male students vs. Female students

Table 5-2: Plasma vitamin A, D and E, beta carotene, total lipid, parathyroid hormone, calcium and phosphate levels of male and female school children after intervention with DHA-rich fish oil formulation or fish meal for 12 weeks

Variables	Control group (n=116)	Fish oil group (n=86)	Fish meal group (n=108)
Retinol (μmol/L)	2.2 ± 0.7	2.3 ± 0.8	2.3 ± 0.8
Beta carotene (μmol/L)	0.9 ± 0.4	1.2 ± 0.7**	1.2 ± 0.7**
α-tocopherol (μmol/L)	20.0 ± 4.8	20.5 ± 4.5	20.5 ± 4.7
Total lipid (mmol/L)	5.1 ± 0.8	5.1 ± 0.8	5.2 ± 0.8
α-tocopherol (μmol) / total lipid (mmol) ratio	4.2 ± 0.9	4.6 ± 1.0$	4.2 ± 0.8
Vitamin D (nmol/L)	42.3 ± 17.5	54.1 ± 17.5**	49.2 ± 17.4*
Parathyroid hormone (pmol/L)	5.8 ± 2.1	5.8 ± 2.1	6.4 ± 2.4
Alkaline phosphatase (U/L)	250.4 ± 72.8	245.9 ± 65.7	253.6 ± 85.0
Calcium (mmol/L)	2.5 ± 0.1	2.5 ± 0.1	2.5 ± 0.1
Phosphate (mmol/L)	1.9 ± 0.4	1.6 ± 0.1	1.6 ± 0.1

** $P<0.001$ Control group vs. Fish oil group; * $p<0.05$ Control group vs. Fish meal group
$ $P<0.001$ Fish oil group vs. Fish meal and Control Groups

5.3.3 Gender-stratified post-intervention group comparison

In the male students, beta carotene and vitamin D concentrations in the fish oil ($p<0.001$) and in the fish ($p<0.05$) groups were higher than in their counterparts who did not receive fish oil or fish meals (Table 5-4). Likewise, in the female students who were given fish oil and fish meals had elevated level of vitamin D ($p<0.001$ and $p<0.05$) compared with the control group students (Table 5-5).

Table 5-3: Plasma vitamin A, D and E, beta carotene, total lipid, parathyroid hormone, calcium and phosphate levels of male and female school children after intervention with DHA-rich fish oil formulation or fish meal for 12 weeks.

Variables	Control group (n=116)	Fish oil group (n=86)	Fish meal group (n=108)
Retinol (μmol/L)	2.2 ± 0.7	2.3 ± 0.8	2.3 ± 0.8
Beta carotene (μmol/L)	0.9 ± 0.4	1.2 ± 0.7**	1.2 ± 0.7**
α-tocopherol (μmol/L)	20.0 ± 4.8	20.5 ± 4.5	20.5 ± 4.7
Total lipid (mmol/L)	5.1 ± 0.8	5.1 ± 0.8	5.2 ± 0.8
α-tocopherol (μmol) / total lipid (mmol) ratio	4.2 ± 0.9	4.6 ± 1.0$	4.2 ± 0.8
Vitamin D (nmol/L)	42.3 ± 17.5	54.1 ± 17.5**	49.2 ± 17.4*
Parathyroid hormone (pmol/L)	5.8 ± 2.1	5.8 ± 2.1	6.4 ± 2.4
Alkaline phosphatase (U/L)	250.4 ± 72.8	245.9 ± 65.7	253.6 ± 85.0
Calcium (mmol/L)	2.5 ± 0.1	2.5 ± 0.1	2.5 ± 0.1
Phosphate (mmol/L)	1.9 ± 0.4	1.6 ± 0.1	1.6 ± 0.1

** $p<0.001$ Control group vs. Fish oil group; * $p<0.05$ Control group vs. Fish meal group
$ $p<0.001$ Fish oil group vs. Fish meal and Control Groups

Table 5-4: Plasma vitamin A, D and E, beta carotene, total lipid, parathyroid hormone, calcium and phosphate levels of the male school children after intervention with DHA-rich fish oil formulation or fish meal for 12 weeks

Variables	Control group (n=51)	Fish oil group (n=37)	Fish meal group (n=48)
Retinol (μmol/L)	2.2 ± 0.7	2.1 ± 0.7	2.4 ± 0.6
Beta carotene (μmol/L)	0.9 ± 0.4	1.4 ± 0.8**	1.2 ± 0.8*
α-tocopherol (μmol/L)	20.2 ± 5.6	21.1 ± 4.0	20.5 ± 3.6
Total lipid (mmol/L)	5.1 ± 0.8	5.0 ± 0.7	5.3 ± 0.8
α-tocopherol (μmol) / total lipid (mmol) ratio	4.2 ± 0.9	4.6 ± 0.8$	4.1 ± 0.8
Vitamin D (nmol/L)	50.6 ± 18.9	63.1 ± 17.3**	58.0 ± 16.5*
Parathyroid hormone (pmol/L)	5.5 ± 1.9	4.9 ± 1.4	5.9 ± 2.1
Alkaline phosphatase (U/L)	237.2 ± 61.8	226.6 ± 39.2	256.7 ± 82.6
Calcium (mmol/L)	2.5 ± 0.1	2.5 ± 0.1	2.5 ± 0.1
Phosphate (mmol/L)	2.4 ± 0.4	1.6 ± 0.1	1.6 ± 0.1

**p<0.001 Control group vs. Fish oil group; *p<0.05 Control group *vs*. Fish meal group ^{+}p<0.05 Fish oil group vs. Fish meal and Control groups; $^{\$}p$<0.05 Fish oil group vs. Control and Fish meal groups

Table 5-5: Plasma vitamin A, D and E, beta carotene, total lipid, parathyroid hormone, calcium and phosphate levels of the female school children after intervention with DHA-rich fish oil formulation or fish meal for 12 weeks

Variables	Control group (n=65)	Fish oil group (n=49)	Fish meal group (n=60)
Retinol (μmol/L)	2.2 ± 0.7	2.2 ± 0.9	2.3 ± 0.8
Beta carotene (μmol/L)	0.8 ± 0.5	1.1 ± 0.7	0.9 ± 0.8
α-tocopherol (μmol/L)	19.9 ± 4.2	20.1 ± 4.9	20.6 ± 5.5
Total lipid (mmol/L)	5.1 ± 0.8	5.2 ± 0.8	5.2 ± 0.8
α-tocopherol (μmol) / total lipid (mmol) ratio	4.2 ± 0.8	4.6 ± 1.0$	4.2 ± 0.8
Vitamin D (nmol/L)	36.1 ± 13.5	47.3 ± 14.6**	41.8 ± 14.6*
Parathyroid hormone (pmol/L)	6.0 ± 2.2	6.5 ± 2.3	6.8 ± 2.6
Alkaline phosphatase (U/L)	261.2 ± 79.6	260.8 ± 77.6	251.2 ± 87.5
Calcium (mmol/L)	2.5 ± 0.1	2.5 ± 0.1	2.5 ± 0.1
Phosphate (mmol/L)	1.6 ± 0.2	1.7 ± 0.2	1.6 ± 0.1

**p<0.001 Control group vs. Fish oil group; *p<0.05 Control group vs. Fish meal group
$^{\$}p$<0.05 Fish oil group vs. Control and Fish meal groups

5.3.4 Pre- and post-intervention comparison

Post-intervention plasma vitamin D (Fig. 5-1) and parathyroid hormone (Fig. 5-2) concentrations compared with pre-intervention (baseline) were higher in the children who received fish oil and fish meals ($p<0.0001$). There was no difference between the pre- and post-intervention concentrations of the two analytes in the control group.

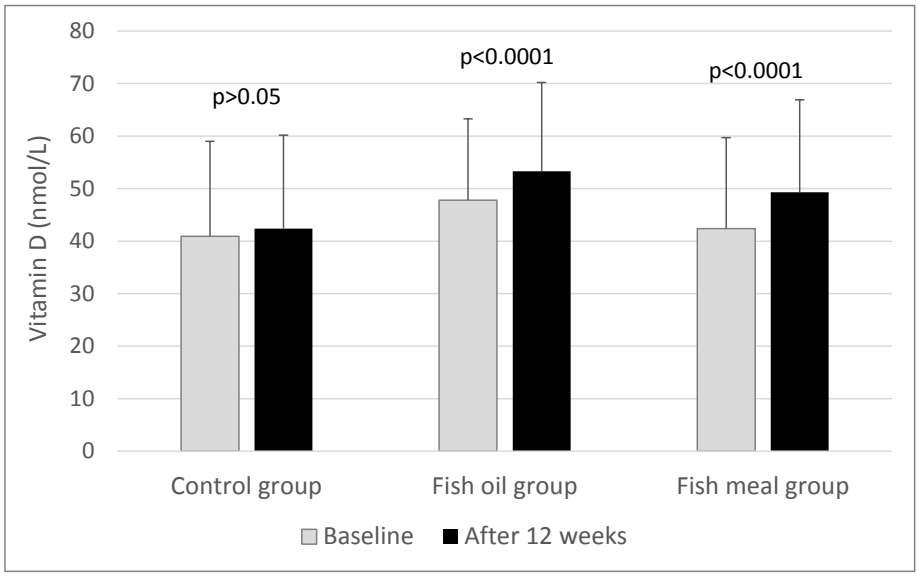

Figure 5-1: Plasma vitamin D concentrations before (baseline) and after intervention with fish oil and fish meal for 12 weeks

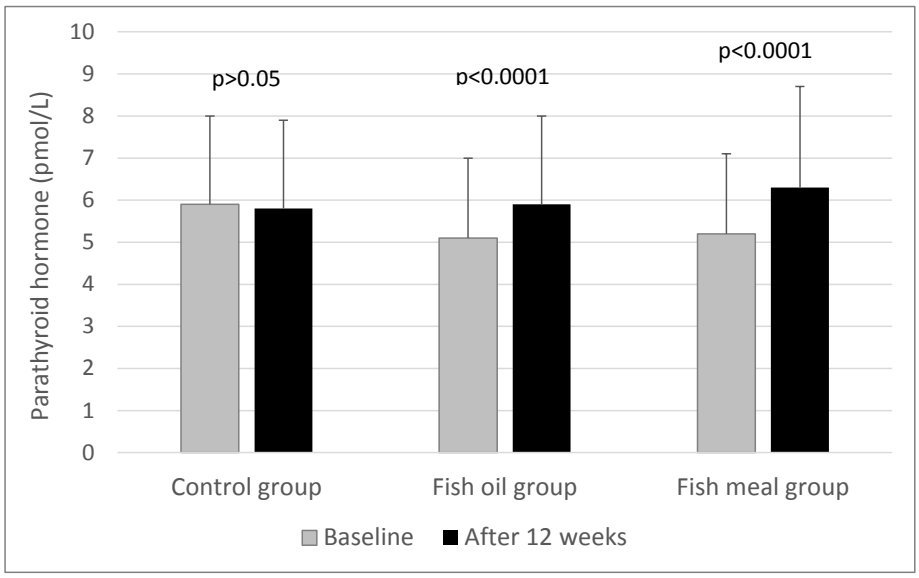

Figure 5-2: Plasma parathyroid hormone levels before (baseline) and after intervention with fish oil and fish meal for 12 weeks

5.4 Discussion

Urbanisation, heavy reliance on imported foods (primarily beef, dairy and poultry products and refined cereals, vegetable oils and sugar) and sweetened beverages and the proliferation of food supermarkets and convenience fast-food restaurants have led to a drastic change in dietary habits in Oman. The impact of the change, which is characterised mainly by intakes of calorie-rich and essential micronutrient-poor foods, on lipid-soluble nutrient (vitamin A, D and E, and beta carotene) status of Omani children has not been fully investigated. Accumulating evidence demonstrates, these micronutrients, in addition to their well-characterised classical functions (Goodman et al., 1966, Bonet et al., 2003, DeLuca, 2004, Black et al., 2008, Sathe and Patel, 2010, Niki and Traber, 2012) play a role in gene expression (Zhang et al., 1992, Azzi et al., 2004, Bastien and Rochette-Egly, 2004, Hossein-nezhad et al., 2013), cognitive function (Grodstein et al., 2007, Olson and Mello, 2010, Soni et al., 2012, Ulatowski et al., 2014) and antioxidant defence (Burton and Ingold, 1984, Lin et al., 2005). Moreover, deficiency/insufficiency of these nutrients is thought to be associated with increased risks of non-communicable diseases.

A biannual supplementation programme with a high dose vitamin A in infants and children aged six to fifty-nine months (UNICEF, 2007, WHO, 2011a) is effective in reducing morbidity, mortality and vision impairment (Beaton et al., 1993, Fawzi et al., 1993, Imdad et al., 2010). Regardless, vitamin A deficiency is still the foremost cause of these preventable problems, particularly in South East Asia and Africa. Based on the prevalence of night blindness and biochemical vitamin A deficiency based estimates, 45 and 122 countries respectively have vitamin A deficiency of public health significance (WHO, 2009). A 0.70 μmol/l serum/plasma vitamin A concentration is the cut-off point of deficiency (WHO, 1996, de Pee and Dary, 2002) which is used as a marker for assessing severity and public health significance in most age groups (WHO, 2011b). A cross-sectional survey (Ministry of Health of the Sultanate of Oman, 2006) on food fortification and micronutrient deficiencies conducted in Oman in 2004 found vitamin A deficiency in children aged 6-59 (5.5%), 6-23 (18%) and 24-59 (3%) months, and in non-pregnant women of reproductive age (0.5%). In the current study, deficiency (≤ 0.70 μmol/l) was not detected in any of the children and only three of them had a marginal status (<1.05 μmol/l). Some of the milk and dairy products in the Omani market are fortified with vitamin A (Alasfoor et al., 2007) and it is mandatory for edible vegetable oils sold in the country to incorporate 60 IU/g of the vitamin. It appears that the children

were able to maintain adequate status by consuming foods fortified with preformed vitamin A as well as vegetables containing provitamin A.

There is a wide variability in blood beta carotene concentration among healthy individuals (Winklhofer-Roob et al., 1997). The variations are primarily a reflection of intake, vitamin A status and genetic make-up (Lacher et al., 2005, Tourniaire et al., 2009, Borel, 2012). Gender-related differences in concentration have also been reported (Hercberg et al., 1994, Olmedilla et al., 1994). Nevertheless, depending on the amount of fruits and vegetables consumed, blood beta carotene levels generally fall between 0.2 and 1.5 μmol/l (Burri, 1997). The present study did not detect gender-related effect on plasma beta carotene, and the values were within the aforementioned range in 87% (0.63±0.31 μmol/l), below in 7% (0.16±0.04 μmol/l) and above in 6% (1.87±0.28 μmol/l) of the children. Fresh fruits, which are an important component of the Omani foods, are eaten three or more times a week (Opara et al., 2007). This Omani dietary habit may provide and an explanation for the 'adequate' beta carotene status in most of the children in the current study.

In contrast to vitamin A, the concentration of plasma beta carotene increased significantly in the fish diet and fish oil groups after intervention for 12 weeks ($P<0.001$) (Table 5-2). This finding, which is consistent with the report that fish oil supplementation enhances the absorption of beta carotene in human (Nair et al., 1993) and rats (Blakely et al., 1992), is rather intriguing since dietary fat is thought to facilitate fat-soluble vitamin uptake and transport.

As is the case with the other fat-soluble vitamins, the blood level of vitamin E (alph-tocopherol) varies considerably between individuals and population groups (Winklhofer-Roob et al., 1997, Valtuena et al., 2011, Peter et al., 2013, Traber, 2014). Nevertheless, a concentration of less than 12 μmol/l in plasma is defined as the cut-off point of vitamin E inadequacy (Institute of Medicine et al., 2000), and the minimum concentration required to help prevent cardiovascular diseases and cancer is thought to be 30 μmol/l (Gey, 1995). 96.6% of the children in this study had concentrations higher and 3.4% lower than the cut-off point (12 μmol/l). Two children had levels (7.38 and 7.89 μmol/l) less than 8 μmol/l, a value which is associated with neurological disease. Since vitamin E is intimately associated with circulating lipids, the ratio of the two nutrients was used to evaluate vitamin E status. All of the children had vitamin E/total lipid ratio higher than the cut-off point 1.11 μmol/mmol suggesting that the 'deficiency'

in the 3.4% of the children indicated by plasma vitamin E concentration may not be related to a low intake.

There was no difference in the post-intervention plasma vitamin E concentration between the three groups (Table 5-2, 5-3 and 5-4). In contrast, the post-intervention vitamin E/total lipid ratio was significantly higher in the children who received the fish oil supplement compared with the fish diet and control groups. This difference was most likely due to the combined effect of omega-3 fatty acids which reduces blood lipid content and the vitamin E incorporated in the supplement to prevent lipid peroxidation.

Consistent with the previous reports of Omani non-pregnant (Al-Kindi, 2011) and pregnant (Al Kalbani et al., 2011) women, school children aged 9 to 12 years (Kilani et al., 2013) and adults aged 18 to 55 (Abiaka et al., 2013), most of the children in the current study were severely deficient (<27.5 nmol/L; 10.5% boys and 28.5% girls), deficient (27.5-44.9 nmol/L; 47.6% boys and 49.4% girls) or insufficient (50 – 74.9 nmol/L; 34.6% boys and 21.5% girls) in vitamin D. Only 7.3% boys and 0.6% girls had a sufficient level (≥ 75 nmol/L) level. As it is borne out by the elevated levels of parathyroid hormone and alkaline phosphatase (Table 5-1) the insufficiency was more pronounced in the female children. The high prevalence of vitamin D deficiency in the children should be a major public health concern because childhood is a period of skeletal mineral acquisition and bone modelling and there is evidence that vitamin D plays a critical role in muscle growth and development, cognitive function and modulation of innate and adaptive immunity.

Omega-3 fatty acids have been shown to enhance bone mineralisation in human and experimental animals but their effect on blood vitamin D has not been investigated. The children who were given oily fishes, which are thought to contain variable amounts of vitamin D, and DHA-enriched fish oil supplement, which was stripped out of vitamin D, had elevated plasma 25-hydroxy vitamin D concentration compared with the control group (Tables 5-2, 5-3, 5-4). It is not obvious how fish oil increases plasma vitamin D. However, since it did not have any effect on PTH or alkaline phosphatase the action may be mediated by the facilitation of vitamin D transport across the intestinal mucosa. Indeed, there is evidence that dietary fat promotes vitamin D absorption (Dawson-Hughes et al., 2015).

Bone mineral density of the children and vitamin D status of rural children with limited access to school transport were not assessed. These limitations will be addressed

in future investigations. This study demonstrates that vitamin D insufficiency is highly prevalent in Omani young school children and it could be mitigated with omega-3 fatty acid supplementation. Various studies have reported vitamin D deficiency/insufficiency in non-pregnant and pregnant Omani women. It is conceivable that Omani children may be at risk of developmental and health problems caused by prenatal and postnatal vitamin D deficiency. Vitamin D plays a crucial role in skeletal and extra-skeletal systems. Therefore, there is an urgent need for a well-thought-out programme which incorporates a fortification of foods and drinks favoured by children and outdoor activities to help tackle this major public health problem.

CHAPTER 6:
Red Blood Cell Fatty Acid Profile of Healthy Omani School Children Before and After Intervention with Omega 3 Fish Fatty Acids

6.1 Introduction

The traditional Omani economy was based on subsistence farming, herding, fishing and trading (The Bank Group, 1972, College of Agriculture, 1995, Al-Mashakhi and Koll, 2007) and the diet of the population consisted mainly of whole grain, legumes, fruits, vegetables and fish (UNICEF, 1973, Musaiger, 1998). However, following the discovery and exploitation of oil five decades ago, the country has undergone a major economic transformation (Musaiger, 1998) and registered a significant progress in health and social care, education and reduction in poverty and mal-nutrition (Al-Lamki, 2010). In the same period of time, the prevalence of non-communicable chronic diseases, such as obesity, diabetes, cancer, high blood pressure and cardiovascular disease (Al Riyami et al., 2012, Rahim et al., 2014a) and the consumption of imported energy-dense foods, vegetable oils, milled and polished grains and carbonated beverages (Musaiger, 1998, US Commercial Service, 2005, Mohammed, 2009) have increased considerably. The numerous fast food outlets and restaurants dotted across towns and the supermarket ready meals have and are contributing to the transformation of the traditional dietary pattern. This change in food culture is likely to be enduring as there is evidence that children and adolescents in Oman and other Arab countries have adopted readily Western eating habits (Chakar and Salameh, 2006, Braithwaite et al., 2014).

Injudicious consumption of contemporary Western pattern diets - high protein and fat of intensively reared land animals, refined sugar, vegetable fat and oils (mainly sunflower, safflower and corn) and low fresh fruits and vegetables and marine foods (Cordain et al., 2005a, Patterson et al., 2012, Misra et al., 2010, Carrera-Bastos et al., 2011a) – have played a critical role in the rise of non-communicable chronic diseases (Carrera-Bastos et al., 2011a, Meyerhardt et al., 2007, Torfadottir et al., 2012) in the last six decades. This deleterious effect is attributed primarily to an excessive amount of saturated, trans and omega 6 fatty acid and an insufficient omega 3 fatty acid and essential micro-nutrient content of the consumed diet (Cordain et al., 2005a, Litin and Sacks, 1993, Simopoulos, 2011).

Cell line, experimental animal and human epidemiological and intervention studies demonstrate that the long chain omega 3 polyunsaturated fatty acids directly, or indirectly via their metabolites, play a pivotal role in neuro-visual development, function and rehabilitation (Martinez, 2001, Helland et al., 2008a, Ryan et al., 2010, Pu et al., 2013), cardioprotection (Nestel et al., 2015, Costanzo et al., 2013), modulation of inflammatory and immune responses (Calder, 2013, Maskrey et al., 2013, Fritsche, 2015)

signal transduction and gene expression (Gdula-Argasinska et al., 2015, Nakamoto et al., 2015, Zaree et al., 2015).

In light of the rapidly shifting nutrition transition in Oman, this study investigated fatty acid status of preadolescence school children before and after intervention with fish oil or oily fish.

6.2 Materials and Methods

6.2.1 Subjects and recruitment

Female (n=160) and Male (n=125) healthy school children aged 9 and 10 years were recruited from three schools in Muscat, Sultanate of Oman. Subsequently, the schools were assigned at random to one to three groups and the children given a 100 gram oily fish sandwich, lightly grilled (Fish Group), fish oil capsule, 403 mg DHA and 53 mg EPA (Fish Oil Group) or their habitual diet (Control Group) during lunch time, on schools days, for twelve weeks. The fish used for the sandwich, which were grouper, sea bream, kingfish, emperor and snapper, supplied between 150 and 200 mg omega-3 fatty acids (EPA, DPA and DHA). To help improve consistency, taste and flavour and consequently compliance the sandwich was prepared by professional chefs of the Intercontinental City Hotel, Muscat. About 8 ml of non-fasting blood specimen was collected from each child before and at the end of the intervention period and stored in a freezer at - 80° C and subsequently transported in dry ice to London for analysis. Ethical approval was obtained from the Ethics Committee of the Ministry of Health, Sultanate of Oman (Ref. MH/DGP/R&S/8/2012), and the National Research Ethics Committee North West – Haydock, UK (REC reference no. 12/NW/0760). Informed and signed consent was obtained from the parents/guardians of the children. Study registration ISRCTN93233285.

6.2.2 Analysis of red blood cell fatty acids

Red blood cell lipids were extracted based on the method of Folch et al. (1957b) by homogenising 0.5 ml of sample in chloroform/methanol (2:1 v/v) containing the antioxidant butylated hydroxytoluene (BHT, 0.01% w/v) under nitrogen. Fatty acid methyl esters (FAMEs) were prepared by acid-catalysed transesterfication reaction by heating the extracted lipids in 4 ml methanolic acetyl chloride (15% v/v) in a tightly sealed vial at 70C° for 3 hours after degassing with nitrogen. The FAMEs were extracted with petroleum spirit, dried and then re-dissolved in heptane for separation by a gas

chromatograph (HRGC MEGA 2 series, Fisons Instruments, Italy) fitted with a BPX 70 capillary column (60m x 0.25mm ID, 0.25μ film). Hydrogen was used as carrier gas at a flow rate of 2.3 ml/min and the injector and detector temperatures were set at 250 and 280°C, respectively. The initial oven temperature which was 60°C increased at 5ºC/min to 160°C, maintained for 5 min, and then increased at 3ºC/min to 205°C and kept constant for 12 minutes. The eluted peaks were identified with fatty acid methyl ester standard mixture certified for quality (Supelco® 37 Component FAME Mix. U47885-U, Sigma-Aldrich, Dorset, UK), GC-MS authenticated fatty acid methyl esters prepared from lipid extract of vegetable seed oils containing alpha-linolenic, gamma-linolenic and stearidonic acids, and bovine brain L-A-phosphatidylethanolamine Type 1 (Sigma-Aldrich, Dorset, UK). Peak areas were computed with EZChrom Ellite, version 3.2 (Scientific software, Pleasant, CA, USA).

6.3 Data Analyses

The continuous variables are expressed as mean and standard deviation (mean± sd). Statistical differences between the data of the female and male students at baseline, and between the three groups at post-intervention were evaluated with an independent (unpaired) t-test and a one-way analysis of variance (ANOVA), respectively. The Bonferroni pairwise multiple comparison post-hoc test was performed when the ANOVA F-test indicated significance. A univariate regression analysis was used to assess relationships between the major fatty acids. P values of less than 0.05 were deemed statistically significant. Analyses were conducted with IBM SPSS statistics, version 22 (IBM Corporation, New Orchard Road, Armonk, New York 10504-1722, USA)

6.4 Results

6.4.1 Demographics and baseline blood pressure and lipids

Age, height, weight, systolic and diastolic blood pressure, plasma triglycerides and HDL, LDL and total cholesterol levels of the children prior to the intervention are presented in Table 6-1. There was no difference in any of the aforementioned variables between the genders ($p>0.05$).

Table 6-1: Baseline characteristics of the children

Characteristics	Boys & Girls (n=285)	Boys (n=125)	Girls (n=160)
Age (year)	9/10	9/10	9/10
Weight (kg)	29.6±7.5	29.3±6.6	29.9±8.2
Height (cm)	133.3±6.6	133.3±6.3	133.3±6.8
Systolic BP (mmHg)	107.2±10.4	107.5±9.5	106.9±10.6
Diastolic BP (mmHg)	63.8±10.3	63.8±9.9	63.8±10.6
Triglycerides (mmol/L)	0.61±0.3	0.59±0.30	0.63±0.26
Total Cholesterol (mmol/L)	4.32±0.68	4.28±0.71	4.35±0.65
HDL- Cholesterol (mmol/L)	1.38±0.32	1.41±0.34	1.36±0.31
LDL-Cholesterol (mmol/L)	2.66±0.55	2.61±0.58	2.71±0.53

6.4.2 Baseline red blood cell fatty acids

The male students had a higher level of myristic (C14:0), palmetic (C16:0) ($p<0.05$) and oleic (C18:1n-9, $p<0.01$) and lower adrenic (22:4n-6, $p<0.05$) acids compared with their female counterparts. The percentages of the other saturated, mono-unsaturated, n-6 and n-3 fatty acids and DHA sufficiency index (DHA/N-6 DPA) were not different between the two groups ($p>0.05$, Table 6-2). The n-3 index correlated positively with arachidonic ($r=0.258$, $p=0.004$) and total n-6 ($r=0.504$, $p=0.0001$) and inversely with total saturated ($r= - 0.765$, $p=0.0001$) and mono-unsaturated ($r= - 0.684$, $p=0.0001$) fatty acids in the male children. Similarly, in the girls, arachidonic ($r= 0.169$, $p=0.030$), total n-6 ($r=0.340$, $p=0.0001$), total saturated ($r= - 0.677$, $p=0.0001$) and mono-unsaturated ($r= - 0.484$, $p=0.0001$) fatty acids and diastolic blood pressure ($r= - 0.207$, $p=0.049$) and body weight ($r= - 0.224$, $p=0.005$) were associated with n-3 index.

Table 6-2: Baseline percent red blood cell lipid acid composition of Omani preadolescent school children aged 9 and 10 years

Fatty acids	Boys & Girls (n=290)	Boys (n=126)	Girls (n=164)
14:0	0.17±0.10	0.18±0.10*	0.16±0.09
16:0	23.5±4.3	24.2±4.5*	22.9±4.1
18:0	15.9±1.4	15.9±1.5	15.9±1.3
20:0	0.36±0.11	0.35±0.11	0.36±0.10
22:0	1.58±0.49	1.56±0.52	1.59±0.48
24:0	3.42±.1.1	3.44±1.1	3.40±0.99
∑ Saturates	44.9±5.9	45.6±6.5	44.3±5.3
16:1n-7	0.17±0.07	0.17±0.07	0.17±0.07
18:1n-7	0.63±0.10	0.62±0.11	0.64±0.10
18:1n-9	11.6±1.5	11.9±1.6**	11.4±1.3
20:1n-9	0.16±0.05	0.15±0.06	0.16±0.05
24:1n-9	2.39±0.72	2.33±0.69	2.44±0.74
∑ Monoenes	15.0±1.9	15.2±2.1	14.8±1.7
18:2n-6	9.31±1.5	9.23±1.5	9.36±1.5
18:3n-6	0.10±0.03	0.10±0.03	0.09±0.03
20:2n-6	0.18±0.06	0.18±0.06	0.19±0.05
20:3n-6	1.33±0.37	1.33±0.41	1.34±0.33
20:4n-6	14.7±1.8	14.6±1.9	14.9±1.8
22:4n-6	2.84±0.87	2.71±0.90*	2.94±0.83
22:5n-6	0.67±0.24	0.66±0.25	0.68±0.22
N-6 Metabolites	19.9±2.7	19.5±2.70	20.1±2.7
∑ N-6	29.2±3.5	28.8±3.8	29.5±3.3
18:3n-3	0.05±0.07	0.05±0.06	0.05±0.08
20:5n-3	0.36±0.14	0.39±0.13	0.35±0.14
22:5n-3	0.99±0.33	0.97±0.37	1.00±0.30
22:6n-3	3.63±1.45	3.50±1.57	3.78±1.35
N-3 Index	4.10±1.32	3.89±1.65	4.20±1.41
N-3 Metabolites	4.98±1.79	4.86±1.95	5.07±1.64
∑ N-3	5.00±1.80	4.84±1.96	5.12±1.67
16:0 DMA	2.45±0.49	2.49±0.52	2.41±0.47
18:0 DMA	3.33±0.56	3.26±0.56	3.38±0.55
18:1 DMA	0.43±0.11	0.42±0.12	0.44±0.10

*Male vs. Female * p<0.05, **p<0.01*

6.4.3 Post-intervention red blood cell fatty acids, blood pressure and plasma lipids

Red blood cell total lipid fatty acid composition of the children after intervention with fish oil or oily fish for twelve weeks is shown in Table 6-3. The control group compared with those who received oily fish and fish oil capsules had higher levels of lignoceric (24:0), nervonic (24:1n-9), docosapentaenoic (DPA, 22:5n-6) ($p<0.05$) and lower eicosapentaenoic (EPA, 20:5n-3), decosapentaenoic (DPA, 22:5n-3), docosahexaenoic (DHA, 22:6n-3) and total n-3 fatty acids, n-3 metabolites, n-3 index and 18:1 dimethyl acetals ($p= 0.0001$). Palmitic and total saturated fatty acids, DHA, DHA sufficiency index and n-3 index were lower ($p<0.05$) and AA, n-6 metabolites and n-3 DPA higher ($p=0.0001$) in the oily fish group than in the children supplemented with fish oil capsules.

In the fish oil group, n-3 index correlated positively with arachidonic ($r=0.394$, $p=0.0001$), adrenic ($r=0.394$, $p=0.0001$), n-6 DPA ($r=0.562$, $p=0.0001$) and total n-6 ($r=0.414$, $p=0.0001$) and negatively with palmitic ($r= -0.762$, $p=0.0001$), total saturated ($r= -0.816$, $p=0.0001$), palmitoleic ($r= -0.384$, $p=0.001$), oleic ($r= -0.347$, $p=0.002$) and total mono-unsaturated ($r= - 0.431$, $p= 0.0001$) fatty acids. Similarly, there was a correlation between n-3 index and arachidonic ($r=0.231$, $p=0.038$), oleic ($r= -0.271$, $p=0.008$) and total saturated ($r= -0.439$, $p= 0.0001$) and mono-unsaturated ($r= -0.213$, $p=0.037$) fatty acids in the children who received oily fish.

Post-intervention blood pressure, plasma triglycerides and LDL, HDL and total cholesterol values of the children are presented in Table 6-4. Systolic and diastolic blood pressure ($p=0.0001$) and plasma triglycerides ($p<0.05$) but not HDL, LDL and total cholesterol ($p>0.05$) were lower in the children supplemented with fish oil compared with those who were fed oily fish. There was no gender-related difference in any of the aforementioned variables between the control and oily fish children ($p>0.05$). The boys in the fish oil group had lower triglyceride and higher HDL cholesterol levels than their female counterparts ($p<0.05$).

Table 6-3: Percent red blood cell lipid acid composition of Omani preadolescent school children aged 9 and 10 years after intervention with oily fish or fish capsule for 12 weeks

Fatty acids	Control (n=102)	Oily Fish (n=77)	Fish oil (n=96)
14:0	0.10±0.07	0.11±0.10	0.12±0.08
16:0	21.1±3.6	19.8±3.6[a]	21.5±3.8
18:0	16.2±0.99	16.2±1.1	16.4±1.1
20:0	0.32±0.09	0.33±0.07	0.32±0.06
22:0	1.57±0.24	1.53±0.27	1.53±0.29
24:0	3.71±0.54[g]	3.45±0.58	3.46±0.73
∑ Saturates	42.9±3.4	41.4±2.9 [a]	43.3±4.0
16:1n-7	0.13±0.06	0.13±0.08	0.12±0.05
18:1n-7	0.63±0.11	0.61±0.09	0.59±0.09
18:1n-9	11.5±1.1	11.3±1.2	11.4±1.2
20:1n-9	0.14±0.09	0.15±0.04	0.14±0.04
24:1n-9	2.65±0.47[g]	2.53±0.51	2.46±0.51
∑ Monoenes	15.0±1.3	14.7±1.4	14.8±1.4
18:2n-6	9.77±1.3	9.64±1.3	10.0±1.2
18:3n-6	0.04±0.03	0.04±0.02	0.03±0.02
20:2n-6	0.15±0.05	0.17±0.05[b]	0.16±0.04
20:3n-6	1.44±0.27	1.45±0.31	1.35±0.25
20:4n-6	14.8±2.1	15.2±1.8 [c]	13.7±2.0 [e]
22:4n-6	3.00±0.57	2.87±0.59	2.42±0.53[f]
22:5n-6 (N-6 DPA)	0.74±0.19[g]	0.67±0.17	0.65±0.14
N-6 Metabolites	20.1±2.7	20.3±2.4	18.3±2.5[f]
∑ N-6	29.9±3.1	30.0±2.7 [c]	28.3±3.0 [e]
18:3n-3	0.03±0.02	0.04±0.02	0.03±0.02
20:5n-3	0.25±0.13[h]	0.41±0.19	0.36±0.12
22:5n-3	1.17±0.29[h]	1.40±0.27 [c]	1.07±0.22
22:6n-3	4.49±1.43[h]	5.63±1.24 [d]	6.25±1.53
N-3 Index	4.74±1.53[h]	6.03±1.39 [d]	6.60±1.63
N-3 Metabolites	5.91±1.69[h]	7.42±1.57	7.59±1.82
∑ N-3	5.95±1.70[h]	7.46±1.58	7.62±1.82
16:0 DMA	1.97±0.31	2.00±0.31	1.90±0.29
18:0 DMA	3.26±0.41	3.46±0.46 [b]	3.37±0.49
18:1 DMA	0.41±0.09[h]	0.48±0.09	0.48±0.08
DHA/N-6 DPA	6.49±2.71	8.77±2.79 [b]	9.86±2.12[f]

Oily Fish vs. Control & Fish oil ([a] p< 0.05), vs. Control ([b] p< 0.05) and vs. Fish Oil ([c] p<0.0001, [d] p<0.05)

Fish Oil vs. Control ([e] p<0.001) and vs. Oily Fish & Control ([f] p<0.0001)

Control vs. Oily Fish & Fish Oil ([g] p<0.05, [h] p< 0.0001)

Table 6-4: Blood pressure, plasma triglycerides and HDL, LDL and total cholesterol of the children after intervention for 12 weeks with fish oil or oily fish

	Control			Oily Fish			Fish Oil		
Characteristics	All (n=102)	Male (n=46)	Female (n=56)	All (n=95)	Male (n=42)	Female (n=50)	All (n=78)	Male (n=34)	Female (n=44)
Systolic BP (mmHg)	–	–	–	111.9 ±9.6	111.9 ±9.1	111.8 ±10.0	101.7 ±7.5**	102.1 ±6.7	101.4 ±7.9
Diastolic BP (mmHg)	–	–	–	67.0 ±11.7	66.6 ±11.6	67.0 ±11.9	60.1 ±7.9**	60. 0±5.5	60.0 ±7.3
Triglycerides (mmol/L)	0.64 ±0.35	0.59 ±0.37	0.67 ±0.33	0.65 ±0.23	0.64 ±0.24	0.65 ±0.22	0.55 ±0.28*	0.48 ±0.27$	0.60 ±0.28
Total Cholesterol (mmol/L)	4.47 ±0.65	4.52 ±0.65	4.44 ±0.65	4.49 ±0.71	4.57 ±0.80	4.43 ±0.63	4.50 ±0.64	4.49 ±0.57	4.52 ±0.70
HDL (mmol/L)	1.39 ±0.29	1.41 ±0.28	1.38 ±0.31	1.41 ±0.33	1.46 ±0.33	1.37 ±0.32	1.44 ±0.32	1.55 ±0.35$	1.36 ±0.28
LDL (mmol/L)	2.80 ±0.54	2.83 ±0.56	2.75 ±0.52	2.79 ±0.54	2.81 ±0.66	2.76 ±0.44	2.81 ±0.55	2.71 ±0.49	2.89 ±0.59

** p<0.05 Fish oil vs. Fish and vs. Control (All), ** p< 0.0001 Fish oil vs. Fish (All); $ p<0.05 Male vs. Female (Fish oil group)*

6.5 Discussion

The primary focus of this study was the n-3 long chain polyunsaturated fatty acids which are thought to be limiting nutrients in Westernised dietary patterns. The sum of red blood cell DHA and EPA percentages, n-3 fatty acid index, was used to assess status.

Previous studies have reported higher levels n-3 long chain polyunsaturated fatty acids in women than in men (Lohner et al., 2013) this distinction is attributed to hormonal effect (Childs et al., 2008) the current study, although the female children had slightly elevated levels of DHA, n-3 metabolites (EPA, n-3 DPA and DHA) and n-3 fatty acid index compared with their male counterparts, the differences were not statistically significant. This was predicable since the children were prepubescent aged 9 and 10 years and the gender-related variation in oestrogen concentration would not be high enough to have a measurable influence on the activity of delta 6 and 5 desaturases.

Consistent with the country's long maritime history and coastline fish is an integral part of the Omani traditional diet. Therefore, the low mean baseline red cell n-3 fatty acid index of the children, which is broadly comparable to those of healthy Guatemalan (Solomons et al., 2015) Danish (Damsgaard et al., 2013) and American (Harris et al., 2013) children of a similar age group, suggests the consumption of fish might have declined among the preadolescent Omani perhaps in favour of the widely available subsidised processed foods (Mohammed, 2009) which are high in saturated and n-6 fatty acids.. The most striking and indeed puzzling finding was the very low n-3 fatty acid index (<2%), which was unrelated to improper specimen collection and processing, in a small number of seemingly healthy children with no history of mental or neurological disorders (Figure 5-1).The short and long-term implications of this finding is not apparent; nevertheless, it is of concern because of the critical role of n-3 long chain fatty acids, particularly in visual and neuronal development, function and brain protection (Ryan et al., 2010, Martinez et al., 2000, Baumgartner, 2016, Farooqui and Farooqui, 2016, Bauer et al., 2014). In addition, in adults, there is evidence that patients with psychiatric conditions and individuals at a higher risk of unexpected death from a heart disease have red blood cell n-3 fatty acid index of less than 4% (Messamore and McNamara, 2016). These observations are pertinent for children since early life is thought to be the genesis of a number of non-communicable chronic diseases (psychiatric and cardiovascular) (Stein, 2003, Abbott et al., 1998, Brown and Susser, 2008, Hollis, 2000, Holman, 1961, McGill et al., 2009b). Indeed, O'Sullivan and colleagues have reported that n-3 fatty acid index correlates with reduced cardiovascular disease risk factors in adolescent boys (O'Sullivan et al., 2011).

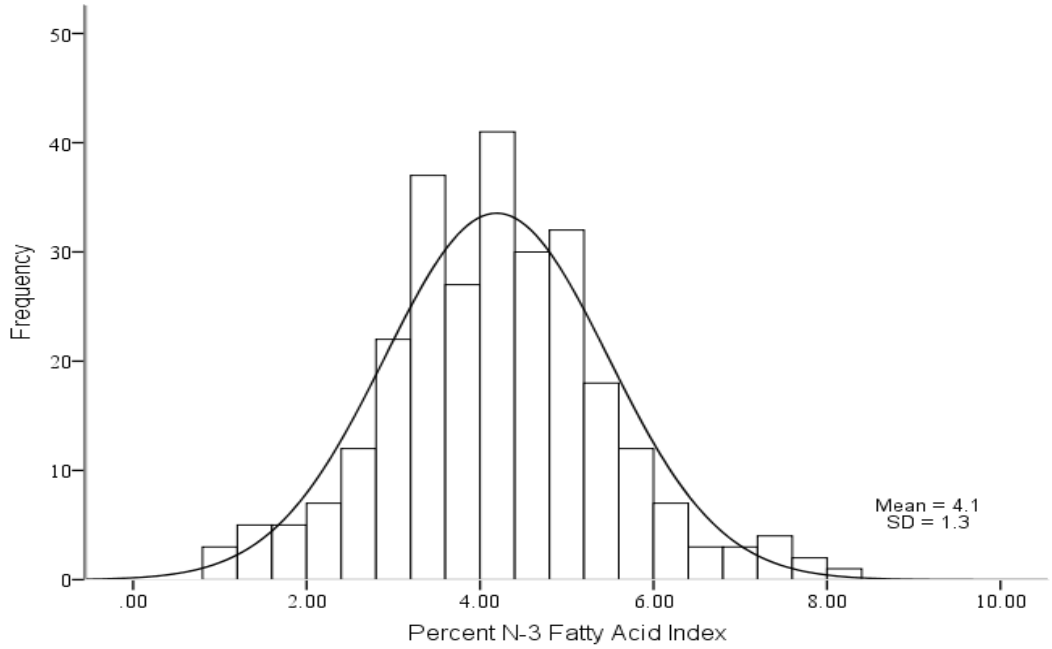

Figure 6-1: Baseline Percent N-3 Fatty Acid Index Distribution

After 12 weeks supplementation, compared with the controls, red blood cell n-3 fatty acid index increased by 27.2% and 39.2% in the oily fish and fish oil groups, respectively. The observed differential increase was a reflection of intake which was 150 to 200 mg/day n-3 long chain polyunsaturated fatty acids in the oily fish and 456 mg/day in the fish oil children. A pilot test conducted on a small number of children prior to the start of supplementation revealed the maximum amount of oily fish that they can consume in a single meal was 100 grams containing the aforementioned amount of n-3 long chain pufa. Although red blood cell n-3 fatty acid index of the children increased with both oily fish (6.03±1.39%) and fish oil (6.60±1.63%) supplementation it did not reach the cardioprotective high value target (≥8%) for adults proposed by Harris and von Schacky (2004). The reason for this is not evident; however, it could be the 12 week supplementation period was short, the 456 mg/day given to the children was insufficient or both. Consistent with our findings, Block and colleagues (2008) have reported 2/3 servings of oily fish a week, 2/3 standard fish oil capsules a day or 2 or more servings of oily fish a week plus standard fish oil capsules did not raise the level of red blood cell n-3 fatty acid index to ≥8%. The American Heart Association (AHA) guidelines have suggested adults need to consume 500 to 1000 mg of docosahexaenoic and eicosapentaenoic acids from oily fish to help reduce the risk of coronary heart disease (Harris and Von Schacky, 2004, Kris-Etherton

et al., 2002b). It is plausible children and adults may respond differently to n-3 fatty acid supplementation; however, from the current study, it appears the lower intake, 500 mg/day, suggested by AHA is unlikely to increase n-3 fatty acid index to the proposed optimal target (Harris and Von Schacky, 2004) in adults.

The fish oil group compared with their counterparts who received oily fish and with baseline had significantly lower levels of systolic (−9.1% and −5.1%) and diastolic (−10.3% and −5.8%) blood pressure and plasma triglycerides (−15.4% and −8.3%). Conversely, in contrast to previous findings (Julian-Almarcegui et al., 2016, Dallongeville et al., 2003), oily fish did not seem to have beneficial effects on any of the above blood parameters in the current study. A plausible explanation for the discrepancy might be that the dose of omega 3 fatty acids, 150 to 200 mg/day, given to the group was too low to have a discernible impact. There is a strong association between childhood and adulthood blood pressure (Chen and Wang, 2008, Magnussen and Smith, 2016); therefore, early supplementation of children with n-3 long chain polyunsaturated fatty acids might help to reduce the risk of development of essential hypertension later in life.

With the exception of palmitolic acid which was lower in the children who were given oily fish there was no difference in any of the other saturated and mono-unsaturated fatty acids between the three groups. This finding was not unexpected as the oily fish and fish oil supplement used in the study contained saturated and unsaturated fatty acids. N-3 fatty acid index correlated inversely with total saturated (Figure 6-2) and mono-unsaturated (Figure 6-3) fatty acids in the oily fish and fish oil groups. This perhaps to be expected since these fatty acids are displaced from membrane by both eiocosapentaenoic and docosahexaenoic acids (Walker et al., 2015, Ye et al., 2010).

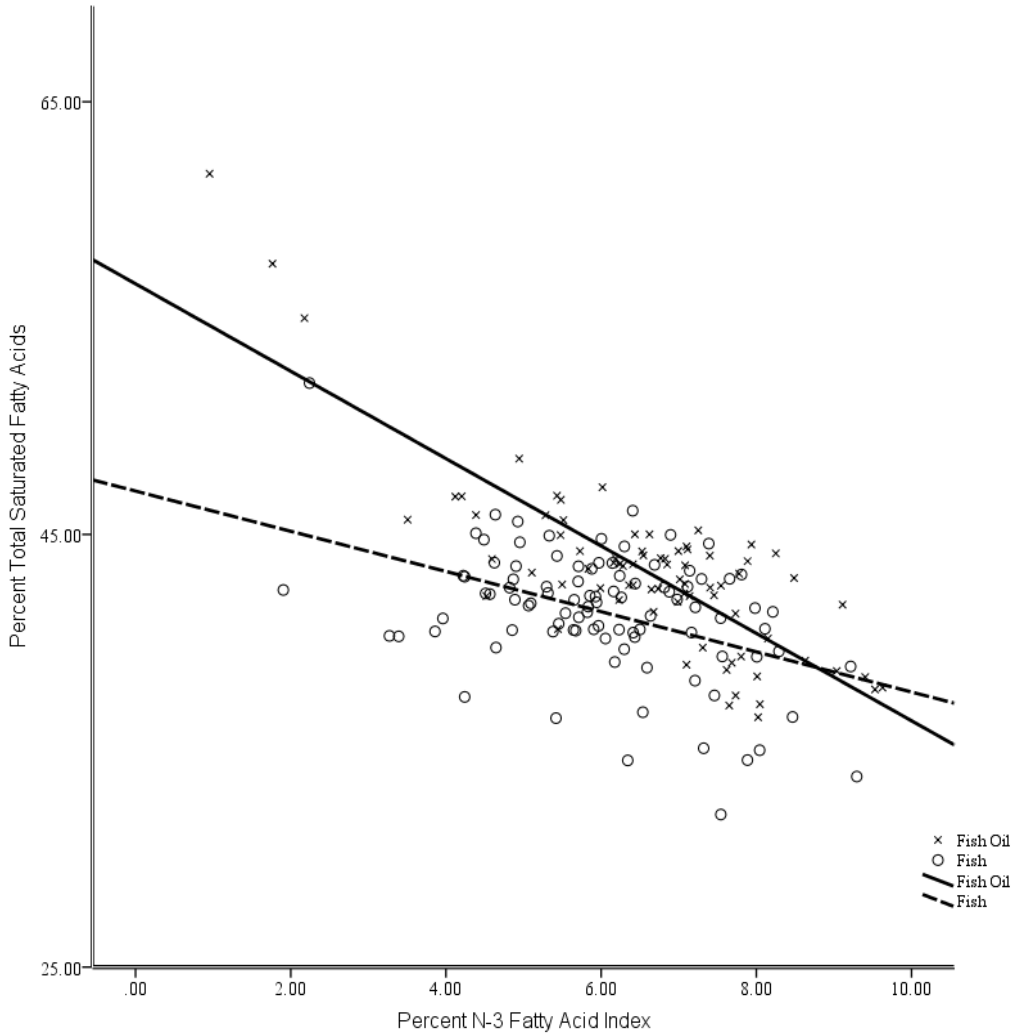

Figure 6-2: Post-intervention Relationship between Total Saturated Fatty Acids and N-3 Fatty Acid Index (Fish oil group r = - 0.816, p<0.0001; Fish group r = - 0.439, p<0.0001)

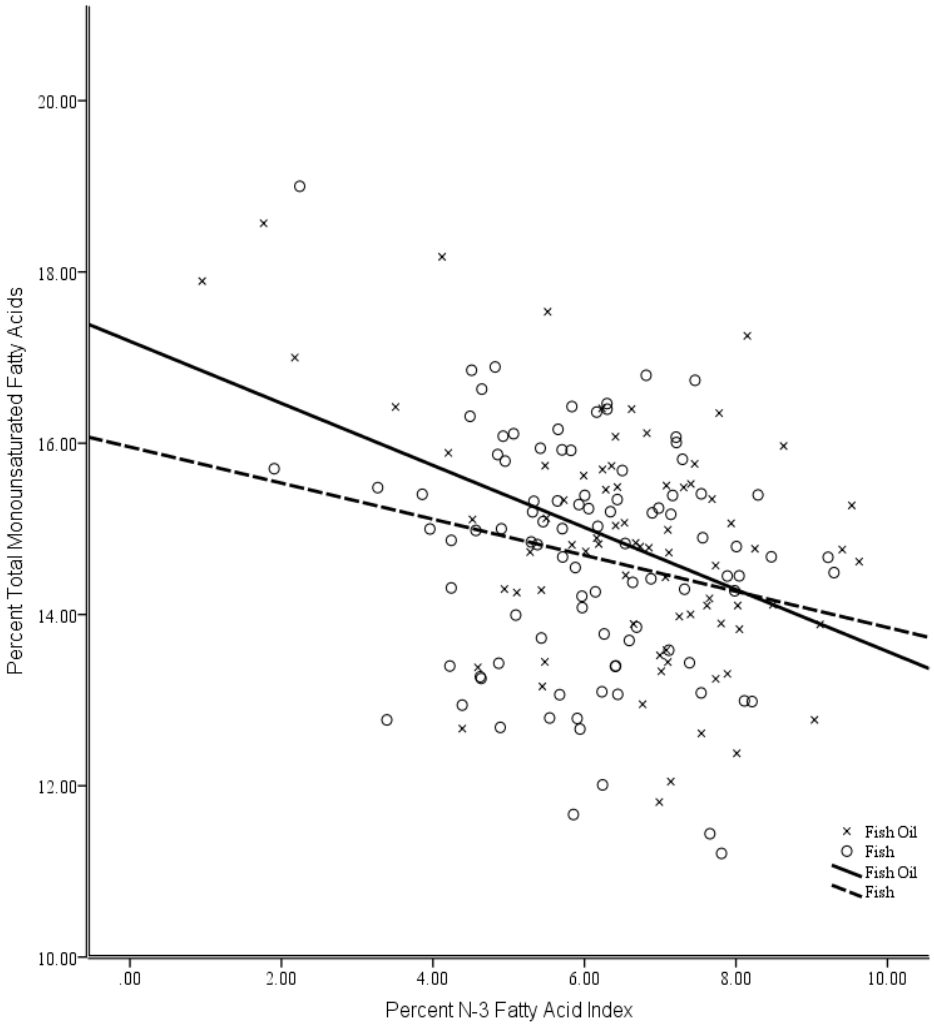

Figure 6-3: Post-intervention Relationship between Total Monounsaturated Fatty Acids and N-3 Fatty Acid Index (Fish Oil Group r = - 0.431, p<0.0001; Fish Group r = - 0.231, p <0.05)

In agreement with previous studies fish oil supplementation increased n-3 metabolites and n-3 fatty acid index and concomitantly reduced arachidonic (Walker et al., 2015, Simopoulos, 2002b, Metcalf et al., 2007, Rajamoorthi et al., 2005), dihomo gamma linolenic and n-6 docosatetraenoic acids. In contrast, oily fish did not decrease the level of the aforementioned n-6 fatty acids. Fish species from the warm-water of Gulf of Oman and Indian Ocean contain appreciable amounts of linoleic, dihomo gamma linolenic and arachidonic acids and this may have counterbalanced the n-6-reducing effect of docosahexaenoic and eicosapentaenoic acids. Paradoxically, although arachidonic, dihomo gamma linolenic acid and n-6 docosatetraenoic acids were displaced by fish oil supplementation, n-3 fatty acid index correlated positively with total n-6 fatty acids (Figure 6-4) and arachidonic acid (Figure 6-5). This finding corresponds with the result of our previous study which indicated significant direct relationships between docosahexaenoic and arachidonic acids in red cell phosphoglycerides of British and Korean pregnant women and their offspring at birth, cord blood (Ghebremeskel et al., 2000). Similarly, Payet and others have reported that the consumption of docosahexaenoic acid acid-enriched egg induces accretion of arachidonic acid in erythrocytes of elderly patients (Payet et al., 2004). Luxwolda et al. (2011) have found a bell curve relationship between erythrocyte n-3 fatty acid index and arachidonic acid level. It appears the incorporation of n-3 and n-5 long chain polyunsaturated fatty acids into cell membrane is highly regulated and the balance between the two fatty acid families is critical for orderly structural organisation and function of cellular and subcellular membranes. Indeed, there is evidence that the relative composition of the major fatty acid classes (SFA, MUFA and PUFA) in membrane lipids of all tissues is strongly regulated over very large variation in diet composition (Abbott et al., 2012).

Ethnic homogeneity, narrow age range and compliance monitoring by teachers were some of the strengths of the study. Learning ability and health-related behaviour of the children with the very low n-3 fatty acid index, and dietary fatty acid intake of the whole group because of the incompleteness of the food composition database were not assessed. In addition, in a sub-group of children, it would have been important to assess if a longer period of supplementation increases the level of n-3 fatty acid index. These limitations must be taken in account in future research.

This study provides evidence that Omani pre-adolescents have a low level n-3 fatty acid index that can be ameliorated by fish oil supplementation or consumption of oily fish. Epidemiological and intervention studies indicate these fatty acids are critical for visual and

neurological development and function, reduction of cardiovascular and inflammatory disease risk factors and healthy ageing. There is a need to tackle this problem through school feeding programme, targeted intervention with n-3 fatty acid enriched food products and/or family nutrition education programme.

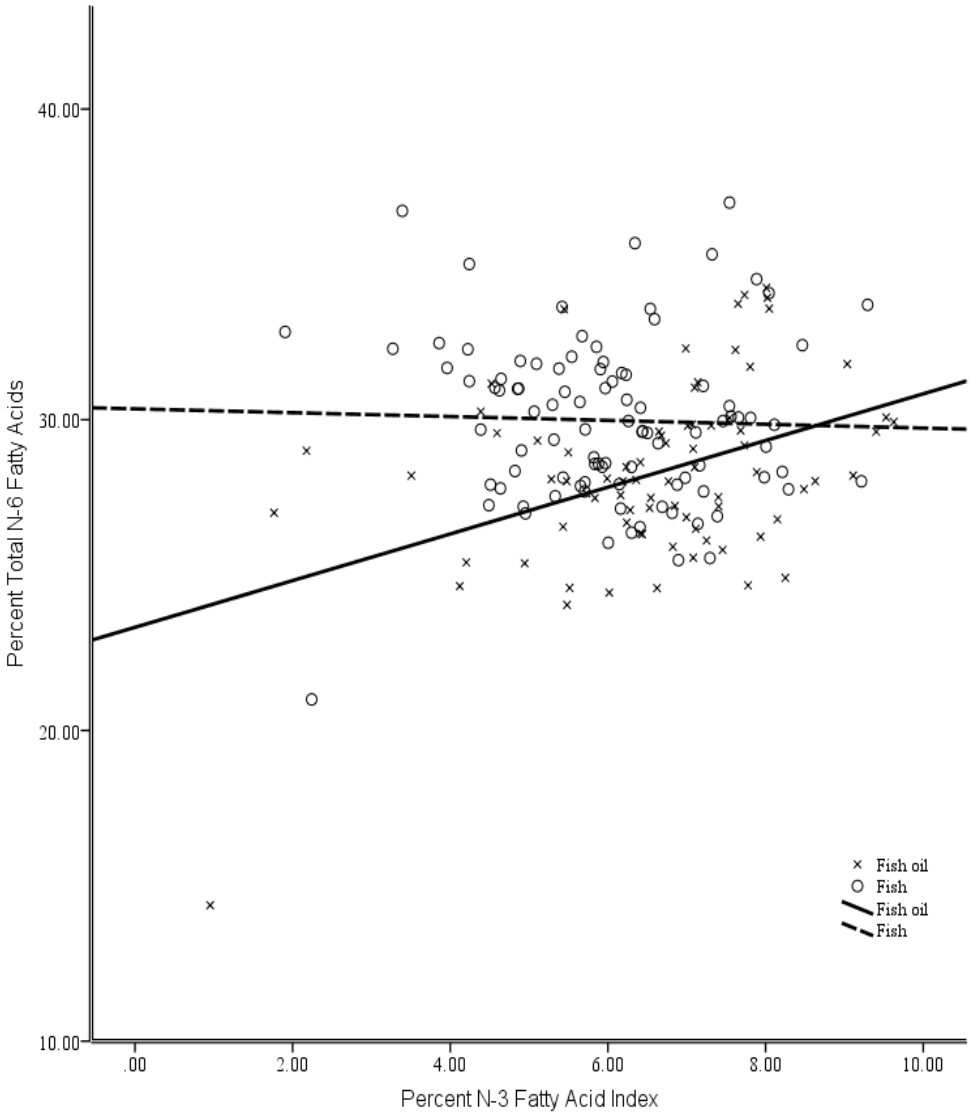

Figure 6-4: Post-intervention Relationship between Total N-6 Fatty Acids and N-3 Fatty Acid Index (Fish Oil Group r = 0.414, p<0.0001; Fish Group r = - 0.032, p>0.05)

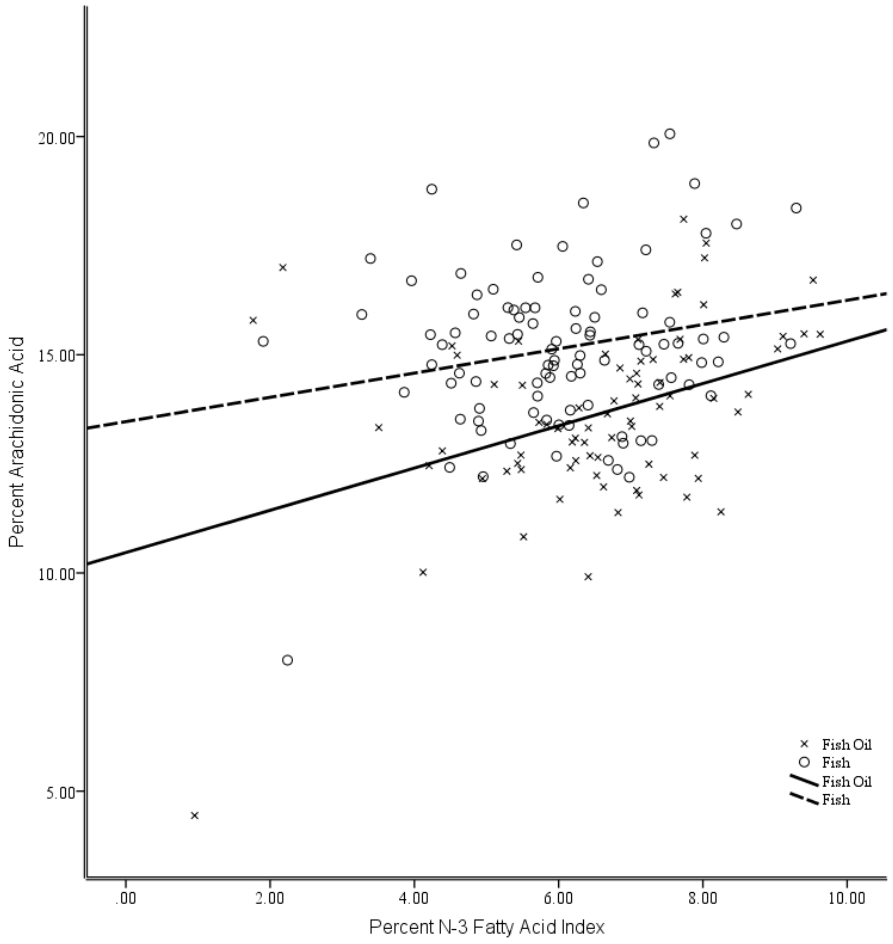

Figure 6-5: Post-intervention Relationship between Arachidonic Acid and N-3 Fatty Acid Index (Fish Oil Group r = 0.394, p<0.0001; Fish Group r = 0.213, p<0.05)

CHAPTER 7:
Overview and Future Research

7.1 Overview

Non-communicable diseases (NCDs) – cardiovascular diseases, diabetes, cancer and respiratory diseases – account for more than 60% of the global disease burden and mortality rate. In the Arabian countries, including Oman, over 50% of annual deaths are due to NCDs. Moreover, obesity, an antecedent of NCDs, has reached epidemic proportions in the region. Childhood NCDs are also on the rise globally: 1.2 million children and youth under the age 20 died of NCDs in 2002 (Mathers, 2009); more than 25% of obese adolescents have signs of diabetes by age 15 (Goran et al., 2003), which accounts for approximately 486,000 children under 15 years of age (Mathers (2009); and of the 497,100 children between 0-14 years found with Type 1 diabetes globally, approximately 64,000 of these are from the Middle East/North Africa region alone, with an additional 10,700 new cases each year.

In light of recent studies identifying the childhood antecedents of adult disease, various national and international committees on NCDs have recommended that children and young adults be the primary focus of any action plan aimed at preventing and controlling non-communicable diseases. Overweight and obesity is a key risk factor to be considered since it is related to other metabolic risk factors for the development of a CVD, such as raised blood pressure, raised blood sugar, raised blood lipids (cholesterol and triglycerides) and dyslipidaemia (National Heart Lung and Blood Institute, 2002, Grundy, 2004). As an individual's BMI increases, so does the risk for coronary heart disease, stroke and diabetes (World Health Organization, 2000).

There is growing evidence on the efficacy of omega-3 fatty acids in the fight against obesity, although in some ways the research is still limited. It has been found that obese individuals have lower ω-3 in their blood when compared to healthy, non-obese controls (Micallef et al., 2009), while Couet et al. (1997) have found that a fish oil diet corresponded to a 0.88 kg reduction of body fat when compared to a control diet. Epidemiological studies have also shown that fish consumption within a healthy eating pattern is associated with lower body weight (Shubair et al., 2005, Schulze et al., 2006). However, less is known about the health impact of fish consumption and fish oil supplementation, when paired with physical activity, on the nutritional status of school children, body composition, blood biochemistry and mental and physical abilities. Dietary intervention studies which that include fish and fish oil in a weight loss diet are also limited (Mori et al., 1999, Thorsdottir et al., 2009).

This research study sought to assess:

1. The nutritional status, body composition, blood biochemistry, mental ability and cognitive function in Omani children aged 9 and 10 years, and
2. The effect of fish consumption, and supplementation with fish oil, on body composition, blood biochemistry, mental ability and cognitive function of these children.

7.2 Conclusion

7.2.1 Study 1 (Chapter 3: dietary analysis)

Both boys and girls in the study sample fell below the DRI for total calories, fat, sugar, and omega-3 and omega-6 fatty acids, while exceeding the DRI for proteins and carbohydrates. The most severe deficiency was found in relation to omega-3 fatty acids: compared to the DRI of 208-207 kcal/day, the students' average consumption level was only 4.2 kcal/day. There was also a significant difference between boys and girls on this measure, with boys consuming 4.8 kcal/day as compared to girls consuming 3.9 kcal.day ($p=0.012$).

In terms of micronutrients, the students' diets were found to be most deficient in calcium and potassium, their daily consumption levels on these micronutrients less than half of the daily recommended intake. While the mean DRI for calcium was 1300 mg/day, the student average was only 465 mg/day; and while the mean DRI for potassium 4500 mg/day, the student average was only 2068 mg/day. The students' consumption of phosphorus, Vitamin A and Vitamin D were also found to fall short of the DRI levels, although to a lesser degree.

The mean body fat and TGS measures were significantly higher among girls as compared to boys, while muscle mass, omega-3 and omega-6, and fasting glucose levels were significantly higher in boys. Our study also found that higher calorie and protein intake was significantly associated with overweight or obesity, which was 28.2% and 22.6% in boys and girls, respectively. These rates are comparable to other countries in the Gulf region and significantly lower than in more developed countries, although there is evidence that these rates are on the rise.

7.2.2 Study 2 (Chapter 4: cognitive assessment)

While the global prevalence of ADHD is estimated to be between 5% to 13% (Faraone et al., 2003), there are few studies that involve Arabian Gulf populations. Anecdotal evidence

suggests that children in the region are not immune, which is confirms by our study which identifies the prevalence rate of PIS, PHIS and ADHD among Omani school children as 7.3% (95% CI: 4.5%, 10.1 %), 3% (1.2, 4.8%) and 8.8% (5.7%, 11.8%), respectively. To our knowledge, this is the first study with a robust methodology to identify the prevalence rate of ADHD among school children in Oman. Compared to other studies, the inclusion of the different ADHD subtypes provides a more complete spectrum of the relevant symptomatology associated with ADHD.

The second goal of this study was to examine the possible role of parental factors (such as sex, educational level, occupation, income and consanguinity) in the development of ADHD, which would provide a vital foundation for devising preventive measures and relevant health educational programs. Statistical analyses indicate that the most significant factors were: reduced family income and non-government jobs were most strongly associated with an increased risk: specifically, family income for PHIS (p=.019) and father's employment sector for ADHDCIH (p=.012). Childhood symptoms of PHIS were also significantly correlated with mother's occupations outside the home (p=.038).

7.2.3 Study 3 (Chapter 5: fat soluble vitamins)

This study demonstrated that vitamin D insufficiency is highly prevalent among Omani school children , they were severely deficient (<27.5 nmol/L; 10.5% boys and 28.5% girls), deficient (27.5- 44.9 nmol/L; 47.6% boys and 49.4% girls) or insufficient (50 – 74.9 nmol/L; 34.6% boys and 21.5% girls) in vitamin , and the effectiveness of omega-3 fatty acid supplementation in counteracting this. The high prevalence of vitamin D deficiency in the children should be a major public health concern because childhood is a period of skeletal mineral acquisition and bone modelling and there is evidence that vitamin D plays a critical role in muscle growth and development, cognitive function and modulation of innate and adaptive immunity.

Compared with the control group, both boys and girls who were given fish meals or fish oil supplement for twelve weeks had increased concentrations of beta carotene and vitamin D (p<0.001). Post-intervention plasma vitamin D and parathyroid hormone concentrations compared with pre-intervention (baseline) were higher in the children who received fish oil and fish meals (p<0.0001). The concentration of plasma beta carotene also increased significantly in the fish diet and fish oil groups after intervention for 12 weeks.

If the prevalence rates reported here reflect trends in the larger population, Omani children may be at risk of developmental and health problems caused by vitamin D deficiency. As such, there is an urgent need for a fortification programme that targets the foods and drinks favoured by children and outdoor activities to help tackle this public health problem.

7.2.4 Study 4 (Chapter 6: red blood fatty acids status)

The spread of contemporary Western pattern diets during the past four decades have played a critical role in the rise of non-communicable chronic diseases. Such diets are typically high in the protein and fat of intensively reared land animals, refined sugar, vegetable fat and oils, and low fresh fruits and vegetables and marine foods. The negative health effects of this dietary pattern is associated with an excessive amount of saturated, trans and omega 6 fatty acids, paired with an insufficient omega 3 fatty acid and essential micro-nutrient content. This study investigated fatty acid status of preadolescence school children before and after intervention with fish oil or oily fish to assess the efficacy of such a diet in counteracting nutritional deficiencies. The primary focus was the n-3 long chain polyunsaturated fatty acids which are thought to limit nutrient assimilation in Westernised dietary patterns.

The mean baseline red cell n-3 fatty acid index of the children was low, comparable to other populations of similarly aged and healthy children reared on a Westernized diet. This suggests that traditional dietary patterns - including the consumption of fish - may have declined in favour of the more widely available processed foods which are high in saturated and n-6 fatty acids. Most surprising was the very low n-3 fatty acid index (<2%).

After 12 weeks supplementation, compared with the controls, the red blood cell n-3 fatty acid index increased by 27.2% and 39.2% in the oily fish and fish oil groups, respectively. The fish oil group compared with their counterparts who received oily fish and with baseline had significantly lower levels of systolic and diastolic blood pressure and plasma triglycerides. In contrast, oily fish did not seem to have beneficial effects on any of the above blood parameters in the current study.

7.3 Limitations of the study

This study has provided valuable information about the effect of a DHA-rich fish diet and oil supplements on plasma fatty acid and fat soluble vitamins in healthy school children. While this study has yielded previously unavailable data, there are a number of limitations

that need to be taken into account, particularly for the design and interpretation of studies that seek to extend the research undertaken here. The intervention period, 12 weeks, was relatively short, and the amount of DHA was not equalised across treatment groups (fish diet vs. fish oil supplementation). Students were recruited only from the capital area of Oman, limiting the generalisability of the study findings. In addition, we were unable to collect important information about the students' nutritional intake, despite efforts to gather these data about the children's habitual diet using 24-hour recall. This was due, in large part, to the study's reliance of parental reports, and the tendency to either over- or under-estimate the intake of certain foods by their children.

Additionally, this study's reliance the Vanderbilt Scales for measuring the cognitive and behavioural functioning of students is another area that could be improved, particularly since they have not been standardised for use with an Omani population. The development of a reliable and valid version of these Scales that is translated into Arabic would greatly improve our confidence in the measure, particularly if this process of standardisation is carried out with an eye toward the cultural specificities relevant to the Omani school population.

7.4 Future investigations

The original data generated from the current investigation has provided valuable insights into the dietary habits and nutritional status of pre-adolescent children from the greater metropolitan area of Muscat. However, these findings cannot be legitimately extrapolated to adolescents and young adults, pregnant women or even to preadolescent children who reside in small towns and rural regions of the country where fast food outlets, convenience stores and supermarkets are fewer and less accessible. Therefore, further studies are required to identify the extent of the westernisation of Omani dietary habits and its impact on the nutritional status of the aforementioned population groups with a particular focus on essential nutrients such as n-3 (omega 3) fatty acids and the fat-soluble vitamins A, D and E.

Thus, one line of extending the current study would address this issue of sampling (with an eye towards generalisability), while others would broaden the population in question (beyond a focus only on pre-adolescent children):

- Dietary intake, body composition, circulating blood lipids and red blood cell fatty acid profile of preadolescent and adolescent children and young adults living in the fishing towns of Sur and Quriyat, Sultanate of Oman.

- Dietary intake, body composition, circulating blood lipids and red blood cell fatty acid profile of adolescents and young adults who reside in the greater metropolitan area of Muscat, Sultanate of Oman.

Additional attention can be given to the role of maternal nutrition and health for the questions investigated in this study:

- Red blood cell omega 3 fatty acid index of Omani pregnant women and their neonates at birth, and their implications for maternal health and foetal neuro-visual development and health.

- Comparative study of breast milk fatty acid composition of Omani mothers from the fishing towns of Sur and Quriyat, and the greater metropolitan area of Muscat.

Finally, the pencil-and-paper measures of cognitive and behavioural functioning, can be supplemented by other, objective measures of physical functioning:

- Combine the current use of cognitive and behavioural measures (the Vanderbilt Scales) in conjunction with functional brain scan imaging, such as PET, fMRI, and related in-vivo neuro-imaging data.

APPENDIX 1:
Published Abstracts

Low dose omega 3 fatty acids reduce fat mass and systolic blood pressure in school children

Al-Ghannami SS[1, 3], Sedlak E[1], Hussein IS[1], Min Y[1], Al-Shmmkhi SM[3], Al-Oufi HS[2], Al Al-Mazroui A[2], Ghebremeskel K[1]

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[2] Ministry of Agriculture and Fisheries Wealth, Muscat, Sultanate of Oman
[3] Ministry of Health, Muscat, Sultanate of Oman

BACKGROUND: Several investigations provide evidence that high and moderate intakes of long chain omega 3 polyunsaturated fatty acids (LCPUFA) reduce systolic and diastolic blood pressure, particularly in hypertensive adults. However, it is not fully elucidated whether or not these fatty acids have such effects in healthy children.
OBJECTIVE: To investigate the effect of a low dose omega 3 LCPUFA on body composition and systolic and diastolic blood pressure in school children.
METHOD: Eighty six Omani School children, aged 9 and 10 years, were given one omega 3 fatty acid capsule containing 403 mg DHA and 53 mg EPA, four days a week, for twelve weeks. Red blood cell fatty acids, body composition and blood pressure were measured at baseline and at the end of the supplementation period.
RESULTS: The children had higher DHA (6.2±1.5 vs. 3.8±1.5, $p<0.0001$), body weight and fat-free mass ($p<0.001$) and lower body mass index (16.4±3.1 vs. 16.6±3.2, $p<0.01$), body fat ($p<0.05$) and systolic blood pressure ($p<0.001$) after twelve weeks of intervention with omega 3 fatty acids compared with baseline. There was no difference in diastolic blood pressure between the two time points ($p>0.05$).
CONCLUSION: The findings of this small study suggest that omega 3 LCPUFA might play a role in reducing fat mass and latent high blood pressure in obese children.

Declaration of Interest: the authors have no relevant interest to declare

The effect of omega 3 fatty acid supplementation on plasma vitamin D status of school children

Al-Ghannami SS[1,3], Sedlak E[1], Hussein IS[1], Min Y[1], Al-Shammakhi SM[3], Al-Oufi HS[2], Al-Mazroui A[2], Ghebremeskel K[1]

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Background: Cell culture, animal and human studies suggest that omega 3 fatty acids, particularly docosahexaenoic, have beneficial effects on bone metabolism. However, although there are several postulations, the mechanisms through which these fatty acids influence bone structure and composition are yet to be fully elucidated.
Objective: To investigate the effect of long-chain omega 3 polyunsaturated fatty acid (omega 3 LCPUFA) supplementation on plasma 25 hydroxy vitamin D (25(OH)D) level of children.
Procedure: Omani children, aged 9 and 10 years, from two randomly selected schools in Muscat were assigned to either omega 3 LCPUFA (n=86) or control (n=120) group. The former group received one omega 3 fatty acid capsule containing
403 mg DHA and 53 mg EPA four days a week for twelve weeks. The control group, who continued on their habitual diet, did not receive any supplement. Red blood cell fatty acid, plasma 25(OH)D, parathyroid hormone and calcium levels were assessed at the end of the intervention period.
Results: The omega 3 LCPUFA group compared with their control counterparts had higher levels of red cell EPA (0.34±0.12 vs. 0.25±0.14%, $p<0.0001$), DHA (6.2±1.5 vs. 4.4±1.5%, $p<0.0001$), 25(OH)D (54.1±17.5 vs. 42.4±17.3 nmol/L, $p<0.0001$). There was no difference in parathyroid hormone (5.79±2.1 vs 5.78±2.0 pmol/L, $p>0.05$) and calcium (2.46±0.09 vs. 2.52±0.07 mmol/L, $p>0.05$) concentrations.

Conclusion: DHA-rich omegas 3 LCPUFA enhance plasma vitamin D level in children. This may be one of the mechanisms by which these fatty acids influence bone mineralisation and structure.

Acknowledgements: Sincere thanks are due to the children, parents and their teachers, the Ministry of Agriculture and Fisheries Wealth, Sultanate of Oman, for financial support and Efamol Ltd. UK for providing the omega 3 fatty acid supplements.

Declaration of Interest: the authors have no relevant interest to declare

Short term supplementation of fish and fish oil improves cognitive ability in children attending school in Muscat Oman

BACKGROUND: Consumption of fish in the regular diet is highly recommended globally for its benefit for all and especially for children. Current study was aimed at assessing the effect of short term consumption (4 months) of fish meals feeding on cognitive ability among children attending the schools in Muscat governorate, Sultanate of Oman
METHODS: 66 Omani School children, aged 9 and 10 years, from Muscat, were given a 150 -200 g fish meal in four times a week for 16 weeks. The fish species were Grouper, Sea bream, Kingfish, Emperor, and Snapper. We have analysed the body composition and mental ability (trial making test and verbal fluency) before and after supplementation of fish. Data (Mean ±S.D) were analyzed using the SPSS version 15 and $p \leq 0.05$ was considered as significant. .
RESULTS: Verbal fluency was significantly increased ($p \leq 0.001$). Girls showed better performance than boys in number of words generated per minute. The performance of both boys and girls were significantly improved in trail making test and when compared with boys, girls performed.
CONCLUSION: Our study results suggest that supplementation of fish for four months enhanced the children's cognitive ability of those are attending schools in Muscat, Sultanate of Oman. Further studies are warranted to find out the effect of fish in biochemical parameters on these children.

Acknowledgements: Support provided by Ministry of Agriculture and Fisheries Wealth, Ministry of Education, Ministry of Health, Sultan Qaboos University Oman and London Metropolitan University, UK were gratefully acknowledged.

Key words: Fish, Fish oil, Verbal fluency test, trail making test, Oman

The effect of fish consumption, fish oil supplementation on iodine, vitamin A and D deficiency

BACKGROUND: It has long been recognized that fish, seafood and marine products are valuable foods. Fish and seafood are low in saturated fat and a good source of protein, iodine, iron, vitamin D , selenium and other trace elements as well as long-chain omega-3 polyunsaturated fatty acids.

OBJECTIVES: To examine the impact of fish and fish oil intake on iodine, vitamin D, and A we have studied a total of three hundred fifty four (n=354) school children of 9-10 years old (4 grade) from three schools in Muscat Governorate in Oman. The children were randomly divided in to fish, fish oil capsule and control groups. The fish group (n=118) received fish menu lunch 4 times a week. The fish oil capsule group (n=118) were given fish oil capsules the third group (n=118) will not receive fish or fish oil capsules. The intervention period was sixteen weeks (four months). The study aimed to assess urinary iodine concentration: a significant number of the children had low levels of vitamin D, iodine and omega 3 fatty acids.

RESULTS: The study revealed that a significant number of the children had low levels of vitamin D, iodine and omega 3 fatty acids. The low levels of vitamin D, iodine and omega-3 fatty acids were ameliorated to a variable degree by fish consumption as well as supplementation with fish oil.

Authors:

Presenter poster : Izzeldin Hussein

Dr Samia Al Ghnamia , Dr Izzeldin Hussein, Dr Kebreab Ghebremeskel

MOH OMAN- London metropolitan

APPENDIX 2:
Methods Materials

NICHQ Vanderbilt Assessment Scale—TEACHER Informant

Teacher's Name: _____ Class Time: _____ Class Name/Period: _____

Today's Date: _____ Child's Name: _____ Grade Level: _____

Directions: **Each rating should be considered in the context of what is appropriate for the age of the child you are rating and should reflect that child's behavior since the beginning of the school year. Please indicate the number of weeks or months you have been able to evaluate the behaviors: _____.**

Is this evaluation based on a time when the child ☐ **was on medication** ☐ **was not on medication** ☐ **not sure?**

Symptoms	Never	Occasionally	Often	Very Often
1. Fails to give attention to details or makes careless mistakes in schoolwork	0	1	2	3
2. Has difficulty sustaining attention to tasks or activities	0	1	2	3
3. Does not seem to listen when spoken to directly	0	1	2	3
4. Does not follow through on instructions and fails to finish schoolwork (not due to oppositional behavior or failure to understand)	0	1	2	3
5. Has difficulty organizing tasks and activities	0	1	2	3
6. Avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort	0	1	2	3
7. Loses things necessary for tasks or activities (school assignments, pencils, or books)	0	1	2	3
8. Is easily distracted by extraneous stimuli	0	1	2	3
9. Is forgetful in daily activities	0	1	2	3
10. Fidgets with hands or feet or squirms in seat	0	1	2	3
11. Leaves seat in classroom or in other situations in which remaining seated is expected	0	1	2	3
12. Runs about or climbs excessively in situations in which remaining seated is expected	0	1	2	3
13. Has difficulty playing or engaging in leisure activities quietly	0	1	2	3
14. Is "on the go" or often acts as if "driven by a motor"	0	1	2	3
15. Talks excessively	0	1	2	3
16. Blurts out answers before questions have been completed	0	1	2	3
17. Has difficulty waiting in line	0	1	2	3
18. Interrupts or intrudes on others (eg, butts into conversations/games)	0	1	2	3
19. Loses temper	0	1	2	3
20. Actively defies or refuses to comply with adult's requests or rules	0	1	2	3
21. Is angry or resentful	0	1	2	3
22. Is spiteful and vindictive	0	1	2	3
23. Bullies, threatens, or intimidates others	0	1	2	3
24. Initiates physical fights	0	1	2	3
25. Lies to obtain goods for favors or to avoid obligations (eg, "cons" others)	0	1	2	3
26. Is physically cruel to people	0	1	2	3
27. Has stolen items of nontrivial value	0	1	2	3
28. Deliberately destroys others' property	0	1	2	3
29. Is fearful, anxious, or worried	0	1	2	3
30. Is self-conscious or easily embarrassed	0	1	2	3
31. Is afraid to try new things for fear of making mistakes	0	1	2	3

Adapted from the Vanderbilt Rating Scales developed by Mark L. Wolraich, MD.

Revised - 1102

NICHQ Vanderbilt Assessment Scale—TEACHER Informant

Teacher's Name: _____ Class Time: _____ Class Name/Period: _____

Today's Date: _____ Child's Name: _____ Grade Level: _____

Symptoms (continued)	Never	Occasionally	Often	Very Often
32. Feels worthless or inferior	0	1	2	3
33. Blames self for problems; feels guilty	0	1	2	3
34. Feels lonely, unwanted, or unloved; complains that "no one loves him or her"	0	1	2	3
35. Is sad, unhappy, or depressed	0	1	2	3

Performance *Academic Performance*	Excellent	Above Average	Average	Somewhat of a Problem	Problematic
36. Reading	1	2	3	4	5
37. Mathematics	1	2	3	4	5
38. Written expression	1	2	3	4	5

Classroom Behavioral Performance	Excellent	Above Average	Average	Somewhat of a Problem	Problematic
39. Relationship with peers	1	2	3	4	5
40. Following directions	1	2	3	4	5
41. Disrupting class	1	2	3	4	5
42. Assignment completion	1	2	3	4	5
43. Organizational skills	1	2	3	4	5

Comments:

Please return this form to: _____

Mailing address: _____

_____

Fax number: _____

For Office Use Only

Total number of questions scored 2 or 3 in questions 1–9: _____

Total number of questions scored 2 or 3 in questions 10–18: _____

Total Symptom Score for questions 1–18: _____

Total number of questions scored 2 or 3 in questions 19–28: _____

Total number of questions scored 2 or 3 in questions 29–35: _____

Total number of questions scored 4 or 5 in questions 36–43: _____

Average Performance Score: _____

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McNeil Consumer & Specialty Pharmaceuticals

D4 مقياس فاندربيت للتقييم- معلومات المعلمين

اسم المعلم: _____

وقت الحصة : _____

اسم الفصل الدراسي / مدته: _____

تاريخ اليوم : _____

اسم الطفل : _____

الصف : _____

تعليمات : عند التقييم ، يجب مراعاة ما يناسب عمر الطفل الذي سيُشخص عند كل عبارة من العبارات التالية ، و كذلك يجب أن يعكس سلوك الطفل من آخر استمارة تقييم تم تعبئتها. يرجى ذكر عدد الأسابيع أو الشهور التي تمكنت فيها من تقييم السلوكيات : _____. ضع دائرة حول رقم واحد فقط من الأرقام الموجودة بجانب كل عبارة ، و الذي تراه يناسب التلميذ ، مع ملاحظة أنه يجب الإجابة على كل العبارات باختيار رقم واحد فقط

هل أُجري هذا التقييم في وقت كان فيه الطفل

☐ **يتناول جرعات دوائية** ☐ **لا يتناول جرعات دوائية** ☐ **لست متأكداً**

	الأعراض	أبداً	إحيانا	معظم الأحيان	طوال الوقت
.1	لا ينتبه لتفاصيل الأمور ويرتكب أخطاء نائجة عن الإهمال، مثل الواجبات المدرسية.	0	1	2	3
.2	يجد صعوبة في التركيز المستمر على المهام والأنشطة.	0	1	2	3
.3	يبدو وكأنه لا يصغي حين يوجه له الكلام مباشرة .	0	1	2	3
.4	لا يتبع التعليمات و يفشل في إتمام الأعمال المدرسية، (ليس بسبب الرفض أو عدم الفهم).	0	1	2	3
.5	يصعب عليه ترتيب المهام والأنشطة، مثل ترتيب دُرجه و طاولته في الفصل.	0	1	2	3
.6	يتجنب ، يكره أو لا يرغب في بدء الأنشطة التي تتطلب منه التركيز الذهني المستمر مثل حل مسألة حسابية في الفصل.	0	1	2	3
.7	يفقد الأدوات و الأشياء اللازمة لإنجاز المهام أو الأنشطة مثل الواجبات المدرسية ، الأقلام ، أو الكتب).	0	1	2	3
.8	يتشتت انتباهه بسهوله مع المثيرات الخارجية				
.9	ينسى نشاطاته اليومية ، مثل إحضار الواجب معه إلى المدرسة.	0	1	2	3
.10	يُعبّر عن مله بيديه أو قدميه أو يتحرك كثيرا على الكرسي.	0	1	2	3
.11	يغادر مقعده في الصف أو في أي مكان يستلزم منه البقاء فيه.	0	1	2	3
.12	يركض أو يتسلق كثيراً عندما يتطلب منه الجلوس في مقعده.	0	1	2	3
.13	لديه صعوبة في المشاركة في الألعاب التي تتطلب الهدوء.	0	1	2	3
.14	دائم الحركة و كأنه يعمل بمحرك.	0	1	2	3
.15	يتكلم بكثرة.	0	1	2	3
.16	يتسرع بالإجابة قبل إتمام المعلم للسؤال.	0	1	2	3
.17	يصعب عليه أن ينتظر دوره.	0	1	2	3
.18	يقطع محادثات الآخرين أو يتطفل على أنشطتهم .	0	1	2	3
.19	يفقد أعصابه (يصبح عصبي لأسباب تافهة).	0	1	2	3
.20	يرفض الانصياع لطلبات أو قوانين الكبار.	0	1	2	3

Always means always
Never means does not occur at all
Sometimes = 1-2 times per day
Often = 4 times and above

D4 مقياس فاندربيلت للتقييم- معلومات المعلمين، تابع

تابع الأعراض		أبداً	أحياناً	معظم الأحيان	طوال الوقت
.21	دائماً غاضب أو مستاء.	0	1	2	3
.22	حقود و يميل إلى الانتقام.	0	1	2	3
.23	يقسو ، يهدد ، أو يخيف الآخرين.	0	1	2	3
.24	يبدأ المشاجرات الجسدية .	0	1	2	3
.25	يكذب ليحصل على مكافأة أو ليتجنب أي عقوبات، مثلاً يحتال على الآخرين.	0	1	2	3
.26	عنيف جسدياً مع الآخرين.	0	1	2	3
.27	سبق له أن سرق أشياء قيّمة.	0	1	2	3
.28	يتعمد تخريب ممتلكات الغير.	0	1	2	3
.29	يشعر بالخوف و الاضطراب و القلق.	0	1	2	3
.30	خجول و يسهل إحراجه.	0	1	2	3
.31	يخاف من تجربة أشياء جديدة خشية ارتكاب الأخطاء.	0	1	2	3
.32	يشعر بعدم (دنو) قيمته أو أنه أقل منزلة من الآخرين	0	1	2	3
.33	يلوم نفسه على المشاكل و دائماً يشعر بالذنب.	0	1	2	3
.34	يشعر بالوحدة وبأنه غير مرغوب أو غير محبوب و يشكو من "أن لا أحد يحبه".	0	1	2	3
.35	يشعر بالحزن و التعاسة أو الإحباط.	0	1	2	3

الأداء الأكاديمي		ممتاز	جيد جداً	متوسط	يعاني من بعض الصعوبة	يعاني من صعوبة شديدة
.36	القراءة	1	2	3	4	5
.37	الرياضيات	1	2	3	4	5
.38	التعبير كتابة	1	2	3	4	5

الأداء السلوكي في الفصل		ممتاز	جيد جداً	متوسط	يعاني من بعض الصعوبة	يعاني من صعوبة شديدة
.39	علاقته بأقرانه	1	2	3	4	5
.40	اتباع التعليمات	1	2	3	4	5
.41	عرقلة الحصة	1	2	3	4	5
.42	انجاز المهام	1	2	3	4	5
.43	مهارات التنظيم	1	2	3	4	5

للاستخدام المكتبي فقط :

عدد الأسئلة من 1- 9 التي احرزت 2 أو 3: _____

عدد الأسئلة من 10- 18 التي أحرزت 2 أو 3: _____

إجمالي النقاط التي أُحرزت في أسئلة الأعراض من 1-18: _____

عدد الأسئلة من 19- 26 التي احرزت 2 أو 3: _____

عدد الأسئلة من 27- 40 التي احرزت 2 أو 3: _____

عدد الأسئلة من 41- 47 التي احرزت 2 أو 3: _____

عدد الأسئلة من 48- 55 التي احرزت 2 أو 3: _____

متوسط نتيجة الأداء: _____

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DIVISION OF ORTHO-MCNEIL-JANSSEN PHARMACEUTICALS, INC.

APPENDIX 3:

Consent Forms & Questionnaires

(FORM 5.3)

Sultanate of Oman

(Fish Group)

Ministry of Health- /Department of Studies & Research

Research and Ethical Review & Approve Committee

Certificate of Informed Consent

Consent form of participating in the project: The impact of eating fish and fish oil on fatty acids (Omega-3), and perception of school students in the governorate of Muscat

Project goal:

Researchers have suggested that there is a close relationship between eating fish, especially rich in Omega-3 fatty acids and health in general. There is little knowledge about the potential impact of eating fish and health in the Sultanate of Oman. the goal of this project was to study the effect of local Omani fish consumption and seafood on the health and also on the level of perception, especially among school children.

The study will be conducted on 354 students in the age group 9-10 years (Grade 4) in three schools in Muscat governorate. Students will be distributed randomly into three groups, where one of them will consume fish and the other fish oil capsules while the third group remains neutral. Your son or daughter has been selected randomly to be in fish group and will be providing a fish meal for them 4 times a week for 4 months.
Their body composition, food intake will be evaluated by food frequency questionnaires, complete blood picture, blood lipids and iodine concentration in the urine through the use of established protocols. The school performance and attention will also be evaluating to both male / female student. All evaluations will be conducted at the beginning of the intervention and when it is completed.

How you can help?
Assent to join us where research will include:

Interview: We would like to ask some questions that will help us to fill the questionnaire; 24 hour reall questionnaire will be used to assess your child dietary intake.

Cognitive assessment: a questionnaire will be given to you about your child cognitive behavior, and another one will be filled by the class teacher.
Physical measurements: such as height, weight and measure the body fat percentage.

Physical fitness: a team from London will assess your child physical activity

All of this will be done at school

Other clinical tests will be taken at the health centre:

Laboratory tests: such as a blood test, urine test, sample will be taken by taking into account safety and hygiene measures.

We will send part of a sample of blood to the London Metropolitan University in Britain for analysis of fatty acids and antioxidant vitamins under the approval of the Research Ethics Committee, which were obtained from a national committee in the UK health service.

Personal data will be dealing in the strictest confidence and will not be used for any other purpose and not be transferred to others without the written consent of the parents of the students. All the data collected from this study will store in a password-protected computer and access will be limited to researchers.

Please note this study will be conducted under full compliance with the principles of data protection law. You are free to withdraw from the study at any time without giving any reason.

Is there any benefit derived for others?
This study will help us to assess the relationship between dietary sources of fatty acids and its potential health and the level of awareness among school students.

What if you do not want to share my son / daughter in the project?
This would not constitute any difference in our dealings with you; you will always get the best deal possible.

Recognition

I certify that I have read and understood the information pertaining to study above. I understand that my participation is voluntary and that I have absolute freedom to withdraw at any time without affecting me or my son / daughter.

I agree to participate in the study

Participant's name		**Date**		**Signature**	
Researcher's name		**Date**		**Signature**	

(FORM 5.3)

Sultanate of Oman

(Omega-3 capsules Group)

Ministry of Health- / Department of Studies & Research

Research and Ethical Review & Approve Committee

Certificate of Informed Consent

Consent form of participating in the project: The impact of eating fish and fish oil on fatty acids (Omega-3), and perception of school students in the governorate of Muscat

Project goal:

Researchers have suggested that there is a close relationship between eating fish, especially rich in Omega-3 fatty acids and health in general. There is little knowledge about the potential impact of eating fish and health in the Sultanate of Oman. the goal of this project was to study the effect of local Omani fish consumption and seafood on the health and also on the level of perception, especially among school children.

The study will be conducted on 354 students in the age group 9-10 years (Grade 4) in three schools in Muscat governorate. Students will be distributed randomly into three groups, where one of them will consume fish and the other fish oil capsules while the third group remains neutral. Your son or daughter has been selected randomly to be in a fish oil capsule group which containing 200 g of DHA 4 times a week for a period of 4 months. Their body composition, food intake will be evaluated by food frequency questionnaires, complete blood picture, blood lipids and iodine concentration in the urine through the use of established protocols. The school performance and attention will also be evaluating to both male / female student. All evaluations will be conducted at the beginning of the intervention and when it is completed.

How you can help?
Assent to join us where research will include:
Interview: We would like to ask some questions that will help us to fill the questionnaire: 24 hour reall questionnaire will be used to assess your child dietary intake.

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Physical measurements: such as height, weight and measure the body fat percentage.

Physical fitness: a team from London will assess your child physical activity

All of this will be done at school

Other clinical tests will be taken at the health centre:
Laboratory tests: such as a blood test, urine test, sample will be taken by taking into account safety and hygiene measures.

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Please note this study will be conducted under full compliance with the principles of data protection law. You are free to withdraw from the study at any time without giving any reason.

Is there any benefit derived for others?
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What if you do not want to share my son / daughter in the project?
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Recognition

I certify that I have read and understood the information pertaining to study above. I understand that my participation is voluntary and that I have absolute freedom to withdraw at any time without affecting me or my son / daughter.

I agree to participate in the study

Participant's name		**Date**		**Signature**	
Researcher's name		**Date**		**Signature**	

(FORM 5.3)

Sultanate of Oman

(Control Group)

Ministry of Health- / Department of Studies & Research

Research and Ethical Review & Approve Committee

Certificate of Informed Consent

Consent form of participating in the project: The impact of eating fish and fish oil on fatty acids (Omega-3), and perception of school students in the governorate of Muscat

Project goal:

Researchers have suggested that there is a close relationship between eating fish, especially rich in Omega-3 fatty acids and health in general. There is little knowledge about the potential impact of eating fish and health in the Sultanate of Oman. the goal of this project was to study the effect of local Omani fish consumption and seafood on the health and also on the level of perception, especially among school children.

The study will be conducted on 354 students in the age group 9-10 years (Grade 4) in three schools in Muscat governorate. Students will be distributed randomly into three groups, where one of them will consume fish and the other fish oil capsules while the third group remains neutral. Your son or daughter has been selected randomly to be in the neutral group so he/she will not receive fish meal or fish oil capsules. Their body composition, food intake will be evaluated by food frequency questionnaires, complete blood picture, blood lipids and iodine concentration in the urine through the use of established protocols. The school performance and attention will also be evaluating to both male / female student. All evaluations will be conducted at the beginning of the intervention and when it is completed.

How you can help?
Assent to join us where research will include:
Interview: We would like to ask some questions that will help us to fill the questionnaire

24 hour reall questionnaire will be used to assess your child dietary intake.

Cognitive assessment: a questionnaire will be given to you about your child cognitive behavior, and another one will be filled by the class teacher.

Physical measurements: such as height, weight and measure the body fat percentage.

Physical fitness: a team from London will assess your child physical activity

All of this will be done at school

Other clinical tests will be taken at the health centre:

Laboratory tests: such as a blood test, urine test, sample will be taken by taking into account safety and hygiene measures.

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Personal data will be dealing in the strictest confidence and will not be used for any other purpose and not be transferred to others without the written consent of the parents of the students. All the data collected from this study will store in a password-protected computer and access will be limited to researchers.

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I agree to participate in the study

Participant's name		**Date**		**Signature**	
Researcher's name		**Date**		**Signature**	

Form Number.....		Sultanate of Oman Ministry of Health Dept of Nutrition

The impact of fish and fish oil capsule intake on omega-3 fatty acid status, Health and cognitive function of Omani school children Age 9/10 years 2012

Parent Questionnaire

Part I. General Information

I1- Student Number in medical register: _____ | | I 1 |

I2 - Name of the School | | | I 2 |
10 - Al Olaa
20 - Al Mashariq
30 - Al Waha

I3 - Group allocation | | I 3 |
1 - Control
2 - Supplement
3 - Fish Supplement

I4 - Name of Student: _____

I5 - Date of interview | | / day | | | /Month | | | | | Year | I 5 |

I6 - Observer Number _____ | | | | I 6 |

I7 - Number of Visit | | I 7 |
1 - First
2 - Second

I8 - Marital status | | I 8 |
1- Married
2- Widowed
3- Divorced
4- Death Parents

I9 - What is the relationship between you and your spouse? | I 9

1- First degree
2- Second degree
3- Distantly
4- No relationship

I10 - What is the highest level of education mother obtained? | I 10

1- Unread and Unwrite
2- Read and Write
3- Primary
4- Preparatory
5- Secondary
6- Diploma
7- Graduate
8- Post graduate

I11 - What is the occupation of the mother? | I 11

1- Public sector
2- Private sector
3- Military sector
4- Freelancers
5- Retired
6- Housewife

I12 - What is the highest level of education father obtained? | I 12

1- Unread and Unwrite
2- Read and Write
3- Primary
4- Preparatory
5- Secondary
6- Diploma
7- Graduate
8- Post graduate

I13 - What is the occupation of the father? | I 13

1- Public sector
2- Private sector
3- Military sector
4- Freelancers
5- Retired
6- Not working

I14 - What is the monthly income for the household?

	I 14

1- (Lowest 100) O.R
2- (100-500) O.R
3- (500-1000) O.R
4- (1000-3000) O.R
5- (3000-5000) O.R
6- (Largest 5000) O.R

Part II: Lifestyle and Dietary Habits

II1- What is the type of activity practiced by the student during free time?

		A			B		C	
	Activity	Yes	No	Code	How many time in week	Code	Duration in minutes	Code
1	Ride bicycle			A1.1		B1.1		C1.1
2	Football			A1.2		B1.2		C1.2
3	Basketball			A1.3		B1.3		C1.3
4	Tennis			A1.4		B1.4		C1.4
5	Swimming			A1.5		B1.5		C1.5
6	Jump rope			A1.6		B1.6		C1.6
7	Ruing			A1.7		B1.7		C1.7
8	Other			A1.8		B1.8		C1.8

II2- What is the kind of activity that spent by the student sitting during free time?

		A			B		C	
	Activity	Yes	No	Code	How many time in week	Code	Duration in minutes	Code
1	TV \ video			A2.1		B2.1		C2.1
2	Electronic Games			A2.2		B2.2		C2.2
3	Computer \ Internet			A2.3		B2.3		C2.3
4	Homework			A2.4		B2.4		C2.4
5	Playing inside the house			A2.5		B2.5		C2.5
6	Reading			A2.6		B2.6		C2.6
7	Drawing			A2.7		B2.7		C2.7
8	Other			A2.8		B2.8		C2.8

II3- Does your child sleep at afternoon?

1- Yes
2- No
3- Sometime

II3

II4- How often does your child eat fish?

1- Daily
2- Weekly
3- Monthly
4- Yearly
5- Don't Know

II4

II5- Does the student have a sensitivity of fish?

1- Yes
2- No
3- Sometime

II5

II6- Does your child eat from the same dish as other family members?

1- Yes
2- No
3- Sometime

II6

II7- How often does your child eat the following foods?

Food Groups	1 Daily	2 Weekly	3 Monthly	4 Occasions	5 Never eat	Answer	
A- Whole grains (wheat, brown rice, pasta, potatoes, barley)							II 7A
B- Other cereals (white wheat flour, white rice, breakfast cereal, corn flakes, potatoes without skin)							II 7B
C- Vegetables rich in vitamin C (peppers, tomato, broccoli, beetroot, radish, etc)							II 7C
D- Vegetables rich in vitamin A (lettuce, cabbage, carrot, squash, green peas)							II 7D
E-Vegetables rich in iron (spinach, parsley)							II 7E
F-Other vegetables (onions, okra, cucumber, eggplant, garlic)							II 7F
G- Fruits rich in vitamin C (citrus fruits, pineapple, guava, cherry, raspberry)							II 7G
H- Fruits rich in vitamin A (mango, avocado, apricot, plum)							II 7H

I-Fruits rich in potassium (raisons, dried figs, dates, bananas, melons)							II 7I
J- Other fruits (coconut, grapes, apples, pears, figs, dates, dried fruits, fresh fruit juice)							II 7J
K- Meat							II 7K
L- Fish							II 7L
M- Chicken							II 7M
N- Eggs							II 7N
O- Nuts and seeds							II 7O
P- Ready-made products (canned meat, shawarma, kebab, fish fingers, fried chicken)							II 7P
Q- Legumes (lentils, beans, chickpeas, dried peas)							II 7Q
R- Milk and milk products (pasteurised & powdered milk, yogurt, cheese, paneer)							II 7R
S- Added Oil (Vegetable oils, margarine)							II 7S
T- Add ghee, butter							II 7T
U- Desserts							II 7U

II8- Do you often use the iodize salt?

1- Yes
2- No
3- Don't Know

	II8

II9- What is the name of salt currently use in your house? _____

	II9

II10- Information on foods that addressed during the twenty-four hours prior

Table of six meals in one day							
	Name of dish / drink intake	A Code of dish/drink	Code	B Amount intake in pieces	Code	C Amount of dish / drink intake in mille	Code
Breakfast (1)			A 10.1.1		B 10.1.1		C 10.1.1
			A 10.1.2		B 10.1.2		C 10.1.2
			A 10.1.3		B 10.1.3		C 10.1.3
			A 10.1.4		B 10.1.4		C 10.1.4
			A 10.1.5		B 10.1.5		C 10.1.5
			A 10.1.6		B 10.1.6		C 10.1.6
			A 10.1.7		B 10.1.7		C 10.1.7
Snack (2)			A 10.2.1		B 10.2.1		C 10.2.1
			A 10.2.2		B 10.2.2		C 10.2.2
			A 10.2.3		B 10.2.3		C 10.2.3
			A 10.2.4		B 10.2.4		C 10.2.4
			A 10.2.5		B 10.2.5		C 10.2.5
			A 10.2.6		B 10.2.6		C 10.2.6
			A 10.2.7		B 10.2.7		C 10.2.7
lunch (3)			A 10.3.1		B 10.3.1		C 10.3.1
			A 10.3.2		B 10.3.2		C 10.3.2
			A 10.3.3		B 10.3.3		C 10.3.3
			A 10.3.4		B 10.3.4		C 10.3.4
			A 10.3.5		B 10.3.5		C 10.3.5
			A 10.3.6		B 10.3.6		C 10.3.6
			A 10.3.7		B 10.3.7		C 10.3.7

Table of six meals in one day							
	Name of dish / drink intake	**A** Code of dish/drink	Code	**B** Amount intake in pieces	Code	**C** Amount of dish / drink intake in mille	Code
Snack (4)			A 10.4.1		B 10.4.1		C 10.4.1
			A 10.4.2		B 10.4.2		C 10.4.2
			A 10.4.3		B 10.4.3		C 10.4.3
			A 10.4.4		B 10.4.4		C 10.4.4
			A 10.4.5		B 10.4.5		C 10.4.5
			A 10.4.6		B 10.4.6		C 10.4.6
			A 10.4.7		B 10.4.7		C 10.4.7
Dinner (5)			A 10.5.1		B 10.5.1		C 10.5.1
			A 10.5.2		B 10.5.2		C 10.5.2
			A 10.5.3		B 10.5.3		C 10.5.3
			A 10.5.4		B 10.5.4		C 10.5.4
			A 10.5.5		B 10.5.5		C 10.5.5
			A 10.5.6		B 10.5.6		C 10.5.6
			A 10.5.7		B 10.5.7		C 10.5.7
Snack (6)			A 10.6.1		B 10.6.1		C 10.6.1
			A 10.6.2		B 10.6.2		C 10.6.2
			A 10.6.3		B 10.6.3		C 10.6.3
			A 10.6.4		B 10.6.4		C 10.6.4
			A 10.6.5		B 10.6.5		C 10.6.5
			A 10.6.6		B 10.6.6		C 10.6.6
			A 10.6.7		B 10.6.7		C 10.6.7

Form Number.....		Sultanate of Oman Ministry of Health Dept of Nutrition

The impact of fish and fish oil capsule intake on omega-3 fatty acid status, Health and cognitive function of Omani school children Age 9/10 years 2012

Student Questionnaire

Part A. General Information

A1- Student Number in medical register: _____ | | A1 |

A2 - Name of the School
10 - Al Olaa
20 - Al Mashariq
30 - Al Waha | | | A 2 |

A3 - Group allocation
1 - Control
2 - Supplement
3 - Fish Supplement | | A 3 |

A4 – Class number forth: 1 2 3 4 5 6 7 8 9 10 11 12 | | A 4 |

A5 – Name of Student: _____

A6 - Observer code _____ | | | | A 6 |

A7 - Sex
1 - Male
2 - Female | | A 7 |

A8 - Date of interview | | / day | | /Month | | | | | Year | A 8 |

A9 - Date of interview | | / day | | /Month | | | | | Year | A 9 |

A10- Weight of the student at birth? ____._____ Kg | | . | | | A12

A11- Length of the student at birth? _____Cm | | | A11

A12- What is the problem suffered at birth? | A12

1 - Cesarean section
2 - Low birth weight
3 - Preterm baby
4 - Oxygen deficiency
5 - Nothing
6 - Other

A13 - Number of Visit | A13

1 - First
2 – Second

Part B. Medical History of the student

Does the student have any of the following conditions?
(Please fill the table from Child healthy Card)

B	Conditions	1 Yes	2 No	Code
1	Diabetes			B1
2	hypertension			B2
3	Obesity			B3
4	Heart condition			B4
5	High blood lipid			B5
6	High cholesterol			B6
7	Anemia 1 Hereditary 2 Non hereditary			B7
8	Goiter due to iodine deficiency			B8
9	Mental disability			B9
10	learning difficulties			B10

Part C: Anthropometric measurement

C1 First observer code | | | | C1

Code	Anthropometric measurement	First Measurement		Second Measurement	
A	Weight KG	C1.A1		C1.A2	
B	Height CM	C1.B1		C1.B2	
C	Waist circumference CM	C1.C1		C1.C2	
D	Mid arm circumference CM	C1.D1		C1.D2	
E	Triceps' skin fold CM	C1.E1		C1.E2	
F	Sub scapular skin fold CM	C1.F1		C1.F2	
G	Height at sitting position CM	C1.G1		C1.G2	

C2 Second observer code | | | | C2

Code	Anthropometric measurement	First Measurement		Second Measurement	
A	Weight KG	C2.A1		C2.A2	
B	Height CM	C2.B1		C2.B2	
C	Waist circumference CM	C2.C1		C2.C2	
D	Mid arm circumference CM	C2.D1		C2.D2	
E	Triceps' skin fold Mm	C2.E1		C2.E2	
F	Sub scapular skin fold Mm	C2.F1		C2.F2	
G	Height at sitting position CM	C2.G1		C2.G2	

Code	Rate		Measurement
H	Fat Mass Rate %	CH	
I	Water Mass Rate %	CI	
J	Muscular Mass Rate %	CJ	
K	Bone Minerals Mass Rate %	CK	
L	Vascular Fats Rate %	CL	

Part D: Medical Examination

A- Complete Blood control (CBC)

Code	Test		Measurement
1	WBC k/ul	DA.1	
2	RBC /ul	DA.2	
3	HGB G/Dl	DA.3	
4	HCT %	DA.4	
5	MCV Fl	DA.5	
6	MCH PG	DA.6	
7	MCHC G/DL	DA.7	
8	PLT /ul	DA.8	
9	LYM %	DA.9	
10	MONO %	DA.10	
11	NEU %	DA.11	
12	RDW %CV	DA.12	
13	MPV FI	DA.13	

B- Serum Lipids

Code	Test		Measurement
1	Cholesterol mmol/L	DB.1	
2	Triglycerides mmol/L	DB.2	
3	HDL cholesterol mmol/L	DB.3	
4	LDL cholesterol mmol/L	DB.4	

Code	Test		Measurement
C	Fasting blood sugar (FBS) mg/dl	DC	
D	urinary iodine mg/dl	DD	
E	Glycosylated HB1	DE	
F	Parathyroid Hormone	DF	
G	Thyroid Function Test	DG	
H	Bone Profile	DH	
I	Vitamin D	DI	

APPENDIX 4:

Ethical Approval

Sultanate of Oman
Ministry of Health
Directorate General of Planning

سلطنة عمان
وزارة الصحة
المديرية العامة للتخطيط

Ref. :
Date :

الرقم: و ص/م ع ت/٧٣٩/٢٠١٢م
التاريخ: ٢٩/ رجب / ١٤٣٣هـ
الموافق: ١٩ / يونيو/ ٢٠١٢م

الفاضل / مدير مكتب الوكيل لشئون التخطيط المحترم

تحية طيبة وبعد ،،،

بالاشارة الى خطابكم رقم :(٢٠١٢/١٥٠٥م) بتاريخ : ١٣ / يونيو / ٢٠١٢م بخصوص مقترح مشروع دراسة تاثير استهلاك الاسماك على نشاط وصحة الطلاب.

عليه .. نود إفادتكم بأنه قد تمت الموافقة على مقترح البحث المشار إليه أعلاه من قبل لجنة مراجعة وإجازة البحوث من الناحيتين العلمية والاخلاقية - (مرفق خطاب الموافقة).
برجاء التكرم بعرض الموضوع لسعادته للتفضل بالتوجيه.

وتفضلوا بقبول تحياتنا ،،،

د / أحمد بن محمد القاسمي
المدير العام
رئيس لجنة مراجعة وإجازة البحوث من
الناحيتين العلمية والاخلاقية

P.O. Box : 393, Postal Code : 100, Muscat - Fax : 24696533
ص.ب : ٣٩٣ ،الرمز البريدي : ١٠٠ ، مسقط - فاكس : ٢٤٦٩٦٥٣٣

Sultanate of Oman
Ministry of Health
Directorate General of Planning

سلطنة عمان
وزارة الصحة
المديرية العامة للتخطيط

Ref. : MH/DGP/R&S/PROPOSAL_ APPROVED/8/2012 ..... الرقم :

Date : 19.6.2012 ..... التاريخ :

..... الموافق :

Professor Kebreab Ghebremeskel
Head of Lipidomics and Nutrition Research Centre; London Metropolitan University
Principal Investigator

Study Title: " The impact of fish and fish oil capsule intake on omega-3 fatty acid status, health and cognitive function of Omani school children "

After compliments.

We are pleased to inform you that your research proposal " **The impact of fish and fish oil capsule intake on omega-3 fatty acid status, health and cognitive function of Omani school children** " has been approved by Research and Ethical Review and Approve Committee, Ministry of Health.

Regards,

Dr. Ahmed Al Qasmi
Director General of Planning,
Chairman, Research and Ethical Review and Approve Committee
Ministry of Health, Sultanate of Oman.

Cc
Day file

P.O. Box : 393, Postal Code : 100, Muscat - Fax : 24696533 ص.ب : ٣٩٣ ،الرمز البريدي : ١٠٠ ، مسقط - فاكس : ٢٤٦٩٦٥٣٣

APPENDIX 5:

Omani Ministry of Health

Recommended Nutrient Intake Tables

Population category	Age-group (years)	Energy (kcal)	Protein (g)	Carbohydrates (g)	Fiber (g)	Vitamin A (µg RE)	Vitamin D (µg)	Iron (mg)	Folate (µg)	Zinc (mg)	Calcium (mg)
Young children	1-3	1000	20-25	137.5-187.5	8-20	350-500	2.5-5.0	5.5	150-200	10	250-400
Children	4-8	1400	28-35	192.5-262.5	11-28	490-700	3.5-7	7.7	210-280	14	350-560
Adolescent											
Males	9-13	2000	40-50	275-375	16-40	700-1000	5-10	11.0	300-400	20	500-800
	14-18	3000	60-75	412.5-562.5	24-60	1050-1500	7.5-15	16.5	450-600	30	750-1200
Females	9-13	1900	38-47.5	261.3-356.3	15-38	665-950	4.8-9.5	10.5	285-380	19	475-760
	14-18	2400	48-60	330-450	19-48	840-1200	6-12	13.2	360-480	24	600-960
Adults											
Males	19-30	2100	42-52.5	288.8-393.8	17-42	735-1050	5.3-10.5	11.6	315-420	21	525-840
	31-50	2400	48-60	330-450	19-48	840-1200	6-12	13.2	360-480	24	600-960
	51-70	2200	44-55	302.5-412.5	18-44	770-1100	5.5-11	12.1	330-440	22	550-880
	>70	1800	36-45	247.5-337.5	14.5-36	630-900	4.5-9	9.9	270-360	18	450-720
Females	19-30	2000	40-50	275-375	16-40	700-1000	5-10	11	300-400	20	500-800
	31-50	2000	40-50	275-375	16-40	700-1000	5-10	11	300-400	20	500-800
	51-70	1800	36-45	247.5-337.5	14.5-36	630-900	4.5-9	9.9	270-360	18	450-720
	>70	1600	32-40	220-300	13-32	560-800	4-8	8.8	240-320	16	400-640
Pregnant	All	2100-2700	42-67.5	290-500	17-52	735-1300	5.3-13.5	11-15	315-540	21-27	525-1100
Lactating	All	2400-2900	48-72.5	330-540	19-58	840-1450	6-15	13-16	360-580	24-29	600-1160

Table 1 Recommended nutrient intakes for protein; carbohydrates; and vitamins of public health importance for various population groups of Oman

Population category	Age-group (years)	Energy (kcal)	Vitamin E (mg α TE)	Vitamin K (µg)	Vitamin C (mg)	Thiamine (mg)	Riboflavin (mg)	Niacin (mg)	Vitamin B6 (mg)	Vitamin B12 (µg)	Fluoride (mg)	Iodine (µg)	Sodium (g)
Young children	1-3	1000	3.5-5.0	20-40	25-30	0.5-0.8	0.6-0.9	6-10	0.5-1	0.5-1	0.5-1	75	2.5
Children	4-8	1400	4.9-7.0	28-56	35-42	07-1.12	0.8-1.3	8.4-14	0.7-1.4	0.7-1.4	0.7-1.4	105	3.5
Adolescent													
Males	9-13	2000	7.0-10.0	40-80	50-60	1-1.6	1.2-1.8	12-20	1-2	1-2	1-2	150	5.0
	14-18	3000	10.5-15.0	60-120	75-90	1.5-2.4	1.8-2.7	18-30	1.5-3	1.5-3	1.5-3	225	7.5
Females	9-13	1900	6.7-9.5	38-76	47.5-57	0.9-1.6	1.1-1.7	11.4-19	0.9-1.9	0.9-1.9	0.9-1.9	142	4.8
	14-18	2400	8.4-12.0	48-96	60-72	1.2-1.9	1.4-2.1	14.4-24	1.2-2.4	1.2-2.4	1.2-2.4	180	6.0
Adults													
Males	19-30	2100	7.3.10.5	42-84	52.5-63	1.1-1.7	1.3-1.9	12.6-21	1.1-2.1	1.1-2.1	1.1-2.1	158	5.3
	31-50	2400	8.4-12.0	48-96	60-72	1.2-1.9	1.4-2.2	14.4-24	1.2-2.4	1.2-2.4	1.2-2.4	180	6.0
	51-70	2200	7.7-11.0	44-88	55-66	1.1-1.8	1.3-2.0	13.2-22	1.1-2.2	1.1-2.2	1.1-2.2	165	5.5
	>70	1800	6.3-9.0	36-72	45-54	0.9-1.5	1.1-1.6	10.8-18	0.9-1.8	0.9-1.8	0.9-1.8	135	4.5
Females	19-30	2000	7.0-10.0	40-80	50-60	1-1.6	1.2-1.8	12-20	1-2	1-2	1-2	150	5.0
	31-50	2000	7.0-10.0	40-80	50-60	1-1.6	1.2-1.8	12-20	1-2	1-2	1-2	150	5.0
	51-70	1800	6.3-9.0	36-72	45-54	0.9-1.44	1.1-1.6	10.8-18	0.9-1.8	0.9-1.8	0.9-1.8	135	4.5
	>70	1600	5.6-8.0	32-64	40-48	0.8-1.3	0.9-1.4	9.6-16	0.8-1.6	0.8-1.6	0.8-1.6	120	4.0
Pregnant	All	2100-2700	7.3-13.5	42-108	52.5-81	1.0-2.2	1.3-2.4	12.6-27	1.0-2.7	1.0-2.7	1.0-2.7	157-202	5.3-6.7
Lactating	All	2400-2900	8.4-14.5	48-116	60-87	1.2-2.3	1.4-2.6	14.4-29	1.5-2.9	1.5-2.9	1.5-2.9	180-217	5.9-7.2

Table 2 Recommended nutrient intakes for protein; carbohydrates; and vitamins of public health importance for various population groups of Oman

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