Improved characterisation of measures of fatness and metabolic risks in older adolescents and young adults in the South Asian population in the UK

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Declaration of Originality

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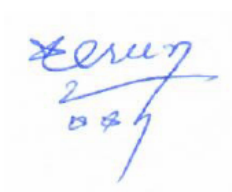
Erum Moqueem: 

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Abbreviations

ADP	Air displacement Plethysmography
BF%	Body fat percentage
BIA	Bioelectrical Impedance Analysis
BMI	Body Mass Index
CT	Computerized tomography
CVD	Cardiovascular Disease
CHD	Coronary heart disease
DASH	Dietary Approach to Stop Hypertension
DXA	Dual X-ray Absorptiometry
DBP	Diastolic Blood Pressure
ECW	Extracellular water
ICW	Intracellular water
FFM	Fat Free Mass
FM	Fat Mass
HD	Hydrodensitometry
HDL	High Density Lipoprotein
HSE	Health Survey for England
HWHL	Healthy Weight Healthy Lives
IDF	International Diabetes Federation
IOTF	International Obesity Task Force
LDL	Low Density Lipoprotein
MRI	Magnetic Resonance Imaging
MS	Metabolic Syndrome
NCMP	National Child Measurement Programme
NDNS	National diet and nutritional survey
NHANES	National Health and Nutrition Exercise Survey
NICE	National Institute for Health and Clinical Excellence

SA	South Asian
SAT	Subcutaneous Adipose tissue
SMM	Skeletal muscle mass
SD	Standard Deviation
SDS	Standard Deviation Scores
SH	Sitting Height
SBP	Systolic Blood Pressure
BP	Blood pressure
T2DM	Type 2 diabetes mellitus
LL	Leg length
LHM	Leicester Height Measure
SES	Socioeconomic status
RCPCH	Royal College of Physician and Children Health
SOPs	Standard operating procedures
WHO	World Health Organization
HSE	Health Survey for England
CDC	Centre for disease control and prevention
TC	Thigh Circumference
TGH	Thrifty Genotype Hypothesis
HTN	Hypertension
NAFLD	Non-alcoholic fatty liver disease
NASH	Non-alcoholic steatohepatitis
IRS	Insulin Resistance Syndrome
TBW	Total Body water
UWW	Under water weighing
VAT	Visceral adipose tissue
WC	Waist circumference
WE	White European
WHR	Waist-to-hip ratio

WHtR	Waist-to-height ratio
NOO	National Obesity Observatory
FFA	Free fatty acid
ALST	Appendicular lean soft tissue
FPG	Fasting plasma glucose
OGTT	Oral glucose tolerance test
IFG	Impaired fasting glycemia
NHS	National Health Service

Abstract

Increasing concerns about obesity and related metabolic risk have demanded better measures to identify individuals who are at higher health risk. This is particularly important in minority ethnic groups, especially those with a South Asian (SA) heritage. Variation in body composition between ethnicities is important in identifying risk. For example, South Asians have a characteristic body composition with a higher proportion of body fat, lower skeletal muscle mass (SMM) and a tendency to accumulate body fat (BF) in the abdominal region at equivalent BMI's compared with those of a Caucasian heritage. The higher percentage of body fat (BF%) in SA children tends to track into adult life and consequently increases the risk of type 2 diabetes and cardiovascular disease. Across infancy, childhood, adolescence and even young adulthood, overweight and obesity are defined using statistically derived cut-off values, typically using centile charts based upon age and gender specific reference data. It remains a challenge to define optimum reference cut-offs for any body composition or anthropometric variable because of the age-related changes in growth and body composition which occurs during the growth and maturation. In view of this continuing challenge, the aim of this study was to extend the work previously undertaken in this research group to develop a full range of growth references for better characterisation of body composition in the UK SA population for the 4-21 years age range. Up until now, there had been a gap in data for adolescents and young adults between 16 to 21 years of age, hence the objective of this study was to generate SA- specific centile curves for anthropometric measurements (height, weight, BMI, waist circumference (WC), leg length and sitting height) and body composition measures (fat mass (FM, BF%), fat-free mass (FFM) and skeletal muscle mass (SMM) between the ages 16 to 21 years.

This was a field-based study where anthropometric measurements of 546 participants were collected from volunteers from a SA background living in the UK. Single-frequency bioelectrical impedance analysis technology was used for assessment of body composition. Body composition and anthropometric data were used to construct the gender and ethnic specific centile curves using the LMS method for all variables. Comparison of centile charts with equivalent data for Caucasians was performed.

It was found that mean height (172.5 cm for male, 159.3 cm for female) for both genders and mean weight for female (57.8 kg) of the population group was lower (as determined by numerical difference in SD score) compared to the UK 1990 reference. Sitting height increased with increasing age whereas there was no or minimal increase in leg length with increasing age. Participants from the SA ethnic group had (numerically) higher WC and slightly high BMI compared to reference population. At equivalent BMIs, SA tended to have a greater WC. BF% in females increased steadily from 6 to 21 years of age while in males BF% decreased after puberty, most likely reflecting the sex hormone driven changes in body composition during adolescence. FM (kg) increased with increasing age and was similar in both genders. At the 50th centile, SA had a lower SMM compared with Caucasians for all age groups in both genders.

In conclusion, this study provides a range of assessment tools in the form of SA specific reference centile charts for children, adolescents and young adults in the UK and are the first set of reference centile charts for anthropometric measurements and body composition in this population group. The findings indicate that the pattern of body composition and anthropometry differs in the SA population compared to their UK Caucasian counterparts. These reference charts will allow health practitioners and researchers to measure and plot child and adolescent growth, development and measures of metabolic risk for this population group, allowing for comparisons with reference data for the same gender and age.

CHAPTER 1 - Introduction and Review of literature

1.1 Defining obesity in children and adolescents

The increased prevalence of obesity has been described as a normal population response to either a dramatic reduction in the amount of physical activity or the major changes in food supply being in excess of population's need (James 2008). Obesity can be simply defined as "an accumulation of excess amount of body fat to the extent that it may have an adverse effect on individual's health" therefore obese individuals can be identified by the quantification of excess body fat (WHO – obesity and overweight, 2020, Agha and Agha 2017). It is now a major public health concern which is affecting countries all across the world (NICE 2006 obesity guidelines). Overweight and obesity is often expressed as an increased body weight corrected for height. Quetelet, a Flemish astronomer and statistician was the first person who noted the relationship of height with body weight in normal young adults suggesting that body mass was least affected by height when the ratio of weight to height squared is used rather than simply using the ratio of the weight to height. After measuring body composition with different methods, it was concluded that Quetelet's formula is more convenient and reliable marker of obesity (Garrow and Webster 1985). Quetelet Index, later stated as the body mass index (BMI), remains the most universal definition for obesity (Keys et al. 1972). The categorisation of overweight and obesity in adults is based on fixed BMI cut-offs. However, it has been established that individuals from different ethnic background vary in their body composition for a given BMI, therefore BMI cut offs now vary for different ethnicity (Heymsfield et al. 2016), (see section 1.8.1).

The introduction of BMI into research and clinical practice was as a result of the association of BMI with mortality and morbidity (Müller and Geisler 2017).

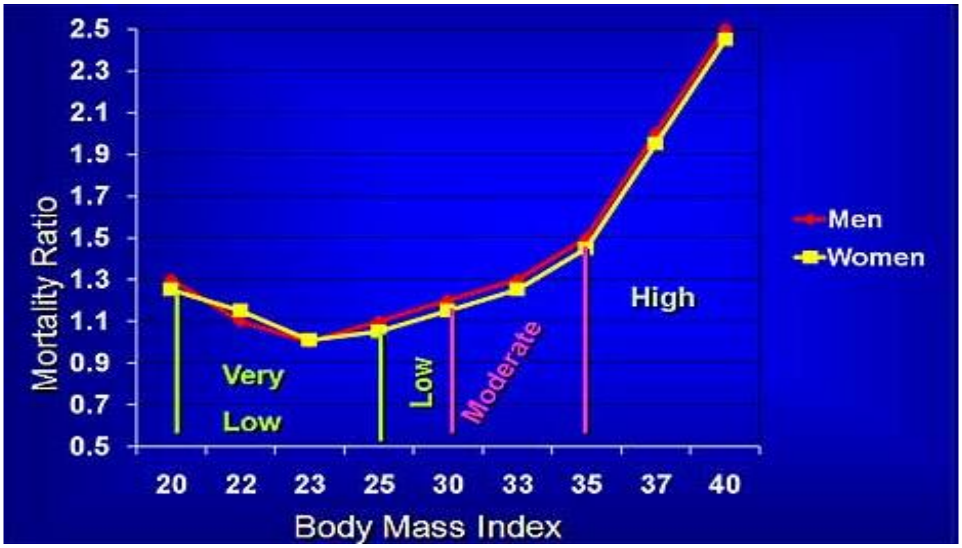


Figure 1.1a: Relationship of BMI with Mortality

Bhaskaran et al 2018 created an adjusted Cox regression models to demonstrate the relationship between BMI and all-cause mortality. BMI exhibited a "***J***" shaped curve with mortality ratio - the estimated hazard ratio per 5 kg/m² increase in BMI was 0·81 (95% CI 0·80–0·82) below 25 kg/m² and 1·21 (1·20–1·22) above 25 kg/m², which means that very low BMI is associated with an increased risk of mortality; alongside, high BMI is also associated with significantly increasing mortality (Bhaskaran et al. 2018).

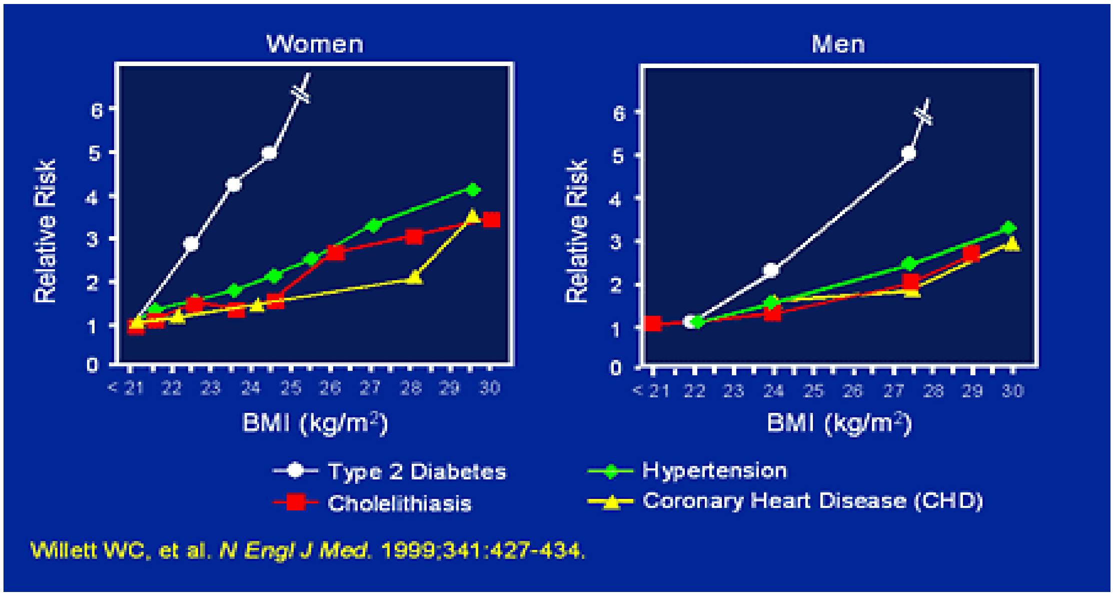


Figure 1.1b: The relation of body-mass index with incidence of relative risk — in women and men specifically, type 2 diabetes, hypertension, coronary heart disease, and cholelithiasis

In a meta-analysis of 230 cohort studies, it was concluded that the risk of premature mortality is increased with increasing BMI. Indeed, it is obesity rather than overweight which was strongly associated with excess mortality (Aune et al. 2016). The association of high BMI with overall and cardiovascular mortality is higher in men than in women (Bhaskaran et al. 2018).

As excess mortality is due to obesity and excess body weight is a well-known risk factor for heart disease and ischemic stroke (Faeh et al. 2011, Abdelaal et al. 2017). In the UK, The National Institute for Health and Clinical Excellence (NICE) guideline indicates that at a lower BMI members of Asian, African and other minority ethnic groups are at increased risk of chronic disorders compared to the white population (Health and Excellence 2013) at the same BMI [see Section 1.8.1 for detail]. Currently, obesity in children is one of the most serious public health challenges of the 21st century (NCD-RisC, 2017; WHO – world obesity federation, 2018). Across infancy, childhood and adolescence, it remains a challenge to define overweight and obese individuals because of the age-related changes in body composition, weight gain and BMI which occurs during the growth and maturation

(Ogden 2002). Thus, in children and adolescents, overweight and obesity are always defined using statistically derived cut-off values, typically using centile charts based upon age and gender specific reference data (Horlick 2001) [Further detail in section 1.8.1]. As such, it is now common practice to use the sex-specific BMI centile charts in several countries such as UK (Cole et al. 1995), USA (Kuczmarski 2002), France (Rolland-Cachera et al. 1991), Hong Kong (So et al. 2008) and Italy (Cacciari et al. 2002).

1.2 Prevalence of overweight and obesity worldwide

The dramatic increase in obesity prevalence is now considered a major global problem as it has prevailed across both developed and emerging economies (WHO – obesity and overweight, 2020). A systematic evaluation of epidemiological studies and health surveys from 1980 to 2008 was conducted to quantify both global and national trends in BMI. It was estimated that in 2008, 1.47 billion adults worldwide had BMI ≥ 25 kg/m^2 (Finucane et al. 2011). Subsequently, the Global Burden of Disease Study 2013 reported that the proportion of adults with a BMI of ≥25 kg/m^2 increased by 8% in both genders (from 29 to 37% in men and from 30 to 38% in women) across the world in 33 years i.e. between 1980 and 2013 (Ng et al. 2014). Recent report published by World Obesity Federation highlighted the current trends and found that by 2025, 1 in 5 adults worldwide is expected to have obesity (World Obesity 2020). Furthermore, it has been found that obese children tend to become obese adults especially as some of the obesity risk factors can originate in or before childhood. This can include prenatal dietary experience and rapid early post-natal growth as well as the establishment of eating habits and physical activity pattern in childhood (van Jaarsveld and Gulliford 2015). Simmonds et al, pointed out an interesting but worrying fact that around 70% of obese adults are usually not obese in their childhood or teenage, however, obese children and teenagers are five times more likely to be obese in their adult life, highlighting the importance to be watchful and monitor children whether they are overweight or not as this can be an important measure to cut down the overall disease burden due to obesity (Simmonds et al. 2016).

1.2.1 Prevalence of overweight and obesity in the UK

According to Health Survey for England (HSE) 2017 it has been estimated that 35.6% of adults are overweight and further 28.7% of adults are obese in England. Among those who are overweight and obese, one in every eight adults is having morbid obesity in England (3.6% of all adults). According to HSE 2017, the percentage of children who were obese has increased from 14% and 17% between 2006 and 2017. Around 30% of children living in England between the age of 2 and 15 were overweight, including 17% of them were assessed under the category of obese in 2017 (HSE 2017- adult and child overweight and obesity). According to National Child Measurement Programme 2017/18 obesity prevalence remained same in reception year i.e. age 4 and 5 while it increased from 20% to 20.1% in year 6 (NCMP 2017/2018).

Furthermore, in the UK, the prevalence of obesity also varies with level of deprivation i.e. lowest household income. It has been estimated in the most deprived areas 38% of women were obese compared to least deprived area where the proportion was only 20% (Conolly et al. 2017). Around 100 million ready-made meals/take-aways are consumed by UK population in a week as published in a report by Cancer Research UK. It is evident that dining out and fast food take away are important contributors to excess energy intake which can ultimately lead to overweight and obesity (Goffe et al. 2017). Like other countries in the world, obesity in UK is also rising and has become the second largest public health issue after smoking (Capehorn et al. 2016). Since 1993, obesity levels have been consistently rising (Fig 1.2 below) (Baker 2018), with the percentage of adults who are either overweight or obese rising from 52.9% to 64.3% (Kyle et al. 2017).

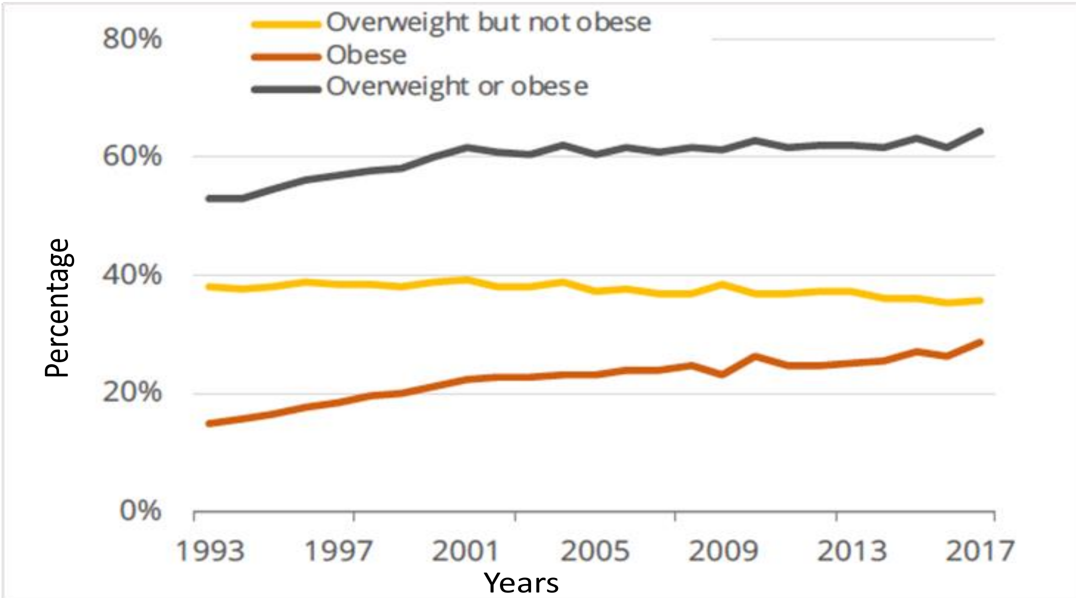


Figure 1.2: Obesity trend in England from 1993 to 2017

(Baker 2018)

Several UK national surveys conducted during the last two decades have revealed a large difference in the prevalence of obesity across different ethnic groups within a population. The National Diet and Nutrition Survey (NDNS) revealed that the tendency of obesity is increasing in young British and South Asian adolescents. Asians were almost four times as likely to be obese as white subjects (Jebb et al. 2004). In addition, the pattern of fat storage varies across different ethnic groups, South Asians tend to have greater body fat percentage, with a tendency to store this fat abdominally. They also tend to have less skeletal muscle mass for a given BMI compared to white Europeans. As far as the general public health awareness is concerned, the South Asian population in the UK should therefore particularly be made aware about the health risk of increased BMI and WC (Gatineau and Mathrani 2011).

The Active Lives Survey data (2017/18) revealed that the percentage of overweight and obesity varies across different socio-economic groups. Children living in more deprived areas are significantly more likely to have excess weight.

In last decade it has been found that the obesity rate is at least twice as high in the most deprived area than in the least deprived area (Fig 1.3) (Baker 2018)

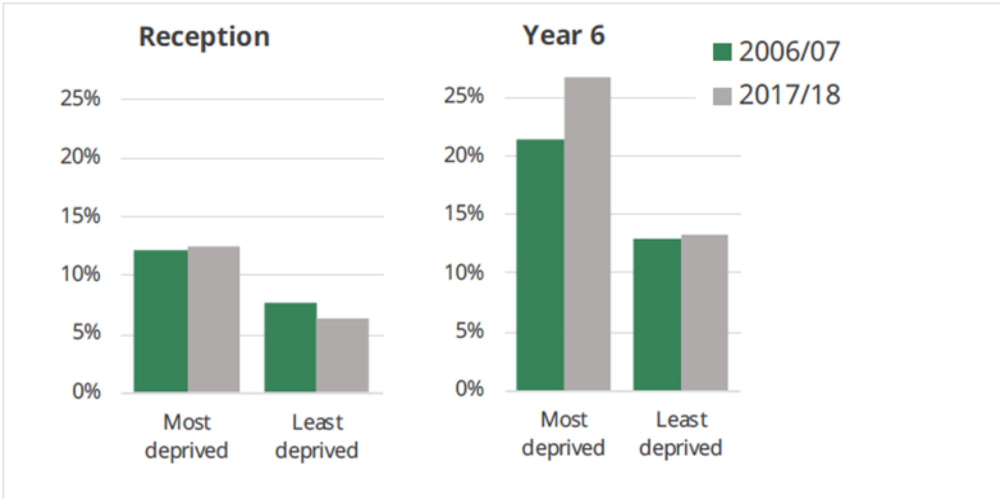


Figure 1.3: Rise in obesity among children age 10-11 in most deprived areas

(Baker 2018)

1.3 Health Consequences of Obesity

This higher prevalence of obesity has adverse consequences on health. The number of obesity related health consequences are discussed below.

1.3.1 Cardiovascular diseases

Cardiovascular diseases (CVD) are a group of diseases that affect both heart and blood vessels. It usually develops when fat (atheromas) deposits on the inner wall of blood vessels causing the narrowing the vascular lumen and sclerosis of blood vessels (atherosclerosis) (Khanji et al. 2016). This adversely impacts the hemodynamic functions of the cardiovascular system including but not limited to increased peripheral vascular resistance (due to increased sympathetic tone), increased circulating blood volume (due to increased intravascular volume caused by sodium retention), increased cardiac output (due to combined increase in stroke volume and heart rate – again due to sympathetic activation) (Koliaki et al, 2018).

Obesity is one of the modifiable risk factors for CVD via having direct (structural, functional and pathological changes in cardiovascular system) and indirect (insulin resistance, T2DM, hypertension and dyslipidemia) impact (Poirier et al 2006). Intentional weight reduction in obese individuals in beneficial for morbidity and mortality related to CVD (Koliaki et al, 2018). Family history and ethnic background are some other important risk factors for CVD that are non-modifiable and have important effect in the incidence of CVD (Khanji et al. 2016).

It was estimated that in 2016, globally, 17.9 million people died from CVD, with three quarter of these death appearing in low- and middle-income countries (WHO – CVD 2017). In the UK, CVD risk factors such as high blood pressure and cholesterol have higher disease burden and around 7.4 million people in UK are living with heart and circulatory diseases (Murray et al. 2013, Tedstone et al. 2020). In England 1 death in every 4 minutes is due to CVD and it has been estimated that healthcare costs due to CVD is around £7.4 billion and wider impact on overall economy is £15.8 billion each year (Waterall, 2019).

Obesity is highly recognised as an independent risk factor and considered as one of the reason for the occurrence of cardiovascular disease (CVD) in adults (Guh et al. 2009, Gruzdeva et al. 2018). Obesity together with insulin resistance impairs vascular function which inhibits the expression of nitric oxide (NO) synthase (eNOS) in endothelial cells and impedes NO generation. These structural and functional changes in the microvasculature leads to increase the risk of CVD (Sorop et al. 2017, Wasserman et al. 2018).

Atherosclerosis is a chronic, progressive disease that impairs human endothelial function and is directly linked with low birth weight which is associated with adult obesity (Norman and Martin 2003, Jornayvaz et al. 2016, Freemark 2018). Risk of atherosclerosis starts in childhood and is accelerated by multiple risk factors which increases with age (Shah and Urbina 2018). Indeed, obese children have increased risk of cardiovascular risk in adulthood (Baker et al. 2007). Thus, obesity increases the risk of developing CVD earlier in life and consequently prolongs the number of years living with CVD (Dhana et al. 2016). Globally, CVD is the number one cause of death, but its prevalence is different in different ethnic groups. SA have a higher risk of T2DM and ischemic heart disease, when compared to Europeans (Schutte 2019). Low income along with social scarcity is strongly linked with CVD (Khanji et al. 2016), due to socioeconomic difference as well as potential genetic and environmental factors in SA they have higher risk of CVD (Schutte 2019).

Diet plays a key role in the development of CVD. Many primary and secondary cardiovascular events can be prevented by a reduction in total energy intake as well as dietary modification (Yu et al. 2018). Current evidence indicates that the traditional Mediterranean diet offers a good healthy dietary pattern to reduce CVD. The Mediterranean diet recommends the intake of plant based foods including whole grains, nuts, and legumes; moderate amount of seafood and milk-based products and; and minimal amount of processed meats and grains, sugar and salt (Yu et al. 2018, Becerra-Tomás et al. 2019). According to “eat well” plan proposed by NHS UK, we should add at least two portions of fish in a week with one fish rich is oil as oil found in fish are particularly high in long chain omega -3 fatty acid considered beneficial for healthier function of heart (Levy and Tedstone 2017).

Furthermore, higher levels of physical Activity (PA) plays a significant role in the prevention of CVD (Gielen and Landmesser 2014). According to the recommendations by UK Chief Medical Officer, every adult should do a moderate intensity activity for 150 minutes or 75 minutes of vigorous intensity activity or a combination of moderate and vigorous intensity activity each week (Gibson-Moore 2019). It is now evident that compared to being inactive half of the recommended amount of PA can lower the incidence of several CVD risk factors (Martinez-Gomez et al. 2020).

1.3.2 Hypertension

According to NICE, hypertension (HTN) is diagnosed as the systolic blood pressure (SBP) greater than 140 mm Hg and/or a diastolic blood pressure (DBP) ≥90 mm Hg in younger, middle-aged and older people in two different days (Boffa et al. 2019).

In patient less than 65 years old treated HTN should focus to bring in a range of 120-129/<80 mmHg while for mature old patients aged ≥65 years this range is around 130-139/<80 mmHg (Williams et al. 2018). According to the estimates published by WHO for 2019, around 1.13 billion people have hypertension globally, with two-thirds of them living in middle- or low-income countries (Zohu et al. 2017). In the UK, after smoking and poor diet, hypertension is the third biggest risk factor for diseases. According to HSE estimates published in 2017, approximately 26.2% of the adult population (around 11.8 million adults) had hypertension in England (Hypertension prevalence estimates in England, 2017). In Europe, >150 million people are affected by hypertension and it has been predicted that by 2025, its prevalence will rise from 15% to 20% (Reynolds et al. 2016). Raised blood pressure is one of the major risk factors for premature and sudden death, coronary heart disease (CHD), stroke, congestive heart failure and renal insufficiency (Aronow 2017, Hall et al. 2019).

Overweight and obesity has an independent effect on HTN. People with higher BMI has increased risk of HTN (Drøyvold et al. 2005). Distribution of fat around the centre is linked with high BP (Yano et al. 2016). Excess visceral adipose tissue releases higher amount of free fatty acids and cytokines hormone in the portal vein that carried it to liver where it interacts with different immune cells and leads to the abnormalities of blood glucose homeostasis, high concentration of plasma glyceride and low HDL that leads to T2DM and CVD (Lafontan and Girard 2008).

Independent of BMI, WC seems to be associated with several risk factors of hypertension in older and middle-aged adults (Guagnano et al. 2000, Levine et al. 2011). Reduction in weight can lead to meaningful reduction in- visceral adipose tissue mass and reduction in SBP (Engeli et al. 2005). Additionally, it has been observed that there is a wide ethnic variation in the prevalence of HTN together with biological, demographic, lifestyle and anthropometric risk factors (Krishnadath et al. 2016). Several population base study in the UK have found that SA men have significantly higher mean BP level as compared to their white counterparts therefore, ethnicity should be considered in management of BP (Whitty et al. 1999, Primatesta et al. 2000, Lane and Lip 2001). Also, a relationship between salt intake and BP has been established and it has been found that a reduction in salt intake can lower BP and risk of heart failure (He and MacGregor 2010). Current UK intakes of salt are around 8g/d whereas recommended guidelines suggest a target of 6g/d (Purdy 2019).

The Dietary Approach to Stop Hypertension (DASH) has been proposed as a life-style modification to manage hypertension, that mainly focusses on healthy eating guidelines (Sacks et al. 2001). It recommends high intake of fruits and vegetables with low fat dairy foods and a reduced / limited intake of red meat and added sugars (Coulston et al. 2013).

For the management of hypertension as with other lifestyle interventions, the DASH eating pattern plays a vital role. The reduction of sodium intake to levels below the recommended limit of 6 g/d together with the DASH diet both lead to a substantial decreased in blood pressure. Importantly, their effect is synergistic when both are undertaken together rather than being adopted as a standalone approach. Longer term health benefits will depend on the ability of individuals to maintain these long-lasting dietary changes including the selection of foods with a lower-sodium content (Tyson et al. 2012, Spence. 2018).

Numerous trials have reported that blood pressure in consistently lower across a various range of patients with hypertension and pre-hypertension (Steinberg et al. 2017). The effect of the DASH diet in reducing both systolic and diastolic blood pressure has been shown to be greater in people age <50 y compared with older individuals (Filippou et al.2020). A meta-analysis has revealed that adherence to the DASH diet could significantly reduce the risk of all-cause mortality by 5%, CVD mortality by 4%, stroke mortality by 3% and cancer mortality by 3% (Soltani et al. 2020).

Consistent implementation of the DASH diet is believed to improve circulation and has been reported to improve inflammatory biomarkers in adults. Hence this could be be a valuable dietary strategy to reduce the inflammatory process (Shirani et al 2017).

1.3.3 Dyslipidaemia

Dyslipidaemia is defined as an abnormal concentration of cholesterol and other lipids in the blood. It is an important feature of metabolic syndrome (MS) and a commonly known risk factor for coronary artery disease. Central obesity or visceral obesity can induce insulin resistance, which is associated with dyslipidaemia, impaired suppression of free fatty acid (FFA) as well as with hypertriglyceridemia and low concentrations of high-density lipoprotein (HDL) cholesterol all of which worsen atherosclerosis (Singh et al. 2011, Ebbert and Jensen 2013). The association of obesity and dyslipidaemia has been observed in adults as well as in children and adolescents. The development of insulin resistance in peripheral tissues is considered to be an important link between obesity, the metabolic syndrome and dyslipidaemia, which eventually leads to an increased hepatic flux of fatty acids from diet and causes intravascular lipolysis (Klop et al. 2013).

1.3.4 Non-Alcoholic Fatty liver disease

The increasing prevalence of obesity is becoming the most common cause of chronic liver disease known as non-alcoholic fatty liver disease (NAFLD) (Sarwar et al. 2018). The estimated prevalence of non-alcoholic fatty liver disease (NAFLD) worldwide is approximately 25% (Araújo et al. 2018). Visceral obesity is a significant risk factor for the onset of NAFLD as the liver is drained by hepatic portal system. High visceral fat leads to an increase delivery of free fatty acids, a product of lipolysis, to the liver which may drive the enhancement of intrahepatic lipid synthesis and storage as well as insulin resistance (Matsuzawa et al. 1995, Sears and Perry 2015). Most people with NAFLD have simple steatosis but in up to one third this disease progresses to its more severe form called non-alcoholic steatohepatitis (NASH). NASH is characterised by liver inflammation and damage thereby determining the risk to develop liver fibrosis and cancer (Dietrich and Hellerbrand 2014). NAFLD is also recognised as a major chronic liver disease in Asia. As there is no current pharmacological treatment for this condition, global awareness together with diet and lifestyle modification is needed so that worldwide strategies can be instituted to change the course of this disease (Ashtari et al. 2015, Younossi 2019). Weight loss is clearly the most effective way to reverse this condition, with emphasis on waist circumference reduction.

1.3.5 Cancer

Consistent research has shown that overweight and obesity are linked with cancer. There are at least six cancers (breast, colon, endometrium, esophagus, renal and pancreatic) which are clearly linked with obesity (Avgerinos et al. 2019). Obesity is considered a modifiable risk factor in cancer. Chronic positive energy balance in obesity induces metabolic changes that favour tumour initiation and progression (Pinheiro-Castro et al. 2019). Approximately 20% of all cancer cases are associated with obesity (Wolin et al. 2010). In men and women, BMI is a predictor of obesity-related risk of cancers (Chadid et al. 2020). Furthermore, in men small hip size and large waist circumference are independent predictors of cancer risk. While emerging evidence suggest that in postmenopausal women, intentional weight or WC loss decreases the risk of obesity-related cancer (Luo et al. 2019).

1.3.6 Metabolic Syndrome

Reaven was the first to describe the phenomenon of clustering of co-morbidities in 1988 and discussed this as Syndrome X (Reaven 1988). Syndrome X, also known as metabolic syndrome (MS), refers to the clustering of abdominal (central) obesity, high blood pressure, insulin resistance, low HDL-cholesterol and dyslipidaemia (Galassi et al. 2006). This ‘clustering’ of co-morbidities appears to confer a 2-fold increase in cardiovascular outcomes and a 1.5-fold increase in all-cause mortality (Mottillo et al. 2010).

Clinical criteria for the diagnosis of MS have been identified. In 2001, the National Cholesterol Education Program (NCEP) Adult Treatment Panel III (ATP III) described the term “metabolic syndrome”. According to this description the presence of any 3 of 5 specific risk factors: Insulin resistance (glucose intolerance), high triglycerides, central adiposity, elevated blood pressure and low high-density lipoprotein cholesterol (HDL-C) (Expert Panel on Detection 2001) is defined as MS. Although insulin resistance is an important component of the MS, the new International Diabetes Federation (IDF) definition suggest its measurement is not essential as it is difficult to measure in clinical practice, whilst abdominal obesity is strongly correlated with other MS components and much easier to measure (Carr et al. 2004, Alberti et al. 2006).

Studies have shown that childhood obesity predicts the risk of development of MS and CVD in adulthood (de Ferranti et al. 2004, Morrison et al. 2007). However, to define paediatric MS it is important to focus on cardiometabolic risk factor in children (Magge et al. 2017).

Currently, there is no consensus on the definition of MS in children. For example, the WHO and IDF vary slightly in their diagnostic criteria. However, MS has been investigated in children and adolescents (Zimmet et al. 2007). Viner et al., (2005) (using the WHO definition) investigated the prevalence of insulin resistance syndrome (MS) using the criterion of having 3 or more components (Table 1.1) of the syndrome obesity (BMI), abnormal glucose homeostasis, dyslipidaemia and hypertension (>95th centile SBP for age). This study found that from a group of 103 obese children and adolescents aged 2 to 18 yrs, one third met the criteria for metabolic syndrome (Viner et al. 2005).

Table 1.1: Definition of components of insulin resistance syndrome or MS

Definition of Insulin Resistance Syndrome (MS) component	
IRS Component	**Definition**
Obesity	BMI >95th centile for age and sex
Abnormal glucose homoeostasis	Any of the following: A. Impaired glucose tolerance: glucose at 120 min >7.8 mM/l B. Fasting hyperinsulinaemia C. Impaired fasting glucose (>6.1 mM/l)
Hypertension	Systolic blood pressure >95th centile for age and sex
Dyslipidaemia Any	Any of the following: A. Low HDL (,0.9 mM/l) B. Elevated total cholesterol (>95th centile). C. Elevated triglycerides (>1.75 mM/l)

Thirty-one percent had obesity alone, 36% had two components of insulin resistance syndrome, 28% had three component of insulin resistance syndrome and 5% had all four components. Studies have shown that with an increase in every 0.5 BMI units (kg/ m^2), each aspect of the metabolic syndrome has shown to worsen (Weiss et al. 2004). Equivalent increases have not yet been identified for increasing WC, even though IDF use WC>90th centile as one criterion (replacing BMI>95th centile) [detail in section 1.8.3].

1.4 Economic burden of obesity

Obesity in term of its prevalence, incidence and economic burden presents a significant danger to national and worldwide public health (Tremmel et al. 2017). The available evidence clearly proposes that higher BMI is related with increased utilisation of health care resources and reduced productivity (Dee et al. 2014). It has been estimated that in 2014 to 2015, £6.1 billion were spent by the UK NHS on all disease and health conditions related to overweight and obesity. The overall cost of obesity to wider society is estimated roughly £27 billion. In 2016, the chief executive of NHS, Simon Steven, claimed that more money is being spent on the treatment of obesity related condition than on police and fire services combined. The evidence proves that obesity is adding tens of billions of pounds of burden to the UK economy every year (Public Health England, 2017) It has been estimated that by 2035, the increasing rate of obesity related diseases including type 2 diabetes mellitus (T2DM), stroke, CHD and cancer will cost an extra £2.5 billion per year. It is estimated that if the growth rate of obesity could be gradually decreases by 1% constantly annually (considering a 20 year planning) from 2015 and 2035, then by the end of this period i.e. 2036, about £300 million could be saved from the cost of wellbeing and social care just in that year (2035) alone (Bhimjiyani et al. 2016). As obesity is linked with decreased productivity and unemployment, therefore it is important to approach individual intervention along with change in society and environment (Blüher 2019).

As increasing prevalence of overweight and obesity in UK is not only associated with poor health status within the society but also a burden on the overall economy, the government has therefore been taking initiatives to manage the situation by proposing and implementing various policies and programmes.

1.5 Current obesity policy

In 2000, the National Audit Office called upon government to work jointly with NHS, policymakers, practitioners and researchers from the public and voluntary sectors to produce the first formal UK policy and strategy to address the obesity crisis (Bourn 2001). England has been viewed as a worldwide pioneer for its presentation of both front-of pack food labelling and the first to restrict the advertisement of food items high in fat, salt and sugar to children. However, the scale of the challenge requires that substantially more should be done for people if they want to be active and healthy. To reflect this, the Government set its new objectives.

This was formalised into the document called, Foresight Report – "*tackling obesities: future choices*" which was published in October 2007. In this report a Foresight map was presented, which helped to visualise the concept of a 'whole systems approach,' because there are many complex behavioural and societal factors that work together and cause obesity (Fig 1.4) (Butland et al 2007). The purpose of this policy document was to help developing a framework for action.

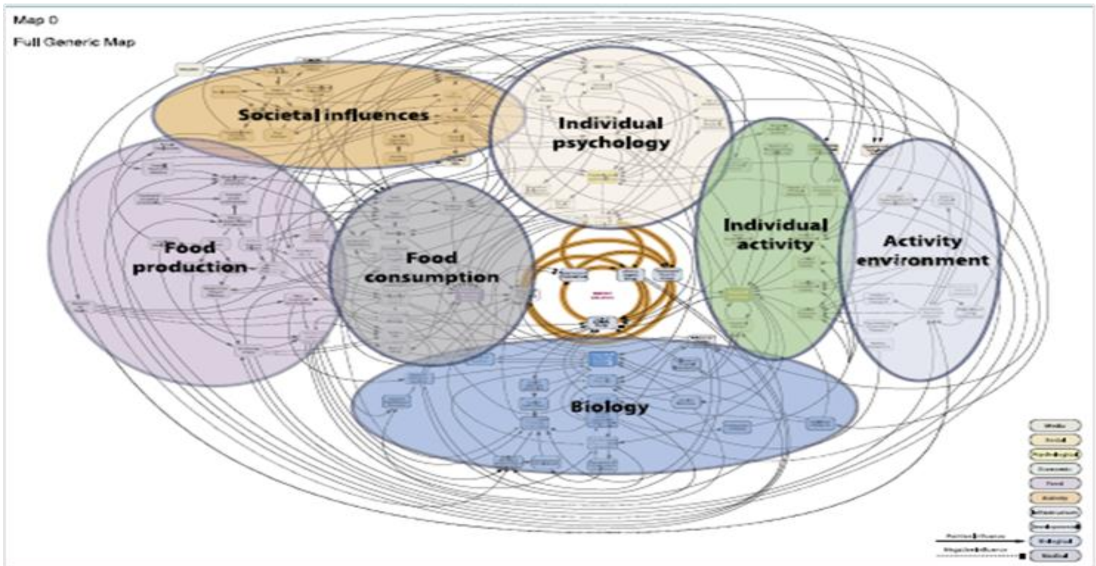


Figure 1.4: The full obesity system map with thematic clusters

(Butland et al. 2007)

This map has sometimes been criticised for its complexity, but the identification of the influences of the environment on personal 'choices' was necessary in order to construct effective strategies. One of the outcomes of this action was "Healthy Weight Healthy Lives (HWHL)." In 2008 the strategy document 'Healthy Weight, Healthy Lives' was published which contained five key targets;

- To encourage children's health
- To encourage healthy eating
- To promote routine physical activity into daily lives
- To encourage health at workplaces
- To provide effective treatment and support for obese

As part of the HWHL strategy the "*Change4life"* program was launched in 2009 which at the time was considered the "biggest ever movement" against obesity anywhere in the world as £75 million were initially assigned to this project. This approach has opened a new option for the people to have choices of their interest which will be prudent to minimise the obesity, especially among children. The motivation for this strategy was not only to pause the soaring trend of obesity by 2020 but also reverse back this to the 2000 levels.

In addition, the National Child Measurement Programme (NCMP) commenced in 2006 as part of the Department of Health's effort to reduce childhood obesity. The height and weight of reception and 6y children from state sponsored schools and institutes have been measured. In England around one million children are measured annually. NCMP has two key features: Firstly, it is an excellent source of surveillance data which help in monitoring obesity prevalence and trends in underweight, healthy weight, overweight and obesity at national and local levels. Secondly it gives information to parents on their child's weight status (Copley et al. 2017).

The NCMP uses the British 1990 growth reference (UK90) to define the BMI classifications, which is recommended by NICE. In the NCMP, overweight is defined as having a BMI at or above the 85th percentile and obese is defined as a BMI at or above the 95th percentile of the British 1990 growth reference (Cole et al. 1995).

1.6 Body composition

The childhood obesity has risen significantly worldwide, and its assessment become more complex particularly during growing phases of development due to body composition change (Jeddi et al. 2014). The study of human body composition has been carried on for over 100 years and yet remains an active area of basic science and translational science exploration and clinical research. Wang et al. 1992 presented a comprehensive model of human body composition which consist of five distinct levels. In which each level is clearly defined with its components which are organised in a way of increasing complexity and covers total body weight. Fig. 1.5 represents these five levels I. atomic: II, molecular: III, cellular: IV. Tissue system: and V. whole body (Wang et al. 1992).

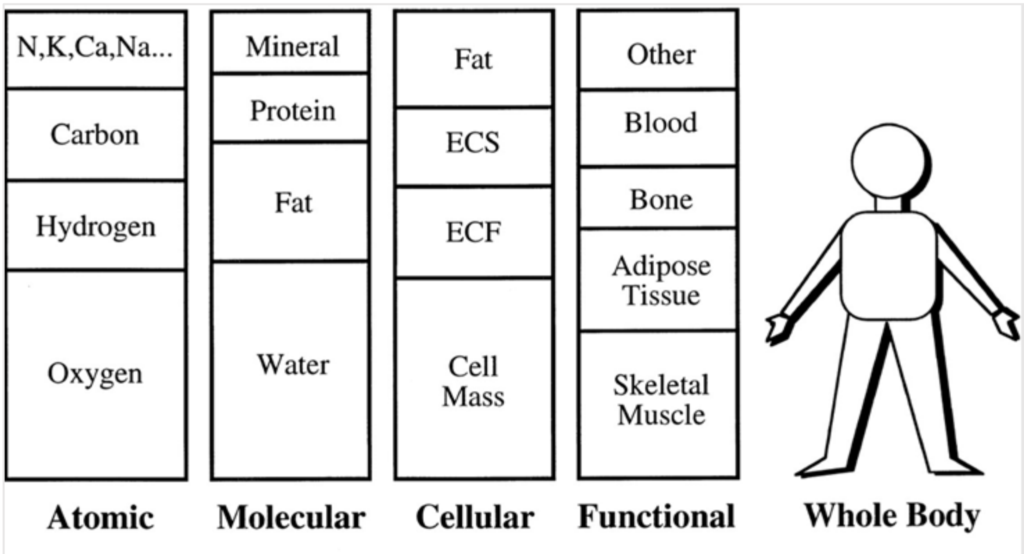


Figure 1.5: Multicompartment model of body composition (Wang et al. 1992)

Extensive research on body composition using two-component molecular level model has been made since last decade (Fig 1.5a). Conceptually in the two-compartmental model, body mass is broadly divided into two compartments at molecular level such as fat mass (FM) and fat-free mas (FMM) which encompasses all the internal organs (such as bones, muscles etc.,) and tissues (such as connective, muscular, epithelial tissue etc) and components such as water, blood (Heyward and Wagner 2004).

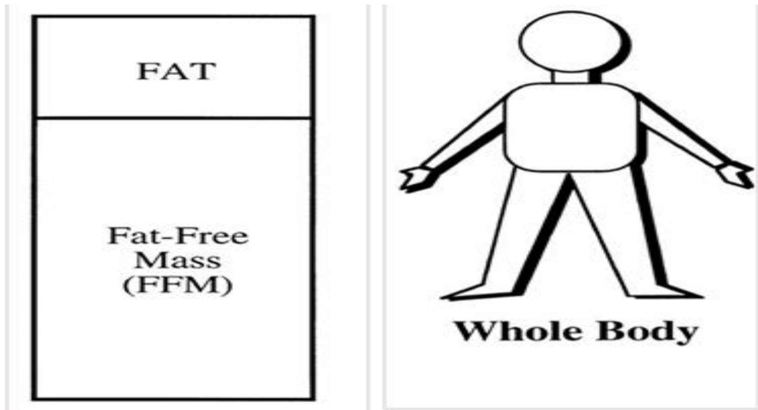


Figure 1.5a: Basic two compartment model

The two-compartment models are based on several assumptions; the key assumptions including

1. Fat mass with a presumed density of 0.9007 g/ml
2. FFM with a presumed density of 1.1000 g/ml
3. Fat mass and fat free mass, for all individuals, have the same densities.
4. Relative contribution of tissue containing FFM remains constant to lean component.
5. Only the amount of fat differs in individuals from the reference body. These assumptions made from the analyses of three male cadavers where the FFM of reference body was analysed to be comprising water (73.8%), protein (19.4%), and mineral (6.8%) (Siri 1961, Brožek et al. 1963, Ellis 2000). Thus, after getting body density (Db) from hydro densitometry, percentage of body fat can be calculated by using equation:

% Fat = (4.95/Db-4.50) 100 (Siri 1961)

It is evident that density of FFM within a body varies with gender, age, ethnicity, physical activity level and level of body fatness (Heyward and Wagner 2004). In order to avoid systematic error in estimation of body fat by using 2-C model equations, researchers have applied multicomponent models (Yeung and Hui 2010). For example, Lohman and his co-workers proposed a four-component model using hydro static weighing, total body water by deuterium dilution, and body mineral content from forearm by photon absorptiometry to determine the body composition in children and adolescents. The results of their work revealed that the disparity in water and mineral content of the FFM has a significant effect on the body density of the prepubescent children (Lohman et al. 2013).

A review of various indirect techniques of assessing body composition and fat distribution is presented.

1.6.1 Hydro densitometry (HD)

For defining total body volume hydro densitometry or underwater weighing technique has long been accepted as the ‘gold’ standard method (Wang et al. 2003). This technique works on Archimedes’ principle which states that “*the upward floating force that is applied on a body immersed in a fluid, is equal to the weight of the fluid that the body replaces and acts in the upward direction*”. When the subject is underwater subject’s body volume can be estimated from the volume of displaced water (Heyward and Wagner 2004). This measurement can be done when subject is fully submerged and the residual volume of air in lungs and the gut should measure separately (Brožek et al. 1963). This application is limited to the population whose underwater weight (UWW) is achievable. Though, it is difficult or impossible for children and elderly people, but the invention of air displacement plethysmography eliminates the requirement for underwater weighing in order to measure the body density (Mattsson and Thomas 2006).

1.6.2 The air displacement plethysmography (ADP)

Air displacement plethysmography (ADP) is considered as an alternative tool to estimate the body volume and body fat for underwater weighing. The principle of this technique is being used in a new device known as “Bod Pod; Life Measurement Instruments”, which is very simple in composition consisting of a “test chamber” and a “reference chamber” divided by a diaphragm. The BOD POD Body Composition System uses the relationship between pressure and volume to derive the body volume of a subject seated inside a fiberglass chamber (Dempster and Aitkens 1995, Mattsson and Thomas 2006).

By deriving body volume along with measurement of body mass, body density can be calculated with subsequent estimation of percent fat and fat-free mass (Dempster and Aitkens 1995). In ADP body volume is calculated indirectly by measuring the volume of air displaced when subject is inside. The Boyle's law states that volume (V) and pressure (P) are inversely related and this principle also applies to measure the air inside the chamber (Fields et al. 2002) i.e. $P1/P2 = V2/V1$. This technique overcomes the difficulties associated with underwater weighing but recalls the ambiguities of the HD technique (Mattsson and Thomas 2006).

The common advantages of both UWW and ADP techniques include enhanced accuracy, the data being more reliable with standardized procedure and considered as a "gold standard method" for use in research lab. Few limitations associated these techniques include equipment being expensive, require an expect technician, accuracy being affected by clothing, hair and hydration status and technique not being validated for athletes of different ethnicities and different bone densities. Additionally, these techniques do not support assessment of regional body composition. (Ackland et al. 2012, Aragon et al. 2017, Larson-Meyer et al. 2018).

1.6.3 Total body water

The measurement of total body water (TBW) is called hydrometry (Heyward and Wagner 2004). Measurement of water is easy as it does not need undressing or any real physical input. The most abundant molecule in the body is water the volume of which can be measured by isotope dilution (Siri 1961, Chumlea et al. 2007). Most commonly used stable isotope labelled water is deuterium oxide, which can be safely administered in humans. D_2O is used to measure TBW because deuterium ($_2H$) is nearly two times heavier than hydrogen ($_1H$) and can be easily spotted by using a mass spectrometer. After equilibrium the concentration of this water is measured to determine TBW (Lohman 1992, Wang et al. 2005).The analysis of body composition using the dilution technique is based on the basic concept that the volume of a compartment of the body can be considered as a controlled proportion of the tracer dose which is fixed in that body compartment inside a brief timeframe (Ellis 2000).

There is relatively stable relationship between water and FFM therefore, prediction of FFM and fat (i.e. body weight minus FFM) can be measured by this water/isotope-dilution (Siri 1961, Chumlea et al. 2007). The estimation of FFM from TBW is based on the assumption of constant hydration of FFM. Pace (1945), was the first scientist who recommended that this hydration constant is 0.73 which further confirmed by other studies (Keys and BroŽek 1953, Moore et al. 1968, Knight et al. 1986) but this hydration ranges between 0.67 to 0.80. Hydration of FFM is maximum 0.8 at birth which ultimately reach to 0.73 during teenage year (Wang et al. 2003, Sopher et al. 2005, Chumlea et al. 2007). Theoretically, in an obese person equilibration time for isotope dilution should be longer as compared to normal weight individual. As adipose tissue contains 15 to 30 % of TBW as extracellular fluid and this proportion increases with the increase of adiposity. Total body water is a useful method which is appropriate for obese but there are some aspects that need to be measured as there is significant increase in hydration of obese individuals, similarly this method is impractical for very small children particularly new-borns and for large scale studies (Mattsson and Thomas 2006, Chamney et al. 2007, Chumlea et al. 2007).

1.6.4 Dual energy X-ray absorptiometry (DXA)

First, the density of bone was used to be calculated by a visual comparison of density of bone and the known densities on the phantom. The next advancement in this field was the innovation of single-photon absorptiometry (SPA) (Cameron and Sorenson 1963). This was not recommended for measuring densities of soft tissues with variable thickness, which then lead to the introduction of the dual photon absorptiometry (DPA) that allowed gamma rays of two different energies to distinguish soft tissue from bone.

Dual X-ray Absorptiometry (DXA) scanners were initially designed to assess total body bone mineral (TBBM) and bone mineral density (BMD) by substituting the technology of dual photon absorptiometry (DPA) which uses expensive and potentially hazardous radioactive sources (Kelly et al. 1988, Kelly et al. 1994). DXA is the most common method which can quantify fat, lean tissue and bone tissues (Roubenoff et al. 1993, Kohrt 1995). The X-ray used for diagnostic purposes and for measuring density must have enough energy that can pass through the body and after passage still be detectable by the sensor (Mattsson and Thomas 2006). The basic principle of DXA is the measurement of conduction of x-rays with high- and low-energy photons through the body. The better photon flux permits the DXA method to be applied for estimation of soft (fat and lean) tissue composition (Crabtree et al. 2007).

One of the key assumptions of DXA is that the attenuation of photon, in soft tissues which is either overlying the bone or adjacent to the bone, is similar (Mattsson and Thomas 2006). The accuracy of a particular DXA scanner for measurement of whole-body composition is generally good with about 1% coefficients of variation for bone mineral content and about 2–3% coefficients of variation for total body fat. DXA is reasonably low budget compared to other imaging options with remarkably shorter scan times and radiation exposure, and there is a long-standing agreement regarding instructions for interpreting DXA images.

One of the limitations associated with the use of DXA is the size of DXA scanner which cannot accommodate obese individuals whose body weight and dimension exceeds the restrictions (Heyward and Wagner 2004).

1.6.5 Computerized tomography (CT) and Magnetic Resonance Imaging (MRI)

The most important advancement in the history of human body composition research is the application of computed tomography (CT) and magnetic resonance imaging (MRI). These are the only validated procedure available for the assessment of internal organs and tissues. Within the clinical settings, these two methods are widely used to measure various soft tissue organs including liver, lungs, brain etc., and high-density organs such as bones. Both MRI and CT have considerably enhanced our knowledge of human body composition and to better understand the relation between body composition and disease risks (Ross 2003, Mattsson and Thomas 2006). More recently, Goodpaster et al. (2000) found that in obesity and T2DM the attenuation of mean muscle is reduced in skeletal muscle and concluded that attenuation of skeletal muscle is related to its lipid content and can be determined by CT.

MRI is also used for body composition studies in children and teenagers. Main function of MRI is to distinguish the amount and dispersal of adipose tissue and skeletal muscle and also subcutaneous adipose tissue, intramuscular adipose tissue, visceral adipose tissue, oedema and various organs (liver, kidneys, heart, spleen, pancreas). MRI is used for quantitative as well as qualitative measurements (Mattsson and Thomas 2006). The influence of weight loss on body composition can be assessed by gaining whole body MRI data. For example, during weight loss process, reduction in muscles and/or adipose tissue occurs. Thus, if loss of skeletal muscle mass in one region is masked by an increase in skeletal muscle mass in another region, this can only be detected by MRI as MRI gives the fast-imaging sequences for qualitative measurement of human skeletal muscle (Ross et al. 2000).

1.6.6 Skinfold thickness measurement

Skinfold thickness measurement is an alternative of laboratory method. Currently this is the most commonly used method for measurement of body fat in children as it is inexpensive and non-invasive. Since the instruments used in this method are portable so can be easily available in clinics, laboratories and school (Deurenberg et al. 1990, Heyward and Wagner 2004).

According to Heyward (1996), the estimation of total body density for deriving percent body fat by using skinfold method is based on 2 key assumptions. Firstly, it is assumed that skinfold measurement is a good measure of subcutaneous fat. Secondly, it is assumed that distribution of subcutaneous fat is similar for all individuals within each gender, therefore sum of skinfold measurements taken from different body areas can be used to estimate total body fat.

Skinfolds are mainly suitable for monitoring variations of fatness in children because they have smaller body size, and most of the fat is subcutaneous fat even in obese children. But its utility is limited in adults particularly overweight or obese adult because there is an upper measurement limit of 45 to 55 mm in most skinfold callipers which confines their use to individuals who are relatively normal weight or thinner. The other limitation associated with this method is that there is prediction error of 3-5% for the assessment of percentage body fat, which is higher in the prepubertal children. Although, the national reference data is available for triceps and subscapular areas but there is a limitation in triceps measurement as a) this site is gender-specific and b) its measurements are confounded by the changes in the underlying triceps muscle rather than an actual change in body fatness (Malina and Bouchard 1988, Brambilla et al. 1994, Duren et al. 2008).

Thus, despite the several advantages, the accuracy with which body fat is predicted is dependent on measurement technique and the validity of the underlying assumptions.

1.6.7 Urinary creatinine excretion

Measurement of skeletal muscle mass has a significant role in nutritional assessment. The recommended technique for its measurement is to monitor the 24-h urinary excretion of creatinine. Creatine is a nitrogenous organic compound, which is found primarily in muscle. Myers and Fine were the first who found that the output of urinary creatinine is directly proportional to the total body creatine content in three species: human, dog and rabbit. This calculation of “creatinine equivalence” (kg muscle mass/g urinary creatinine) was based on three key assumptions (Myers and Fine 1913, Walker 1979, Heymsfield et al. 1983), which are 1) the creatine is present within the skeletal and smooth muscle 2) creatinine formed from non-enzymatic hydrolysis of creatine which is an irreversible process and 3) the creatinine undergoes renal excretion at a constant rate.

The calculation of this constant is limited by the fact that there is a lack of an alternative and acceptable non-invasive procedure for the measurement of muscle mass to which creatinine method can be compared. Secondly, the excretion of creatinine is dependent on how much creatine you have in your diet. Its excretion increased by 10-30% with creatine-rich diet and decreased during the creatine-free diet. So, there is restriction of diet during measurement period (Heymsfield et al. 1983, Caprio et al. 1989, Duren et al. 2008). The creatinine proportionality is about 17 to 20 kg muscle for each g of creatinine; however, the variability and accuracy of these appraisals stay unreliable. The utilization of urinary creatinine discharge as an index of muscle mass is theoretically interesting that gives valuable information in deliberately chose subject groups (Heymsfield et al. 1983).

1.6.8 Bioelectrical impedance analysis (BIA)

This fact has been established for more than hundred years ago that human tissues and in turn the whole human body has the ability to conduct an electric current (Ellis 2000). Galvani was the first scientist who discovered the electrical conductance properties in animal tissues. It has been recognised that the electrolytes present in aqueous tissue of the body act as main conductor of an electric current whereas body fat and bone have relatively less conductance properties. Further studies on this property of tissues and whole body have led to the discovery of Bioelectrical Impedance analysis (BIA) in 1970s (Whittaker 1951, Lukaski 1996).

BIA is based on 2 compartmental body composition model. It measures the impedance or resistance of small electric current when it passes through water pool of whole body by employing Ohm's Law, which states that "*the resistance (R) of a substance is proportional to the voltage drop of an applied current as it passes through the resistive substance*".

R=E/I

E= voltage drop

I = current

(Kushner 1992)

A schematic diagram which will improve understanding about body compartments that BIA expect to analyse is shown in Fig 1.6 below.

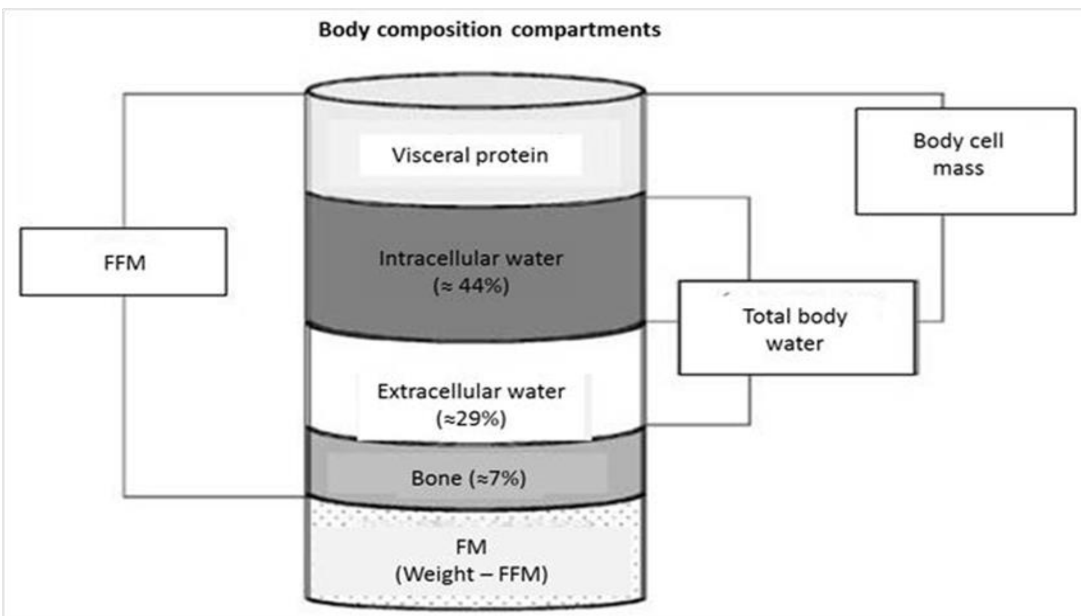


Figure 1.6: Schematic diagram of fat-free mass (FFM), total body water (TBW), intracellular water (ICW), extracellular water (ECW), and body cell mass (BCM)

(Kyle et al. 2004)

One of the two compartment i.e. FFM, which includes everything except body fat (Fig 1.6) can be predicted by the estimation of total body water (TBW). A greater volume of TBW allows better flow of current through the body (Kyle et al. 2004). The fundamental assumptions used for this indirect estimation of volume of TBW included the following.

Measurement of Body composition by BIA assume that the dispersal of TBW and electrolyte is inversely proportional to the resistance of a determined electric current. Fig 1.7 explains that this resistance (R) of the conductor made of similar material and having a uniform cross-sectional area is directly related to its length (L) and inversely related to its cross-sectional area (A). Despite the fact that conductivity of human body is not constant, and it is not in uniform cylindrical shape, a practical relation can be constructed between the coefficient of impedance ($Length^2$ / R) and the volume of water that contains electrolytes which helps transmitting the electrical current through the body (Mialich et al. 2014).

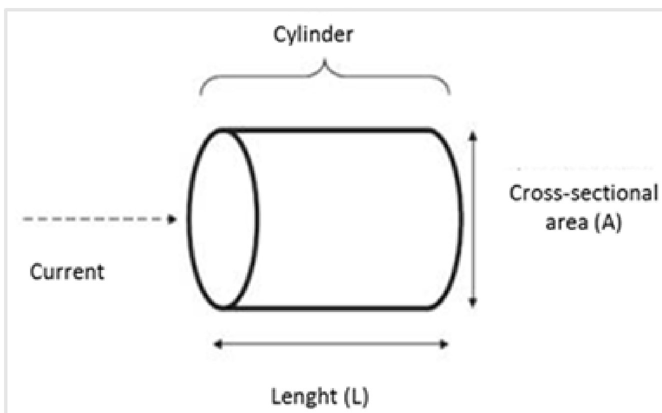


Figure 1.7: Principles of bioelectrical impedance analysis (BIA)

Fat-free mass is determined by the bioelectrical impedance using the principle of BIA which states that the impedance of a geometrical system is related to the length of conductor, configuration, signal frequency and its cross-sectional area. With the conductor configuration being constant along with constant signal frequency, the impedance to the flow of current can be identified to the progression of current $\Rightarrow Z = \rho L/A$, where Z is impedance in ohms, ρ is volume resistivity in ohm X cm, L is conductor length in cm, and A is conductor cross- sectional area in

cm_2 (Fig 1.7). Multiplying both sides of the equation by L/L gives: $Z = \rho L_2/AL$, where AL equals volume (V). Thus, Z = pL2/V (Lukaski 1990).

The most commonly used BIA is Single-frequency BIA (SF-BIA) which asses TBW and FFM but its ability to distinguish the intracellular and extracellular compartments in TBW is limited (Lim et al. 2009). To overcome this limitation multifrequency BIA was developed which differentiate intracellular water (ICW) and extracellular water (ECW) compartments in TBW. This differentiation is useful for exploring hydration variation between these two compartments. An added advantage of multifrequency BIA is that it helps in evaluating leg skeletal muscle mass (Heymsfield et al. 1996).

BIA is a non-invasive, quite low in cost and fast method for measuring body composition. The advantage of BIA is its portability and requires less involvement of participants which makes it more attractive for large scale studies (Foster and Lukaski 1996). There are several factors which can affect its precision and validity e.g. position of the body and its hydration status. That's why result should be interpreted with caution in individuals. Validity of BIA is also influenced by sex, age, disease state and ethnicity (Rush et al. 2006).

In 1980s BIA equation include only height and resistance but to increase the accuracy of its prediction later it started to include other variables such as weight, age, gender, reactance and anthropometric measurements of trunk. Different BIA equation were made for the estimation of FFM and validated against the criterion measure (Kyle et al. 2004). Due to increasing trend of obesity and different health condition related to this obesity it is important to estimate the body composition in different population group.

BIA equations have been developed for 12 to 80 yrs of age group from non-Hispanic whites, non-Hispanic blacks and Mexican-American background males and females (Chumlea et al. 2002). These equations were not recommended for other population group. Asian Indians specific BIA equations were developed for FFM prediction. This new proposed equation was based on easily measured variable and was applicable to male and female Asian Indian populations living in Western countries. This Specific equation is considered more suitable than BMI and are recommended to use in field studies as it covers wide age and body fat ranges (Rush et al. 2006).

Different studies has been conducted to explore the accuracy of BIA , such as Leahy et al. (2012) investigated the accuracy of BIA in comparison to DXA for the evaluation of total and regional body composition and finally concluded that there is a small statistically significant difference (~ 4%) between the two methods which indicates that for determining FFM in young adults BIA can be used instead of DXA. A good level of correlation between TBW and body impedance has been confirmed in both normal subjects and in patients with overhydration. This good correlation reveals that the impedance method has potential of quick and easy prediction of total body water volume (Hoffer et al. 1969).

BIA has been used for the estimation of body composition over hundred years. Since 1994 significant improvement has been made in BIA technology which increase the utility of this technique in clinical as well as research setting (both lab and field based) for the evaluation of skeletal muscle mass (SMM) and body fat percentage (Ellis et al. 1999).

1.6.8.1 Segmental Body Composition Analyzer

The segmental body composition analyser has 8-contact electrode (two on each hand and foot) which allows the rapid evaluation of whole body as well as regional body composition. These extra electrodes increase the efficiency of the segmental BIA over the conventional BIA using foot-foot electrodes. A pre-defined electrical signal is circulated through injector electrodes which is measured via receiver electrodes to calculate the impedance across the subject’s tissues.

A total of 5 segments are measured, each arm, each leg and remainder (trunk +head) of the body which is based on the difference between total body estimate and the corresponding appendicular estimates. The alignment of electrode for the measurement of this segmental impedance measurements were based on the study of Organ et al. (1994). The 8-contact electrode system has the ability to evaluate mean regional lean soft tissue (LST) and whole-body SM as an alternative of DXA and MRI which are costly and cannot be easily applied in field settings. Segmental BIA systems thus provide important new research and clinical opportunities.

BIA is considered as an innovative diagnostic tool to evaluate the human body fatness in such a fast growing and rapidly changing lifestyle. This technology has made a great progress in the measurement of body composition such as Body fat%, Fat free mass, Total Body water, Basal Metabolic rate and segmental fat distribution which are the key parameters to evaluate the physical fitness. (Subhedar et al. 2014).

1.7 Body composition under the concept of 2-compartment model

As described earlier the two compartmental model visualises the body as having 2 main entities – fat, called fat mass and anything which is not fat, called fat free mass. These are discussed below

1.7.1 Fat mass and Body fat percentage

Now a days for public health nutrition practice it is very important to find out measures of overweight and obesity and their relation to metabolic risk. In this setting for successful surveillance along with all anthropometric measurement, accurate measurement of FM and percentage body fat (BF%), is also very important (Reilly et al. 2010, Lanham-New et al. 2019). Due to increase in adiposity it has become very important to classify subject health status based on this adiposity, currently there is no known published ranges of percentage body fat. However, figure 1.8, 1.9 and 1.10 shows the healthy range of body fat for standard adults, standard adults from Asians and a range of body fat for children that offer the base and motivate the development of internationally applicable healthy body fat range (Gallagher et al. 2000).

Figure 1.8: Healthy body fat range for standard adults

(Gallagher et al. 2000)

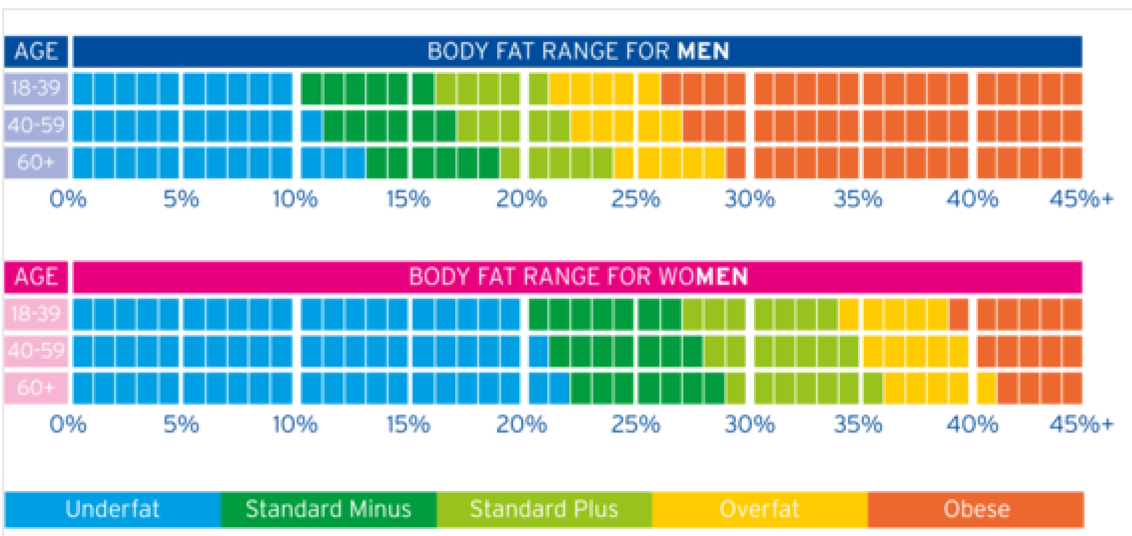


Figure 1.9: Healthy body fat range for standard Asian adults

(https://www.tanita.asia/?_page=understanding&_lang=en&_para%5B0%5D=1)

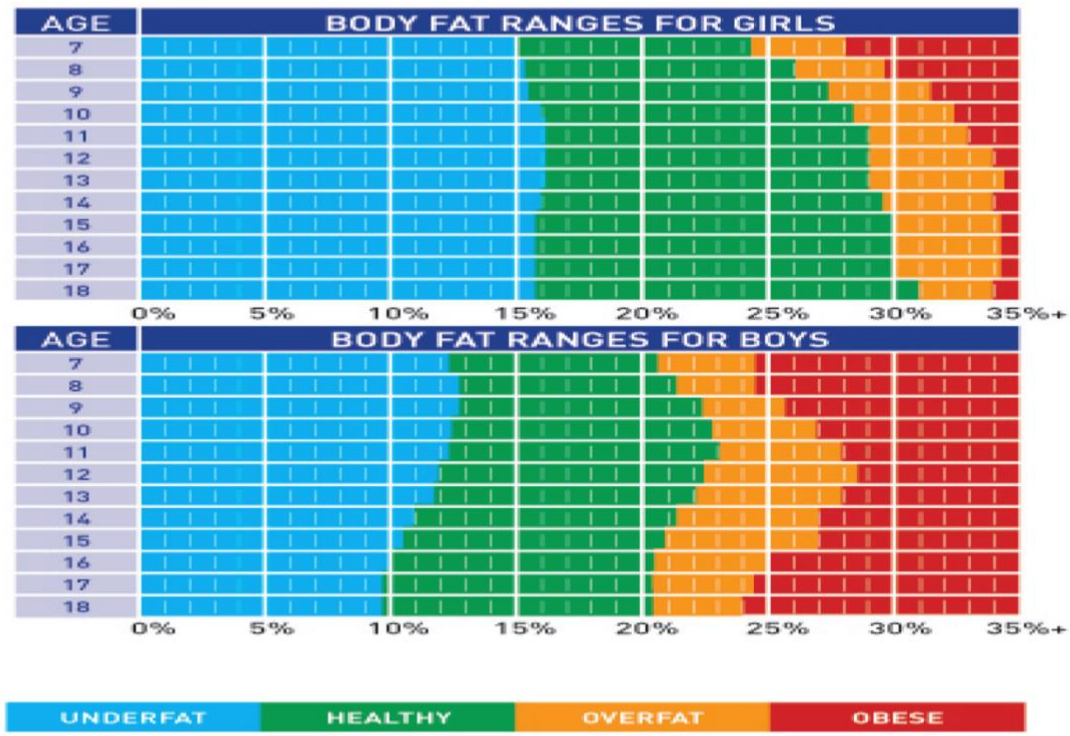


Figure 1.10: body fat ranges for children

https://www.tanita.asia/upload/understanding/1/self/573bbf83ae587.pdf

The men with > 25% of body fat and women with > 30% of body fat are agreed to be considered as obese by majority of the scientific/clinical communities and health care providers (Snitker 2010). Obesity is an abnormal condition in which extra body fat is stored to an extent to have undesirable and adverse effect on individual's health (Paediatrics and Health 2004). Increasing fatness of children and young people has developed the interest of pediatric obesity and have become one of the major parts of global public health crisis. There are many different factors that can influence the body composition in children such as growth, metabolic activity, physical activity and physical fitness. In children defining obesity becomes more challenging because BMI is highly age dependant. Similarly, gender is a basic concern in assessment of obesity because boys and girls have different growth pattern (Daniels et al. 1997, Pietrobelli et al. 2004, Wang and Lim 2012). There is limited data available for the direct measurement of adiposity in children. Generally, BMI is used to categorise individuals as overweight or obese but BMI does not differentiate between fat and fat-free mass (Misra and Khurana 2011). It is very important to go beyond BMI for accurate assessment of metabolic health at an individual level (Goossens 2017). Except total fat it is also very important to measure the distribution of fat in the body because adipose tissue around the visceral organs gives substantial negative health outcome including the development of T2DM, coronary heart disease and osteoarthritis (Björntorp 1992, Agha and Agha 2017). It has been suggested that distribution of fat differ between different ethnic group, so it is important to consider this difference when describing health outcome. Several studies have shown that in South Asian population at a low BMI it does not mean that there will be low body fat percentage (BF%) in this population group (Misra and Khurana 2011). Lee et al. (2014) has proved that the deposition of visceral adipose tissue (VAT) is higher in South Asian as compared to Europeans for a given total Body fat.

There is a specific distribution of body fat in the South Asian population. For a similar value of BMI in white European, SA have a significantly greater total abdominal fat and intra-abdominal adipose tissue (Kalra et al. 2013). This tendency of having comparatively higher abdominal adiposity in South Asians is believed to play a vital part in their increase susceptibility to develop MS (Wells, 2007). This greater tendency towards an abdominal distribution of body fat has been extensively studied (see below).

Neel proposed the “thrifty genotype hypothesis (TGH)” hypothesis in 1962 which was based on the assumption that during the evolutionary course since pre-historic times, humans were exposed to periods of food sufficiency and insufficiency otherwise known as feast and famine. Due to this constant switch between the two states of food supply, over thousands of years, humans have adapted to rapidly store energy, during periods of food abundance. Combined with periods of famine, those who were not able to adapt in this way, did not survive, hence a selection pressure was created in favour of those expressing the thrifty genotype. However, in the 21st century, due to the constant surplus food energy in modern life, this adaptation has adversely impacted the body (in other words the genotype is working against the individual and is manifested in the tendency to gain excess weight in the form of obesity and subsequently developing T2DM (Neel,1962; Neel et al. 1998).

However, the TGH has its own limitations such as failing to completely explain the phenomenon. For example, babies born at term with a low birth weight (<2.5 kg) usually are pre-disposed to develop abdominal obesity and the hence T2DM and CVD later in life. To counter explain this phenomenon, Hales and Barker proposed the "thrifty phenotype hypothesis" in 1992 (also known as the Barker Hypothesis). They reasoned that when the foetus is challenged in utero with an energy insufficient environment, the foetus will preferentially channel the scarce energy to vital organs especially the brain and nervous system compared to other organs such as the pancreas and skeletal muscle. If this foetus is born into the same poor nutritional conditions in their childhood and adult life, their bodies will not be in such a great need for a well-developed glucose-response system. However, if the same individual who once was a thrifty foetus possessing an ill-equipped pancreas is exposed to supra-nutrition early post-natally (e.g. formula feeding) and in life later, their pancreas will fail to deal with the excess glucose energy and will be prone to develop T2DM and MS (Hales and Barker. 1992).

Speakman, in 2008, proposed a different approach called the "drifty genotype hypothesis" which explains that as the predation selection is over, the main reason for the current distribution of genetic variants is the drift rather than selection, resulting in excess weight gain and obesity in modern populations (Speakman, 2008).

The phenomenon of central obesity in South Asians can also be explained by the "adipose tissue overflow hypothesis" proposed by Sniderman et al. 2006. They explained that total fat stored in the body can be categorised into three compartments

- superficial subcutaneous adipose tissue – present though out the body, act as a primary storage site and metabolically inert.
- deep subcutaneous adipose tissue – storage site for excess energy (mainly in the upper body)
- visceral adipose tissue – storage site intra-abdominally for excess energy

The adipose tissue in the superficial subcutaneous compartment is comparatively metabolically inert compared with the other two compartments, which are more closely related to dyslipidaemia and dysglycaemia due to higher rates of transmembrane flux of fatty acids. The tendency of central adipose tissue in South Asians was also explained by Sniderman on the same principle that South Asians have a smaller superficial subcutaneous adipose tissue compartment compared with white Europeans, hence they tend to deplete their storage capacity more quickly and develop central adiposity and metabolic complications of obesity (Sniderman et al. 2007).

The higher percentage of body fat in SA children may continue into adult life and consequently increases the existing risk of T2DM and Cardiovascular diseases among SA (Nightingale et al. 2015). Johnson et al. (2015) demonstrated that younger generation are more prone to acquire overweight and obesity throughout their lives and thus have greater risk of prolonged health condition. Historically, fat mass hypothesized as an inert energy store, but recent study recognizes the importance of many hormonal products of adipose tissue, which exerts its effect on fat free tissue. Therefore, it is becoming important to categorise FM and FFM and observe their changes with the passage of time (Ahima 2006, Atherton et al. 2013). Notably, recent papers have begun to use percentage body fat (BF%) measured by BIA as the ‘gold standard’ to scale the clinical and public health strategies for childhood obesity (Sung-Chan et al. 2013).

Fig 1.11a and 1.11b shows the relationships between BMI and body fat (kg) and BF% in men and women (Pasco et al. 2012)

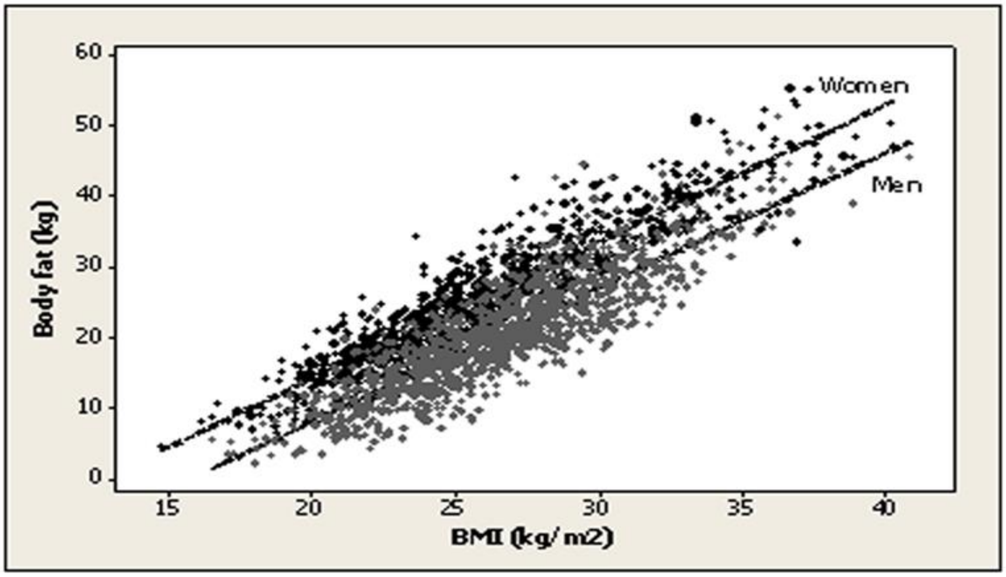


Figure 1.11a: BMI has linear relationship with total body fat (kg)

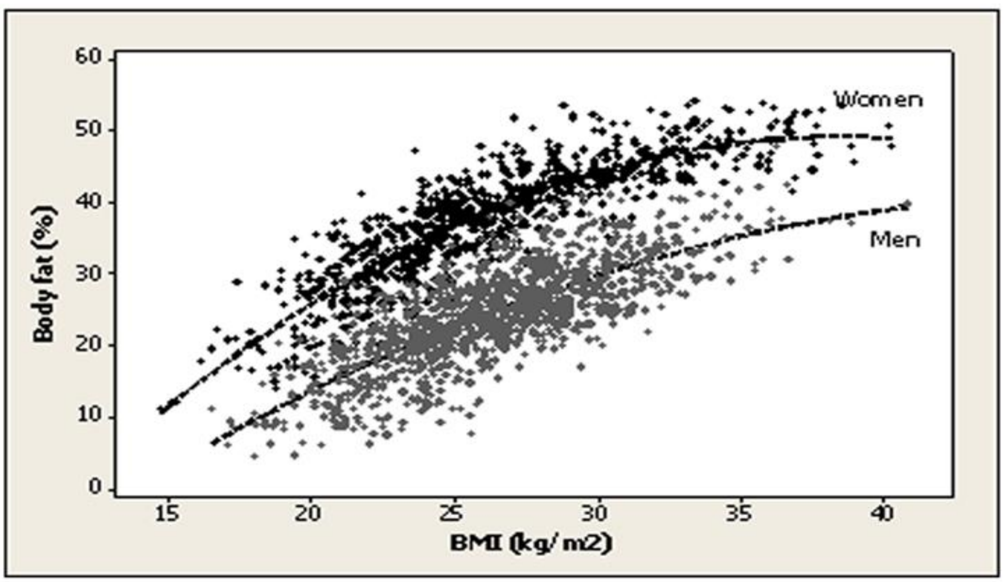


Figure 1.11b: The relationship between BMI and %BF is nonlinear

In fact, absolute value of FM is not achievable with any in vivo technique, because all are indirect and based on different assumptions, however, the assessment of fat and lean masses into the clinical and public settings has been made possible with the improvement in technology used in BIA and its amalgamation into step-on scale (Dehghan and Merchant 2008, McCarthy 2014). By using this BIA system first gender specific BF% references were developed for Caucasian children aged between 5.0 and 18.5 years (Fig 1.12a and 1.12b).

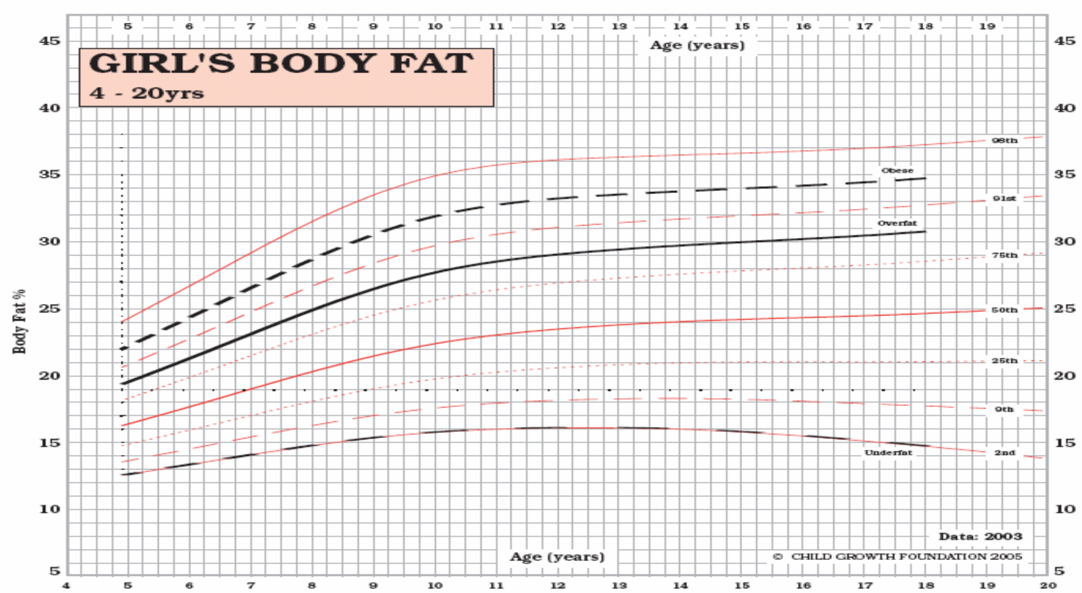


Figure 1.12a: The UK %BF reference chart for girls

(McCarthy et al. 2006)

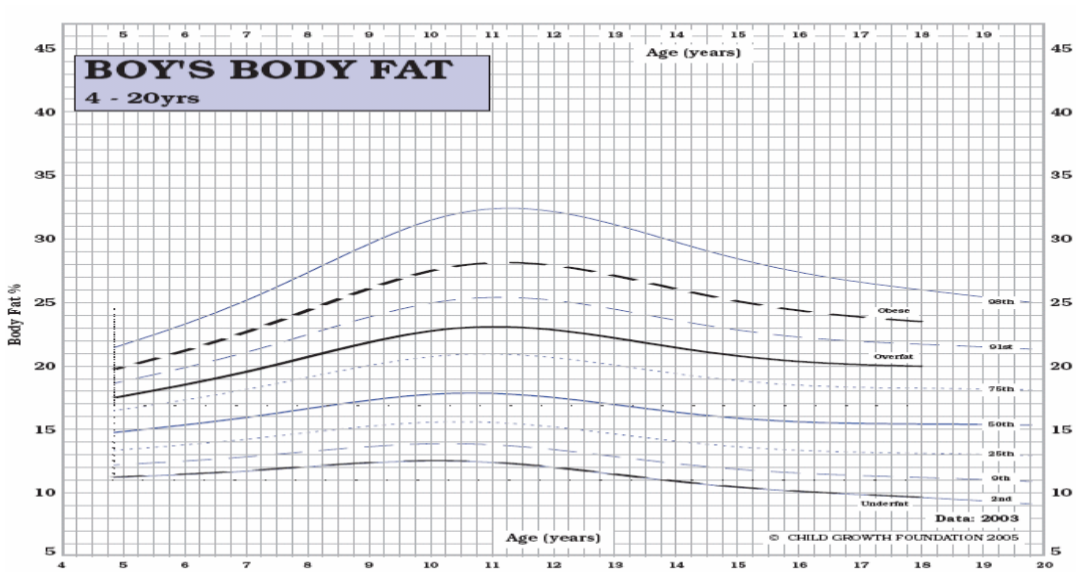


Figure 1.12b: The UK %BF reference chart for boys
(McCarthy et al. 2006)

These charts clearly explain the difference of total BF% between gender as well as gives the pattern of body fatness across childhood and adolescence. These charts also explain the pubertal influence on body fat in both genders. For example, it is clear from the chart that after puberty girls have higher percentage of body fat than boys. These charts were developed with seven centiles in which 2nd centile was used to defined underfat whereas the 85th and 95th centile were used to define the overfat and obese boundaries respectively. Furthermore, for the use of clinical and epidemiological studies these cut off broadly correspond with the International Obesity Task Force's (IOTF) BMI cut-offs, underfat, overweight and obese (McCarthy et al. 2006).

It has been wide established that distribution of body fat is different in children of different ethnic groups (Eyre et al. 2017). Over the last decade or so we have seen that body fat centile charts have been developed in different pediatric population groups, for example, for Hong Kong, Turkish, Iranian and Indian children. These charts give the direct assessment of adiposity which has a clear clinical benefit over body mass index. They help to reduce misclassification e.g. muscular children who used to be categorized as overweight or obese just based on body mass index and to improve the screening of children in clinical set up (Sung-Chan et al. 2013, Jeddi et al. 2014, Chiplonkar et al. 2017).

1.7.2 Fat Free Mass (FFM)

In human body composition research, the 2C model has been used for more than 50 years and still serves a key function role in new body composition technologies (Wells et al. 2012). Throughout infancy, childhood and adolescence, proportions of FM and FFM varies depending on age, health status as well as ethnicity (Jensen et al. 2019). There is the assumption that the chemical composition of the FFM is constant with a density of 1.1 g/ml at 37 ^{o}C with a constant water content of 72-74% (Lukaski 1987). It has been found that at birth all mammals have higher hydration of FFM while concentrations of protein and mineral are low. This hydration decreases with age until chemical maturity is reached whereas protein and mineral content increase alongside. Initially there was no theoretical basis for the constant hydration of FFM, therefore a cellular level model was constructed which indicates that hydration of FFM can be determined by four factors: hydration of body cell mass, hydration of extracellular fluid, ratio of extracellular solids to TBW and ratio of extracellular water to intracellular water. However, the constant hydration of the FFM is defined in states of excess adiposity where a higher hydration levels is typically seen, reflected by a higher ratio of ECW to ICW in the adipose tissue part of connective tissue (Wang et al. 2000). This drawback is applicable for all body composition assessment methods based on the 2C model. This issue is overcome using the 3C model in which the water content of the FFM is measured directly. However, despite these observations, Visser et al. (1995) have observed no relationship between the FFM hydration and age. Even though the hydration of the FFM decreases significantly during growth, a “constancy” of the FFM hydration can therefore only be assumed in nonelderly adults.

In overweight and obese populations there remains conflicting evidence concerning the relationship between adiposity and bone mass/density. The assumption of a constant mineral content of the FFM is appropriate in all settings, as an increase in percentage of FM has been associated with a lower bone mineral density (Dolan et al. 2017, Bierhals et al. 2019).

1.7.2.1 Skeletal Muscle Mass (SMM)

To date, main focus has been on the measurement of the FM and FFM for assessment of body composition while the role of skeletal muscle mass has been historically ignored, however, role of skeletal muscle mass has now gained a greater attention as a marker of metabolic health (McGill Jr et al. 2000, Smith Jr et al. 2004). In the recent years, it has now been highlighted that skeletal muscle strength and mass plays an important role in prevention of chronic diseases in adults (Ebner et al. 2015, Lee et al. 2019). Additionally, studies have suggested that there is a strong relationship between appendicular lean soft tissue (ALST) and total body SMM (Fig 1.13). This is based on the fact that a substantial fraction of extremity lean soft tissue is skeletal muscle and a large proportion of total-body skeletal muscle is found in ALST (~75%) (Kim et al. 2002, Steene-Johannessen et al. 2009).

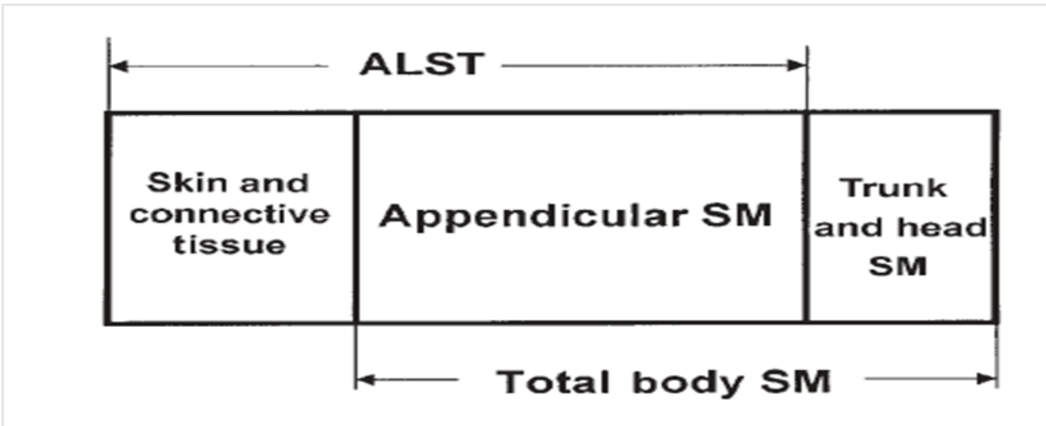


Figure 1.13: Relations between total body skeletal muscle mass (SMM) and appendicular lean soft tissue (ALST). ALST is the sum of lean soft tissue from arm and legs

As SMM is now considered an independent marker of metabolic health, hence in the nutritional assessment of children and adults this is envisaged as an important component to quantify (Mahoney et al. 2004, Johannesen et al. 2009). Muscle strength has a robust relation with insulin sensitivity which ratifies the association of low muscle fitness with raised metabolic risk (Benson et al. 2006, Johannesen et al. 2009). Skeletal muscle is quantitatively a key tissue for whole-body insulin-mediated glucose disposal (DeFronzo et al. 1985, Abdul-Ghani and DeFronzo 2010) and therefore important in T2DM risk. For energy production, SM consumes both glucose and free fatty acid (FFA) as fuel sources.

In addition, sarcopenia, which refers to the age-related loss of muscle mass and strength, has now gained much clinical and public health interest. Initially sarcopenia was considered only an age-related weakness primarily due to loss of muscle mass but now it has been proven that with age muscle mass and strength both decrease while decrease in strength is greater than decrease in muscle mass. Excess intake of energy and low physical activity together with insulin resistance and some variations in hormonal setting may lead to the development of so called 'sarcopenic obesity'. Indeed, there is no evidence linking obesity with low muscle strength. The imbalance between muscle strength and muscle mass is coupled with significant, negative health consequences in older individuals (Sayer et al. 2008, Stenholm et al. 2008). Until recently it has been very difficult to quantify skeletal muscle both within and outside of specialized research centers. Due to this difficulty there has been a lack of normative data related with age and gender which makes the use of SMM in nutritional surveillance restricted. It has been necessary to define and determine the healthy levels of SMM in children and adolescents (as well as in adults and elders) both for clinical and epidemiological purposes. As growth patterns differ between males and females during growth, SMM increases with increase in FFM (Forbes 1978 , Lee et al. 2020). These changes increase the requirement for sex-specific centile curves with variable cut off at different ages. Accurate quantification of total and regional SM is with imaging methods, including computed axial tomography (CT) and magnetic resonance imaging (MRI) but direct measurements of SM with MRI or CT are expensive or high in radiation exposure (Zhou et al. 2007).

An alternative method for measuring total-body SM is dual energy X-ray absorptiometry (DXA) (Kim et al. 2002), whole-body K+ counting (Wang et al. 2007) and biochemical assessment of 24-h creatinine excretion (Heymsfield et al. 1983). Kim et al. (2002) and Kim et al. (2006) developed the prediction model for multiple ethnicities including Caucasians, African Americans, Hispanics and Asians by DXA. Two different equation were used - one was for those at Tanner stage 5 (around age 15) and beyond and the second for children yet to achieve Tanner stage 5 (below age 15). Thus, DXA offers total-body SM mass across most of the human life span. However, all these procedures require technical expertise, are time consuming, expensive and invasive for individuals (Bazzocchi et al. 2016).

BIA is a simpler, non-invasive and inexpensive method which can differentiate between FM and FFM on the basis of electrical conductance and impedance. The use of multiple-frequency impedance provides a much clearer picture of individual differences between total and extracellular fluid compartments in the body and body composition (Chumlea and Guo 1994).

Despite the fact that it is somewhat less precise yet at the same time give useful compensation over DXA because it is economical, compact, quick and simple to utilize. Moreover, BIA can recognize FM and FFM independently for the trunk and limbs. The FFM in the limbs is additionally isolated into SMM and mineral (bone) and thus offers a good substitute for total SMM (McCarthy et al. 2014). By Using the same BIA technology, centile curves for appendicular skeletal muscle mass (SMM) (muscles of arms and legs) have been generated in three different formats namely absolute SMM (kg), percentage of total body SMM and SMM as a percentage of FFM, which gives a good proxy for whole body SMM. These charts act as a reference population which clearly demonstrate the variations across human growth and help users for better assessment of body composition in children and youth population in greater detail compared with equivalent BMI reference charts (McCarthy et al. 2014).

As previously stated, arms and legs have almost 75% of whole-body SMM, with the upper leg (thigh) containing a predominantly large proportion of SMM. Consequently, thigh circumference (TC) has a potential to act as a proxy for leg SMM. In this context, it is of interest that in adults a link between low TC and risk of developing heart conditions/diseases or early death has been demonstrated. This adverse outcome of low TC is most likely related to less muscle mass in the thigh area. Even though more research is needed in this area, it is possible that the anthropometric measurement of TC can assist clinicians and researchers in the early identification of individuals who may be at increased risk of early morbidity and mortality (Heitmann and Frederiksen 2009, McCarthy et al. 2014). AS TC may assist in the early identification of morbidity, the first set of TC centile charts for the

UK pediatric population have been developed (Samani-Radia and McCarthy 2011).

1.8 Measures of obesity

1.8.1 BMI and growth chart

In 1869 Adolphe Quetelet, established a simple method for classifying people's weight relative to an ideal body weight for their actual height. The ratio of body weight (kg) over height squared (m^2) was termed as Quetelet's Index (Eknoyan 2008). In 1972 Ancel Keys renamed Quetelet index as the 'body mass index' (BMI), together with the evidence to support its current extensive usage (Blackburn and Jacobs Jr 2014). This weight-height index is a surrogate measure of fatness in which the square of height is used to remove the height and weight relationship (Keys et al. 2014). As BMI is a non-invasive technique involving simple measurements, it has become the most adopted method for measurement of overweight and obesity at the clinical and population levels. Table 1.2 represents categories for defining obesity.

Table 1.2: Division of obesity showing BMI categories such as underweight, overweight and obese

BMI (kg/m^2)	Category
<18.5	Underweight
18.5 – 24.9	Normal (healthy) weight
25.0 – 29.9	Overweight
30 – 34.9	Obese
35 – 39.9	Severe obese
≥40	Morbidly obese

BMI is a proposed measure of fatness but does not measure the distribution of adiposity throughout the body. It is reported in various studies that compared to white Europeans, South Asian children and adults have higher percentage of body fat, particularly higher concentration of visceral adipose tissue and less muscle mass at same BMI, and thus cause central obesity. Therefore, BMI measurement cannot not treat all ethnicity equally in the estimation of obesity and its complications (Misra et al. 2003, Rush et al. 2004, Misra et al. 2007, Haroun et al. 2009, Hudda et al. 2018).

Given the known differences in body composition between white Europeans and South Asians at any given BMI values, the World Health Organization (WHO) determined two lower cut-offs to identify at "risk" (>23kg/m^2) and at "increased risk" (>25kg/m^2) of obesity related morbidity for adult Asian populations. Similarly, a lower cut-off has been introduced by Indian Health Organizations which is used to define overweight (23kg/m^2) and obesity (25kg/m^2) in the native Indian Asian population (WHO expert consultation 2004, Aziz et al. 2014). Furthermore, the American Diabetes Association has adopted lower BMI thresholds for screening of T2DM in all Asian ethnic groups in the United States (Misra 2015). Table 1.3 summarise these cut offs. These BMI cut-offs have since been adopted by NICE UK for migrant South Asians in UK (Nice 2013).

Table 1.3: Cut-offs of obesity and abdominal obesity for Asian Indians vs International Criteria

Variable	Consensus guideline for Asian Indians[a]	Prevalent International Criteria
General obesity (BMI cut-offs in kg/m^2)	Normal: 18.0 – 22.9 Overweight: 23.0 - 24.0 Obesity: > 25	Normal: 18.5 - 24.9[b] Overweight: 25.0 – 29.9[b] Obesity: >30[b]
Abdominal obesity (WC cut-offs in cm)	Men: >90[c] Women > 80[c]	Men: > 102[d] Women: > 88[d]
a From Consensus guidelines for Asian Indians b According to the World Health Organization guidelines c Both as per Consensus guidelines and International Diabetes Federation (for Asian Indians) d According to Modified National Cholesterol Education Program, Adult Treatment Panel III guidelines		

For an obesity screening purposes, BMI has been identified as having a 'high specificity' i.e. it identifies few non overweight children as being overweight and 'low sensitivity' i.e. it fails to classify relatively large number of children who has excess fat thus BMI underestimate obesity prevalence for measurement of overweight and obesity (Samadi et al. 2013). The underlying reason for this specificity-sensitivity issue can been illustrated in figure 1.14. The data on BMI and body fatness have been selected from National Health and Nutrition Examination Survey (NHANES) 1994 study where body fatness was measured by using BIA.

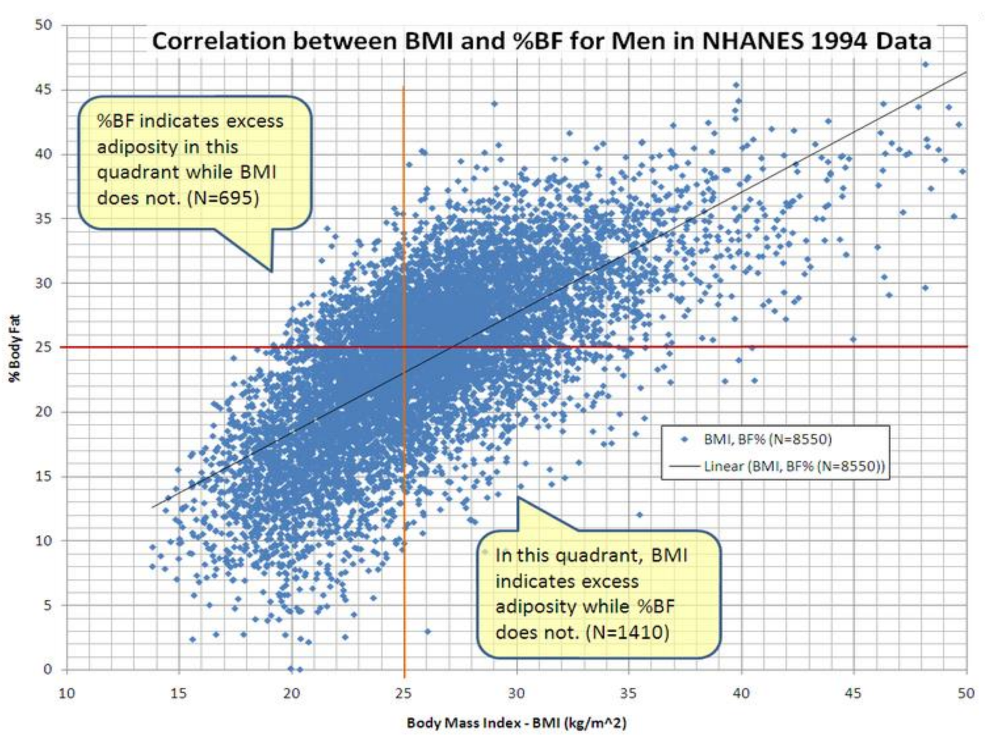


Figure 1.14: Graphical illustration of BMI misclassification

(https://commons.wikimedia.org/wiki/File:Correlation_between_BMI_and_Percent_Body_Fat_for_Men_in_NCHS%27_NHANES_1994_Data.PNG)

It can be seen that there is substantial misclassification of individuals with some having a high body fatness but healthy BMI and others having a high BMI but healthy body fatness. Thus, as a measure of overweight or obesity, the BMI must be interpreted with caution at both the individual and population levels. Ranasinghe et al. (2013) supported the use of BMI to predict body fat percentage/obesity, in a population but emphasised that age and gender should be considered more closely. Among children and adolescents, due to gender differences as well as variations in body composition across growth and maturity with age, overweight and obesity classification becomes more complex (Viner et al.2010, Nuttall 2015, McCarthy 2017). Unlike in adults, where fixed cut-offs are used to define, for example overweight and obesity (BMI 25 and 30 respectively), such kind of approach cannot be used in children. To overcome this complexity in infants, children and adolescents, sex-specific BMI centile curves have been constructed based on nationally representative data (Cole et al.1995, WHO 2000). Therefore, most frequently, measurements are interpreted through a series of curves in which variable of interest is distributed graphically in a reference population against age, which are specific for each sex (Cole and Lobstein 2012). An individual percentile reflects a child's position relative to a reference population (for that gender and age), with the percentile representing the %age of children below this value for age and gender. The 50th percentile represents the median value of the population, whereas the 98th percentile represents the top 2% and the 2nd percentile representing the bottom 2% of the population distribution (McCarthy 2017). These cut-offs are used to define different categories. These charts are more suitable for assessment of individual children in a clinical environment. While a standard deviation score (SDS) or z score is often used for population level survey. The Z-score system defines the anthropometric value as a number of standard deviations (SD) or Z-scores below or above the reference mean or median value. Each SDS is equivalent to a percentile on a chart. An SDS of zero represents the median value. A fixed Z-score interval implies for children of a given age.

Z-score (or SD-score) = (observed value - median value of the reference population) / standard deviation value of reference population

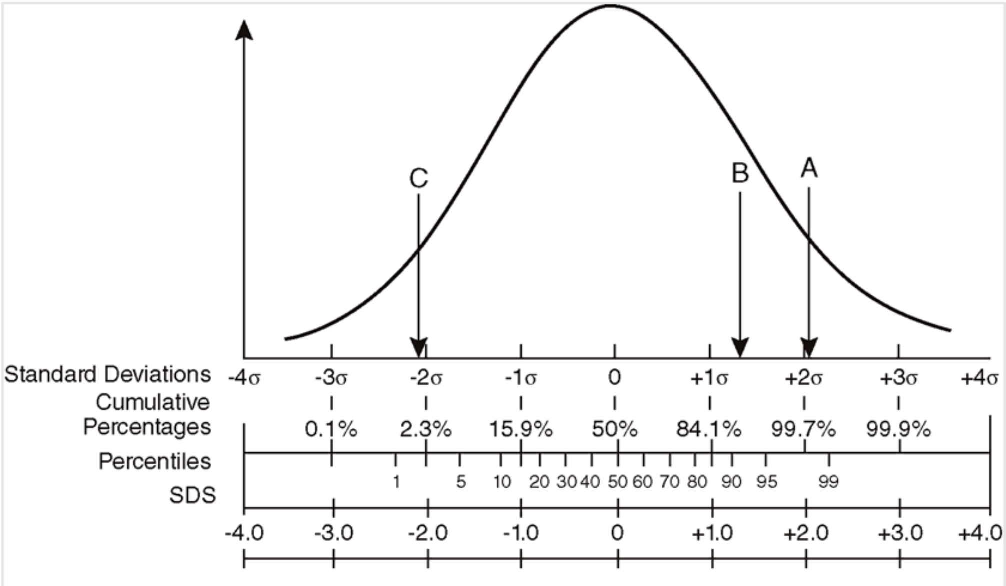


Figure 1.15: Relationship between centiles and standard deviation scores (SDS) in a normally distributed variable

In the above figure 1.15, using BMI as an example, the arrow at point A identifies an SDS = +2.05, which equates to the 98th percentile – the clinical cut-off to define obesity. The arrow at point B identifies an SDS = +1.34, the 91st centile and the clinical cut-off to define overweight. At point C lies the cut-off to define underweight set at the 2nd percentile or an SDS = -2.05. The standard deviation of 0 lies at 50th percentile.

The production of centile growth curves is greatly aided if the underlying reference data follows the Gaussian distribution. Likewise, the construction of SD scores which are of much practical value in the assessment of growth is much easier for variables with a normal distribution (Cole et al. 1995). However, if the variable is not normally distributed, then centiles curve created from such data are much less efficient at the extreme values because the standard errors increasing steeply towards the tails of the distribution (Tanner and Whitehouse 1975). The importance of smoothed centile curves over a simple reference range particularly comes to play when a specific variable is highly dependent on another independent variable, for example height dependent on age etc, (Cole and Green 1992).

The idea for making the centile curves smooth is not only for cosmetic reasons, but there is also the valid scientific rationale behind it. Physiologically, substantial changes in body composition can occur in the measurement of dependent variable by small changes in the independent covariate, so in an ideal scenario the centiles should change smoothly to avoid the introduction of any bias in representation and ultimately the interpretation of dependent variable (Cole and Green 1992). Fig 1.16 shows age related changes in BMI in both genders.

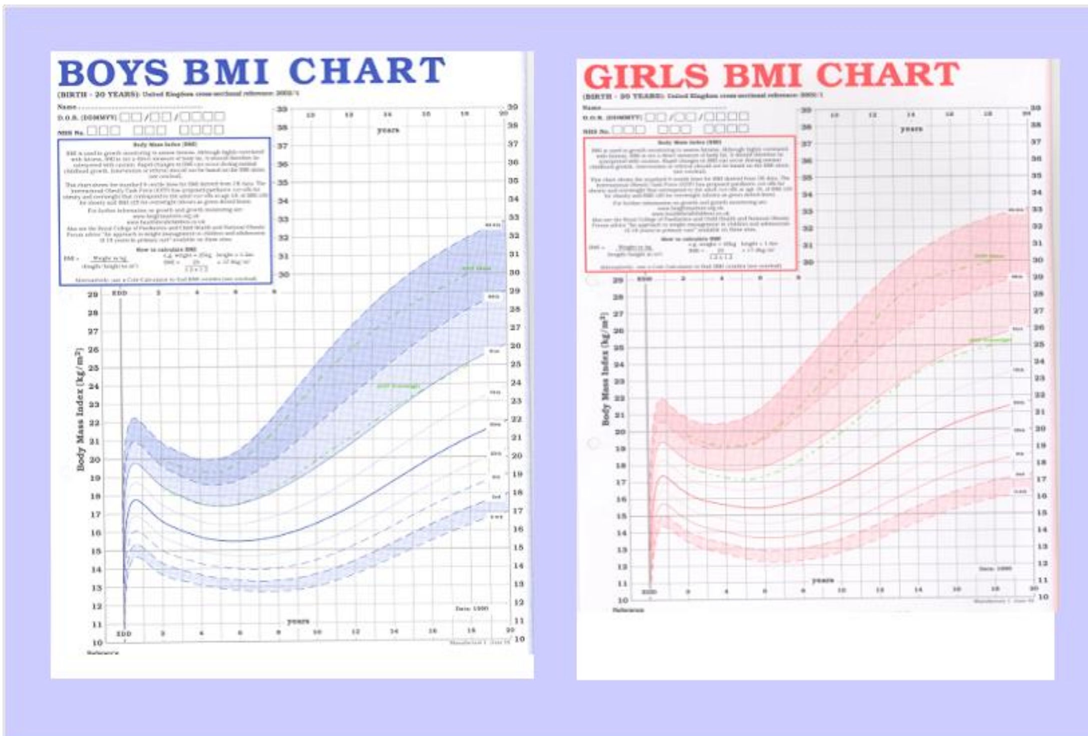


Figure 1.16: Gender-specific UK BMI reference charts

The shape of the BMI centile curves reveals that throughout the first year of life there is a rapid increase in BMI then it decreases until the age of approximately 5 years, which again starts to increase into adulthood (Cole et al. 1995). Rolland-Cachera et al. (1984) used the term ‘adiposity rebound’ for this BMI increase from age 5 years and inferred that this is the age when adiposity begins to increase. Numerous studies have examined this association which shows that an early rebound (before age 5.5 years) is followed by a higher adiposity level than a later rebound (after age 7 years). Therefore, it can be used as a tool for monitoring the child's adiposity development (Rolland-Cachera et al. 2006). Since then, various studies have intimated early adiposity rebound as a predictive indicator of obesity in later childhood, adolescence, and adulthood (Kang 2018).

In clinical practice, reference centile growth curves are the commonly used screening tool to identify and monitor growth of any body part such as leg length, waist circumference or parameters such as weight, height or BMI in any individual (Cole and Green 1992). Childhood overweight and obesity based on BMI using population reference data (Barlow and Dietz 1998, Prentice 1998) is defined through specific centile cut-off points. These specific cut-offs on percentile charts vary between source of the charts and their resolution. In US, BMI centile chart produced by center for disease control and prevention (CDC) uses the 85th and 95th centiles to represent overweight and obese respectively. Equivalent BMI cut-offs on UK charts use the 85th and 95th centiles for public health/epidemiological purposes only. In clinical settings the 91st and 98th centiles are the recommended cut-offs for overweight and obesity (Gatineau and Mathrani 2011) and developed as standard centiles on UK BMI charts.

These statistically calculated cut-offs do not relate with rate of disease in all population. For easier interpretation of obesity prevalence an additional set of curves has been generated known as the International Obesity Task Force cut-offs (Cole et al. 2000). IOTF developed international cut-offs for comparison of obesity prevalence internationally (Cole et al. 2000). The IOTF charts were developed by averaging BMI data across six countries (Brazil, Great Britain, Hong Kong, the Netherlands and the US). These centiles cut offs were extrapolated back from the adult BMI of 25 kg/m^2 for overweight and 30 kg/m^2 for obesity at age 18 years. Close examination of these IOTF curves indicates that the overweight cut-off lies on or close to the 91st centile for boys and for girls. While for obesity the IOTF cut-off lies above the 98th centile for both boys and girls (see respective BMI charts, Fig 1.17).

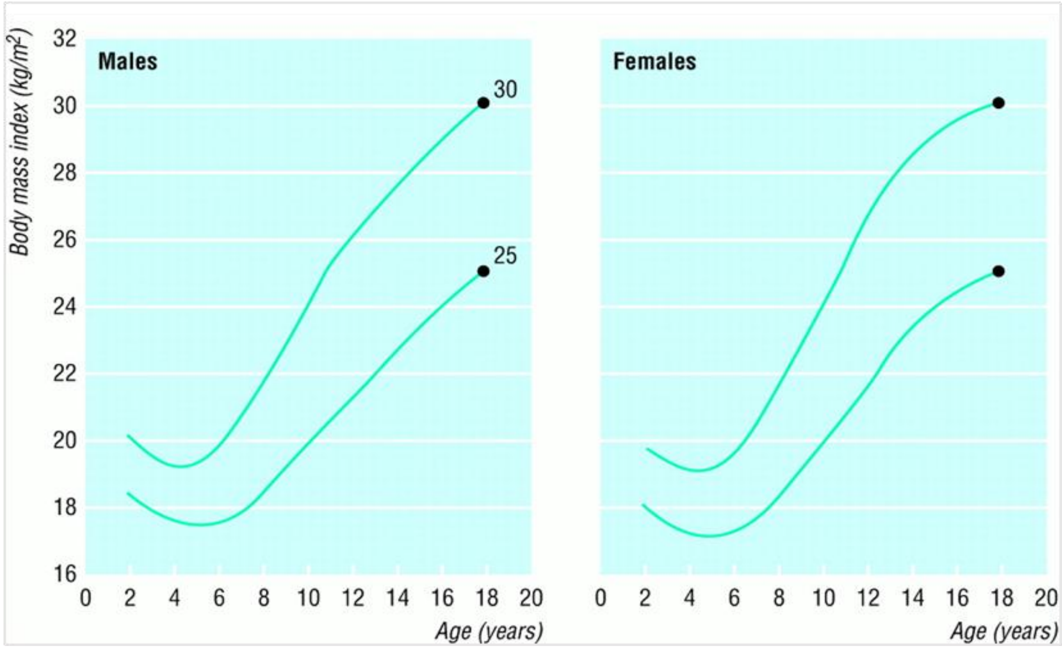


Figure 1.17: Gender-specific IOTF cut-offs for overweight and obesity

(Cole et al. 2000)

BMI nevertheless has some main drawbacks when used in children. As children and adolescents have less defined obesity-related morbidity than adults so it become very difficult to identify a cut-off point with surety when the health risk of obesity starts to rise suddenly (Cole et al. 2000). The IOTF cut-offs principally consider that at 18 years of age there is no more growth which is not essentially correct. Evidently, growth data suggest that gain in stature ceases earlier than weight stabilizes thus BMI can increase beyond age 18y. Indeed, the BMI curves do not give the impression of flattening off at around age 18 years thus suggesting that BMI is still increasing beyond at age 18y (Speiser et al. 2005). Furthermore, as BMI correlates with both FM as well as FFM across childhood and adolescence (as it represents the sum of these two), it becomes difficult to determine which component is greater when BMI is higher. The evidence highlights that the assessment of overweight and obesity based on BMI may not exactly identify those children who are at risk of obesity-related ill health. Despite these limitations, it is yet widely used in clinical practice and epidemiological studies.

1.8.2 LMS method for growth curves

In order to address the distributional concerns for the data which may not be normally distributed, centile curves for all variables (height, weight, sitting height, BMI, body fat%, fat mass, fat free mass and skeletal muscle mass) are created for each dataset for both gender using the Cole's LMS method. The LMS method is based on an underlying assumption that the Box-Cox power transformation/adjustment of the data at each age will adjust the data as normally distributed. Hence this method involves normalising the data at each age using a "Box-Cox power transformation" and summarising the data in terms of three smooth age specific curves called L (lambda), M (mu), and S (sigma) (Cole et al. 1995).

The conversion process confirms that the values of L, M, and S change efficiently with age so that they can be represented as smooth curves plotted against age. The M curve relates to the median of the variable at each age and the S curves relate to the coefficient of variation of a specific variable at each age whereas the L curve permits for the significant age dependent skewness in the distribution of the said variable (Cole et al. 1995).

The numerical values are set for L, M, and S in the form of table for a series of ages. There is a formula which characterise the points on each centile curve and L, M, and S represents the values for fitted curves of corresponding age and further to this, z specifies the z score for the required centile in the formula (Cole et al. 1995). This approach has three following advantages:

1. It can evaluate the extreme centiles more accurately than the basic "sort and count" procedure with skewness in the distribution.
2. The required centiles are generated by this approach along with the conventional ones.
3. LMS method has functionality to generate the centiles, thereby convert the data directly to SD scores.

1.8.3 Waist Circumference

The importance of waist circumference is highlighted by the fact that conditions such as T2DM, hypertension and other heart diseases, which are believed to be related to obesity, are associated with central adiposity (NOO, 2009). Furthermore, the European Prospective Investigation into Cancer and Nutrition (EPIC) conducted a large prospective cohort study in which nearly 360,000 participants from nine European countries were included. The study results gave the firm evidence of a relationship between central adiposity and risk of premature death (Pischon et al. 2008).

For clinical assessment of risk for metabolic disease, the measurement of Waist Circumference (WC) is needed in addition to BMI because the rise in morbidity and mortality depends both on increase in BF% as well as on central adiposity (Cole et al. 2000, Rennie et al. 2003, Federation 2006). The assessment of body fat requires complex and costly laboratory-based techniques such as CT or MRI scanning which are very effective, however, these techniques are associated with the risk of radiation, hence these techniques could be deemed unacceptable for routine and repeated use in children (Duren et al. 2008). Due to the aforementioned risks, anthropometric measurements such as WC and waist-to-hip ratio (WHR) are considered a simple and accurate indicator for central adiposity (McCarthy and Ashwell 2006). WC is used to measure abdominal fat which is made of two different components: subcutaneous adipose tissue (SAT) and visceral adipose tissue (VAT). VAT is drained by the portal system which delivers free fatty acids mobilized from VAT directly into the liver. It is assumed that this direct and excessive delivery of free fatty acid to the liver is a major driver of insulin resistance which is the key risk factor for metabolic Syndrome (MS) (McCarthy 2017).

MS is a cluster of risk factors associated with cardiovascular disease (CVD). Although the complete biological mechanisms of these risk factors remain unclear, however, central obesity and insulin resistance are recognised as an important contributing factor (Rutter et al. 2003). Multiple definitions were used to define MS which caused misperception. Conclusively, The International Diabetes Federation (IDF) consensus worldwide (Table 1.4 below) defined MS (Federation 2006) which focused on central or abdominal obesity, measured by waist circumference as the key underlying factor (with ethnic specific values for WC). This new definition covers all relevant criteria and can be used both in clinical and epidemiological studies worldwide.

Table 1.4: The new International Diabetes Federation (IDF) definition

According to the new IDF definition, for a person to be defined as having the metabolic syndrome they must have: **Central obesity** (defined as waist circumference* with ethnicity specific values) **plus any two of the following four factors:**	
Raised triglycerides	≥ 150 mg/dL (1.7 mmol/L) **or specific treatment for this lipid abnormality**
Reduced HDL cholesterol	< 40 mg/dL (1.03 mmol/L) in males < 50 mg/dL (1.29 mmol/L) in females **or specific treatment for this lipid abnormality**
Raised blood pressure	systolic BP ≥ 130 or diastolic BP ≥ 85 mm Hg **or treatment of previously diagnosed hypertension**
Raised fasting plasma glucose	(FPG) ≥ 100 mg/dL (5.6 mmol/L), **or previously diagnosed type 2 diabetes** If above 5.6 mmol/L or 100 mg/dL, OGTT is strongly recommended but is not necessary to define presence of the syndrome.

** If BMI is >30kg/m², central obesity can be assumed and waist circumference does not need to be measured.*

In the UK, NICE recommended thresholds for WC of 94 cm or higher for men and 80 cm or higher for women to identify individuals who are at increased risk of obesity-related health problems, while a threshold of 102 cm or more for men and 88 cm or more for women to identify individuals at significantly increased risk Table 1.6 represents the combine cut off of BMI and WC (WHO, 2011). However, these thresholds are not appropriate for all individuals from different ethnic background. As previously stated, people from South Asian origin have higher obesity-related risk at lower BMI and lower waist circumference levels than a white European population because they have more centralised distribution of body fat (NICE, 2006; Stegenga, et al., 2014)

Table 1.6: Combined cut off points of BMI and WC for measuring overweight and obesity and association with disease risk

	Body mass index	Obesity class	Disease risk (relative to normal weight and waist circumference)	
			Men < 102 cm Women < 88 cm	Men >102 cm Women >88 cm
Underweight	<18.5			
Normal	18.5–24.9			
Overweight	25.0–29.9		Increased	High
Obesity	30.0–34.9 35.0–39.9	I II	High Very high	Very high Very high
Extreme obesity	>40.0	III	Extremely high	Extremely high

Source: NHLBI Obesity Education Initiative (2000)

Table 1.7 shows ethnic specific cut offs for WC. The IDF and South Asian Health Foundation made an agreement on WC threshold for South Asian (SA) and Chinese ethnic groups and recommended that healthy WC threshold should be reduced from 94cm to 90cm for men and women threshold should remain same (Zimmet et al. 2007, Kumar 2013).

Table 1.7: IDF Waist Circumference Cut-offs

Country/Ethnic group		Waist circumference
Europids* In the USA, the ATP III values (102 cm male; 88 cm female) are likely to continue to be used for clinical purposes	Male	≥ 94 cm
	Female	≥ 80 cm
South Asians Based on a Chinese, Malay and Asian-Indian population	Male	≥ 90 cm
	Female	≥ 80 cm
Chinese	Male	≥ 90 cm
	Female	≥ 80 cm
Japanese**	Male	≥ 90 cm
	Female	≥ 80 cm
Ethnic South and Central Americans	Use South Asian recommendations until more specific data are available	
Sub-Saharan Africans	Use European data until more specific data are available	
Eastern Mediterranean and Middle East (Arab) populations	Use European data until more specific data are available	

The IDF consensus worldwide definition of the metabolic syndrome (Federation 2006).

Due to this gender and ethnic specific cut off for WC, BMI cut offs have been revised for people from Asian background. It is evident from different studies that both BMI and WC can precisely classify obesity related health problem than either alone that's why World Health Organisation (WHO) recommended threshold is also endorse by NICE in their obesity guidance.

Initially, it was assumed that the phenomenon of central obesity and excess visceral fat was related only in adulthood and it is here that WC is commonly used as a proxy of central fat accumulation and distribution in adults (Janssen et al. 2002). However, (De Ridder et al. 1992, Fox et al. 1993) were among the first researchers who observe the accumulation and deposition of intra-abdominal/visceral fat in children. Later, researchers have demonstrated that abdominal obesity is related with cardiovascular disease risk in children and WC has relationship with visceral fat in children (Brambilla et al. 2006, McCarthy 2014). For example, the Bogalusa Heart Study revealed that in children aged 5 to 17 years abdominal fat measured by WC was linked with abnormal concentrations of low-density and high-density lipoprotein cholesterol (considered an adverse and atherogenic lipoprotein profile and raised fasting insulin concentration (Freedman et al. 1999).

Regardless of age, stature, weight, gender and ethnicity, increasing WC is indicative of insulin resistance suggested by elevated basal insulin concentration along with abnormal concentrations of plasma triacylglycerols and low density lipoprotein (LDL) and High density lipoprotein (HDL) cholesterol (Freedman et al. 1999). In addition, many recent studies have reported the relationship of WC with insulin resistance, non-alcoholic fatty liver disease (Ju et al. 2013, Pang et al. 2015, Almeida et al. 2018) and elevated blood pressure (Choy et al. 2011). Thus, WC can be used as a predictor of MS for identification of children who are at risk (Hirschler et al. 2005). Ma et al. (2017) conducted a study on Adolescents in z. It is a non-age dependent method that is highly applicable for screening of CVD risk factor in adolescents. In clinical report presented by Magge et al. (2017). It was found that to define paediatric MS, it is important to focus on clustering of risk factor that leads to CVD.

Due to development changes and age-related differences in children and teenagers, Zimmet et al 2007 developed new definitions for MS for children which divides children into three age groups:

- 6 years to younger than 10 years.
- 10 years to younger than 16 years.
- 16 years plus.

Table 1.8 shows consensus definition for all three age groups, in which abdominal obesity is the “sine qua non.” Due to insufficient data on children younger than 6 years they were excluded from this definition. IDF suggest that for the age group of 6 to 10 yr, MS as an entity cannot be diagnosed, but for these children with abdominal obesity, a strong message of weight reduction should be given. For the age group, 10 yr to younger than 16 year with abdominal obesity, a diagnosis of metabolic syndrome can be made based upon the following metabolic criteria 3 or more of the following. For 16 years plus, the criteria for the diagnosis of MS was the same as defined by IDF for adults which is already described above in table 1.4

Table 1.8: IDF consensus definition of MS in children and adolescents

Age group (years)	Obesity* (WC)	Triglycerides	HDL-C	Blood pressure	Glucose (mmol/L) or known T2DM
6–<10	≥90th percentile	Metabolic syndrome cannot be diagnosed, but further measurements should be made if there is a family history of metabolic syndrome, T2DM, dyslipidemia, cardiovascular disease, hypertension and/or obesity.			
10–<16 Metabolic syndrome	≥90th percentile or adult cut-off if lower	≥1.7 mmol/L (≥150 mg/dL)	<1.03 mmol/L (<40 mg/dL)	Systolic ≥130/ diastolic ≥85 mm Hg	≥5.6 mmol/L (100 mg/dL) (If ≥5.6 mmol/L [or known T2DM] recommend an OGTT)

(Zimmet et al 2007)

After gaining evidence that information on the WC in children is important for recognition of overweight and obesity and metabolic risk, it was important to produce national reference data for WC in this age group. The first WC percentile curves were generated for the Italian (1996) and Spanish (1999) childhood populations (Zannolli and Morgese 1996, Moreno et al. 2000). Figure 1.18 shows the first WC percentile curves for British children were developed in 2001 which revealed the patterns of waist circumference in Caucasian children and can be used for both clinical and epidemiological use (McCarthy et al. 2001). Following these British charts, different countries across the globe developed their own WC centile charts including USA for age 2 to 18 yr (Fernández et al. 2004), Canada for age 11 to 18 yr (Katzmarzyk 2004), Australia for age 7 to 15 yr (Eisenmann

2005), Malaysia, Germany and Poland (Nawarycz et al. 2010, Kromeyer-Hauschild et al. 2011, Poh et al. 2011).

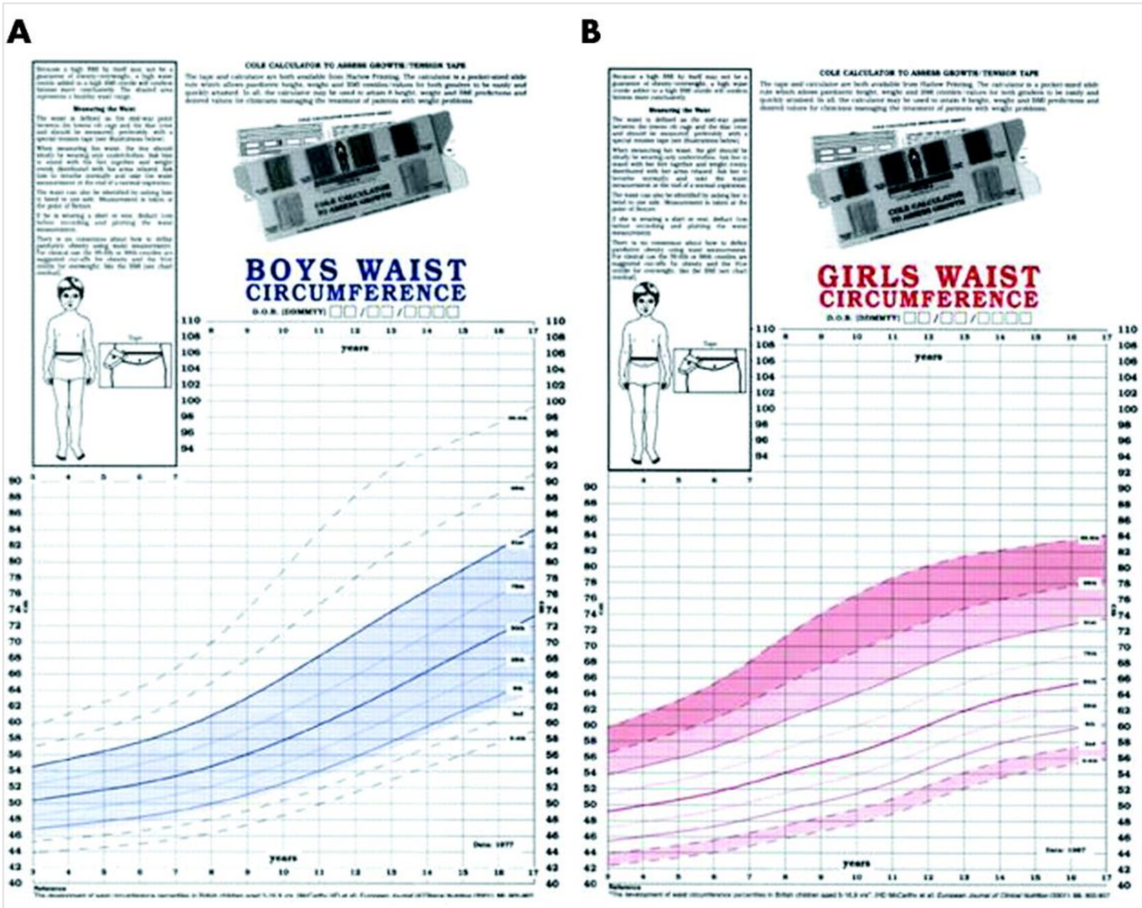


Figure 1.18: Gender-specific UK WC reference charts

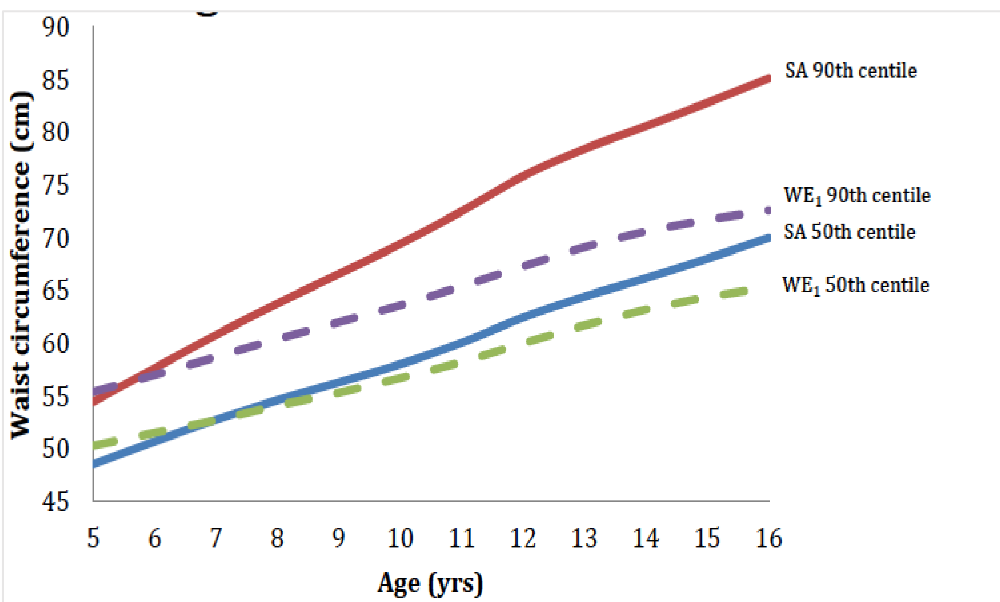
(McCarthy et al. 2001)

It is important to note that the IDF definition of MS in children and adolescents includes WC > 90th centile which supplanted the previous definition of obesity based upon BMI > 95th centile. This was a critical advancement in the recognition of abdominal obesity rather than general obesity as a key risk factor. With respect to the British WC centile charts, it is clear that mean WC increases with age. However, this increase is higher in boys and at the end of age range these curves begin to plateau in girls while in boys it still rising up which actually depict the gender -specific influence on WC (McCarthy et al. 2001).

Considering these centile charts were based upon measurements collected up to 40 years ago, it was important to determine whether abdominal obesity has increased over time. Moreover, studies in the UK and elsewhere have shown that over the past 10–20 years, abdominal fatness has increased dramatically in infants, children and adolescents to a greater extent than overall fatness (McCarthy et al. 2005, McCarthy 2006). Like this, a study was conducted to compare changes over time in WC and BMI using cross sectional surveys of WC and BMI data from 1977 to 1987 with similar data collected 10-15 years later. It was observed that in British youth aged 11-16 years, central fatness had increased much faster than body mass index over 10-20 years (Mindell et al. 2012).

However, due to variation in fat distribution among different ethnicities these charts were not necessarily suitable for other population groups. With this in mind, (Shah et al. 2019) developed the first WC percentile charts for SA children and adolescents aged 4 – 13.9 y and compare this to the centile charts developed by McCarthy et al. (2001), at 50th and 90th centile. SA had higher WC overall particularly at the age of 8y onwards in boys and 9y onwards in girls.

Figure 1.19: Comparisons of WC between UK WE (UK 2001) and SA boys at 50th and 90th centile



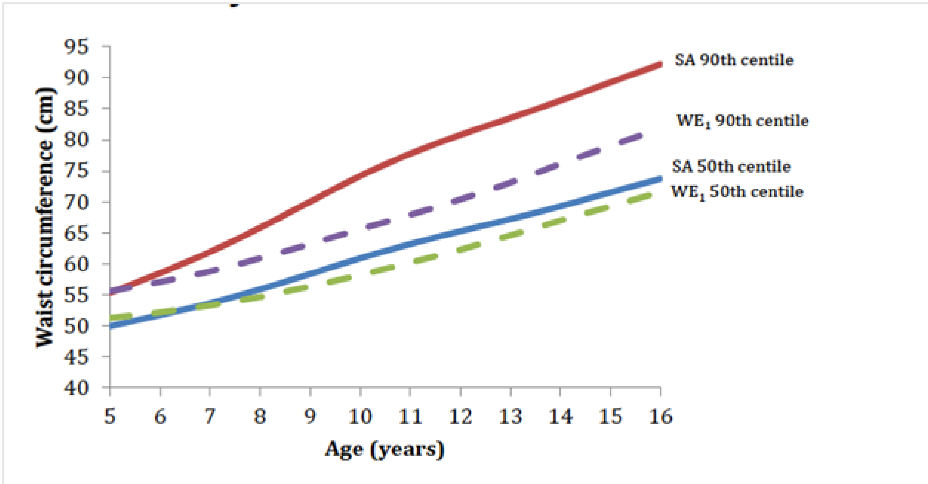


Figure 1.20: Comparisons of WC between UK WE (UK 2001) and SA girls at 50th and 90th centile

In both sexes, at 90th centile difference starts from age 6 y and continues onward (Fig 1.19 and 1.20) indicate that SA have higher trend to store fat in the development stage. This supports well the IDF recommendation of determining abdominal obesity in children from age 6y onwards (Zimmet et al. 2007). It is evident that overweight and obesity track into adulthood so, in high risk population preventive measure should start from age 6 year (Wardle et al. 2006). Furthermore, given that the WC charts for the UK SA child population terminates at age 14y, one aim of the work in this thesis was to extend the curves into later adolescence and early adulthood (see ch. 5).

1.8.4 Height

Height measurement is the representation of body size and its linear growth. It includes neck, head, trunk and length of lower limbs. Thus, its measurement is the distance between vertex of head and floor. Positioning of head is an important element during the height measurement thus, for gaining accurate measurement standardised protocols are always followed (Gerver et al. 2018). Height is a sensitive marker of growth as it changes across childhood and adolescence and used to reflect impaired growth and development that children can experience due to poor nutrition and repeated infection, as well as other causes (McCarthy 2017).

Stunting refers to compromised linear growth and remains an important nutritional disorder worldwide, especially in relation to iodine deficiency or protein-energy malnutrition. The stunting along with variations in metabolic activities have long-lasting effects which can lead in non-communicable illness such as hypertension and other obesity-related disorders (Martins et al. 2004).

Height measurements are mostly used in combination with weight as a part of body mass index calculation. Before the age of 12 y, height and adiposity are closely correlated with each other, hence the reason that BMI can misclassify taller young children as overweight. Although in younger children the primary mechanism of this association is ambiguous, longitudinal studies have shown that among children, increase in height causes a relative gain in weight, hence resulting a simultaneous increases in BMI (Forbes 1977, He and Karlberg 2001). The age-related decrease has been seen in the association between height and adiposity which probably linked with the normal decrease in insulin sensitivity which happens during adolescence (Caprio et al. 1989). In adults, final achieved height is linked to various morbidities particularly metabolic complications and chronic Heart disease in shorter adults and increased risk of cancers in taller adults (McCarthy 2017, Giovannucci et al. 2019).

1.8.5 Waist to height Ratio

The waist-to-height ratio (WHtR), computed by dividing the waist circumference (WC) with height, is a relatively recent development as an anthropometric index for a proxy of central adiposity and it has been suggested this measure has greater practical benefits compared with the more traditional BMI measurement (Ashwell and Gibson 2014). In adults, several cross-sectional and prospective studies and meta-analysis have found that WHtR is a somewhat better predictor of CVD than WC and BMI (Yoo 2016). During the past 10–20 years, mean values of WHtR have critically risen up which indicates that in children central fatness has increased dramatically (McCarthy and Ashwell 2006).

It is now evident that irrespective of total obesity, central obesity is more closely related to most of the adiposity-related health risks (Ashwell and Gibson 2014). This simple index act as measure of abdominal fatness corrected for height as an acceptable amount of fat stored on the upper body part (McCarthy 2017). This simple index can overcome the debates of different BMI values for assessing health risk in different population. For example, Asian populations tend to have shorter height and thus obesity-related health risks commence at a smaller amount of central fat i.e. smaller WC than their Caucasian counterpart (NOO 2011, WHO expert consultation, 2004). Division of WC with height neutralise these differences and covers the adjustment of stature which is different in different population groups and therefore can be used as a more sensitive indicator than WC alone (Saeed and Al-Dabbagh 2003).

The adjustment of WC for height means that the same cut-off values to be considered suitable for different ethnic groups. A cut-off value of 0.50 WHtR has been proposed which is independent of age, gender and ethnicity. This boundary value translates into the simple screening message - ‘Keep your waist to less than half your height’. This simple message is particularly valuable for public health for all ethnic groups as well as in clinical setting (Ashwell and Hsieh 2005, McCarthy and Ashwell 2006).

Substantial statistical evidence from various studies including more than 300,000 adults from different ethnic groups have been published, which suggest the superiority of WHtR over WC and/or BMI for detecting cardiometabolic risk factors in both genders. It has been proposed therefore, that WHtR should be considered as a surrogate screening tool for obesity and metabolic risk (Ashwell et al. 2012).

1.8.6 Sitting Height

Sitting height (SH) is measured by using a specific sitting height table. The distance between the top of the head and the buttocks is called sitting height

(Gerver et al. 2018). In case of lower limb defects, sitting height can also be used as a substitute for stature growth (Fredriks et al. 2005).

In research settings, measurement of body proportion gives some important indications about the growth of lower and upper body parts which has been linked to risk of metabolic disease (McCarthy 2017). In children, body proportion can be measured via ratio between (sitting height and leg length (SH/LL) or sitting height and height (SH/H) and compare this with age references (Fredriks et al. 2005).

Both men and women with comparatively shorter legs for their height have a higher risk of being overweight or obese, thus sitting height ratio seems to be a more sensitive anthropometric measure to identify obesity in both sexes (Henriques et al. 2018). Furthermore, it has been observed that in respect to the pattern of human growth, during the postnatal period, growth occurs more in limbs than in the trunk. This suggests why their growth may be more susceptible to environmental stress such as diet, infection and psychological distress (Wu and Berry 2018). For groups of children and youth, a high sitting height ratio (i.e., short stature due to relatively short legs) usually reflect an adverse environment outcome. During the last two centuries, a positive secular growth change has been observed (Fredriks et al. 2000) and research indicates that instead of genetics, leg length and body proportions are more strongly influenced by the environment (Bogin and Varela-Silva 2010).

1.8.7 Leg length

The difference between height and sitting height or between flat length and head near length is defined as sub-ischial leg length (Gerver et al. 2018). It has been observed that during physical development across the human species, relative leg length reflects nutritional status and wellbeing. Furthermore, in adulthood, it has an important association with epidemiological risk and syndromes (Bogin and Varela-Silva 2010). A broader review of the literature indicates that an adult’s shorter stature due to generally shorter legs, are associated with adiposity, insulin resistance (Asano et al. 2006) CHD (Lawlor et al. 2004) and liver dysfunction (Fraser et al. 2008).

Acknowledging the importance of body proportion, more than 45 years ago in UK, the first reference centile curves for body proportions of children were constructed by Tanner and Whitehouse (Tanner and Whitehouse 1975). Dangour et al. (2002) recognised that those reference centiles were not suitable for the contemporary childhood population because current children have higher leg length than a generation ago. They therefore developed up-to-date sitting height and sub-ischial leg length centile curves for boys and girls based on a population residing in Southeast England (Dangour et al. 2002). To date, the development and use of SH and LL measures in the South Asian child and adolescent population is lacking. Hence one aim of this study was to develop such centile charts.

1.8.8 Weight

Weight is a simple measure that can be obtained using a static or portable weighing scale. It represents the accumulation of body mass reflecting the growth of FFM and FM. Its accuracy, however, depends on several factors including hydration status of individual as well as its clothing and in very small infants, the contents of the gastrointestinal tract and bladder. Generally excess weight for age is considered the result of excess body fat accumulation. Being overweight at a young age carries a significant risk for overweight in adolescence and adulthood. It is considered that during a period of intentional weight loss, this will be reflected in loss of body fat, but this is not necessarily true as weight loss will also be reflected in a loss of FFM. It is important to consider this issue carefully when observing body weight and weight loss of an individual in any given health assessment. Weight for age and height for age centiles are generally used in infants while BMI chart are used from age 2y onward. However, reference growth chart has been developed by Royal College of Paediatric and Child Health (RCPCH), CDC and WHO for monitoring the growth of infants and young adults too. The WHO growth charts are standards; they recognise how children should grow when provided optimal conditions. Figure 1.21 shows the WHO reference centile weight for age and height for age in both boys and girls respectively. These charts direct the size of a child compared with children of the same age and maturity who have shown optimum growth.

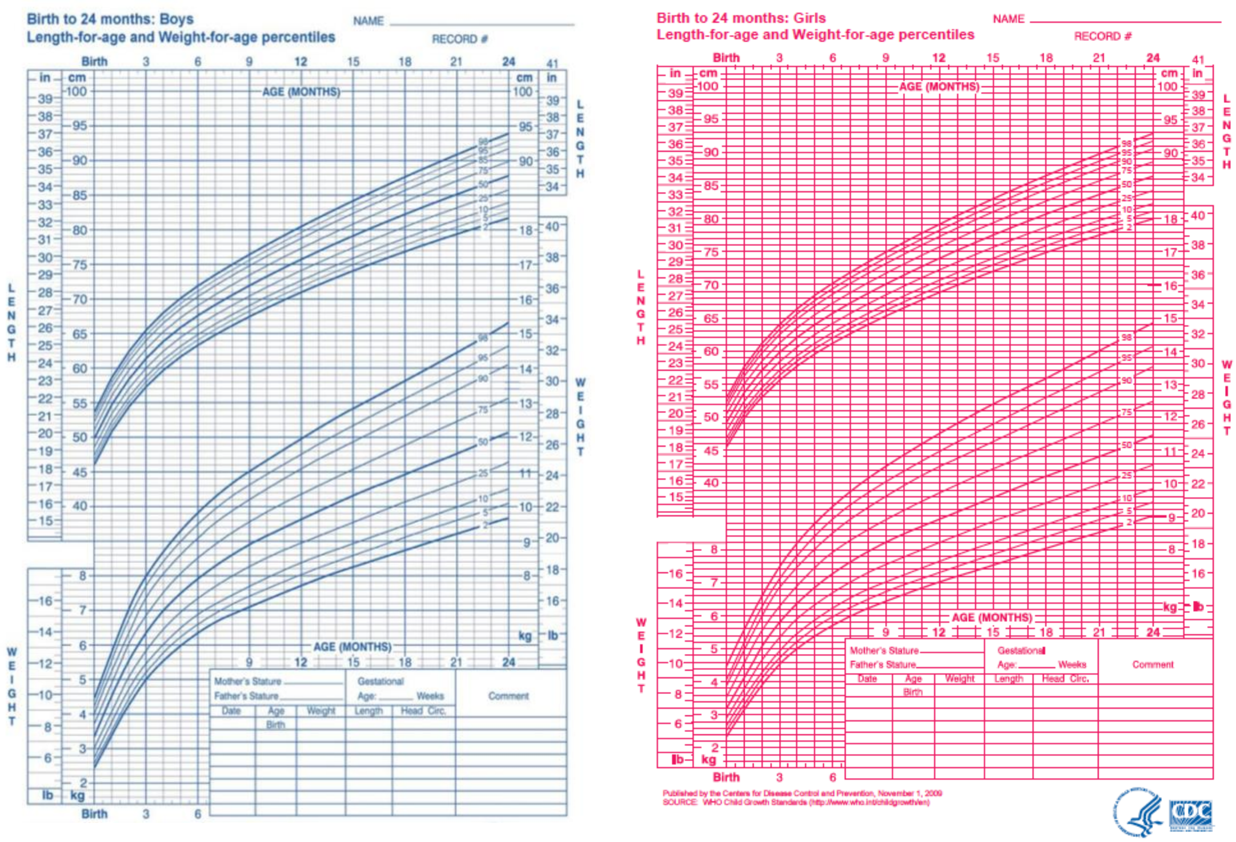


Figure 1.21: WHO reference centile weight for age for boys and girls aged 0 to 24 months.
Source: www.rcpch.ac.uk/Research/UK-WHO-Growth-Charts

As it is known that BMI is not a good tool for identifying young adults with obesity related risk, hence UK-WHO experts developed the reference charts (Fig 1.22 and 1.23) (Davies, 2012) for young adult boys and girls too for age 2 to 18 year. These charts have been split for 2 different age groups – 2-9 years and 9-18 years, for both genders.

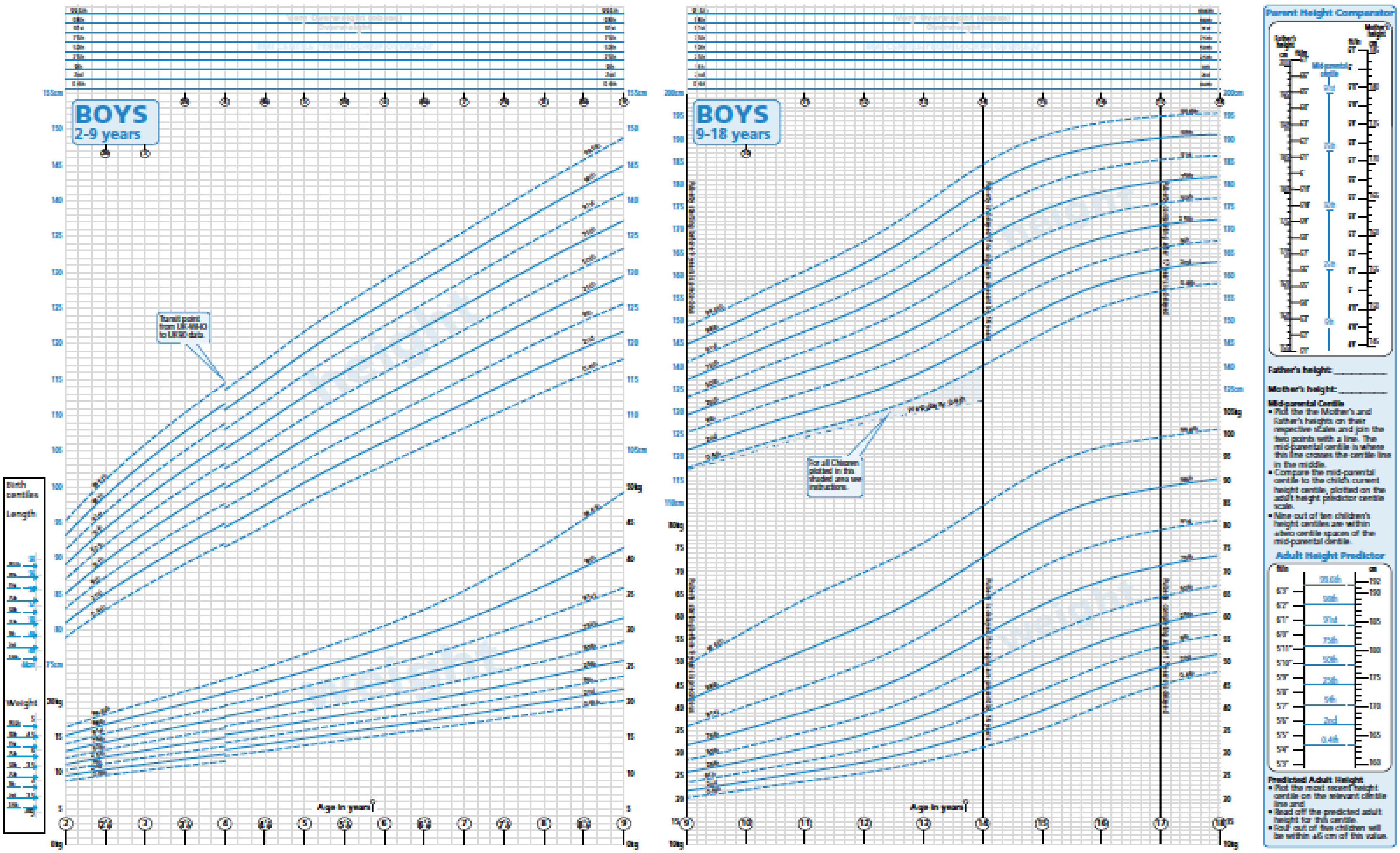


Figure 1.22: UK-WHO growth chart for 2-18 years boys

(Davies, 2012)

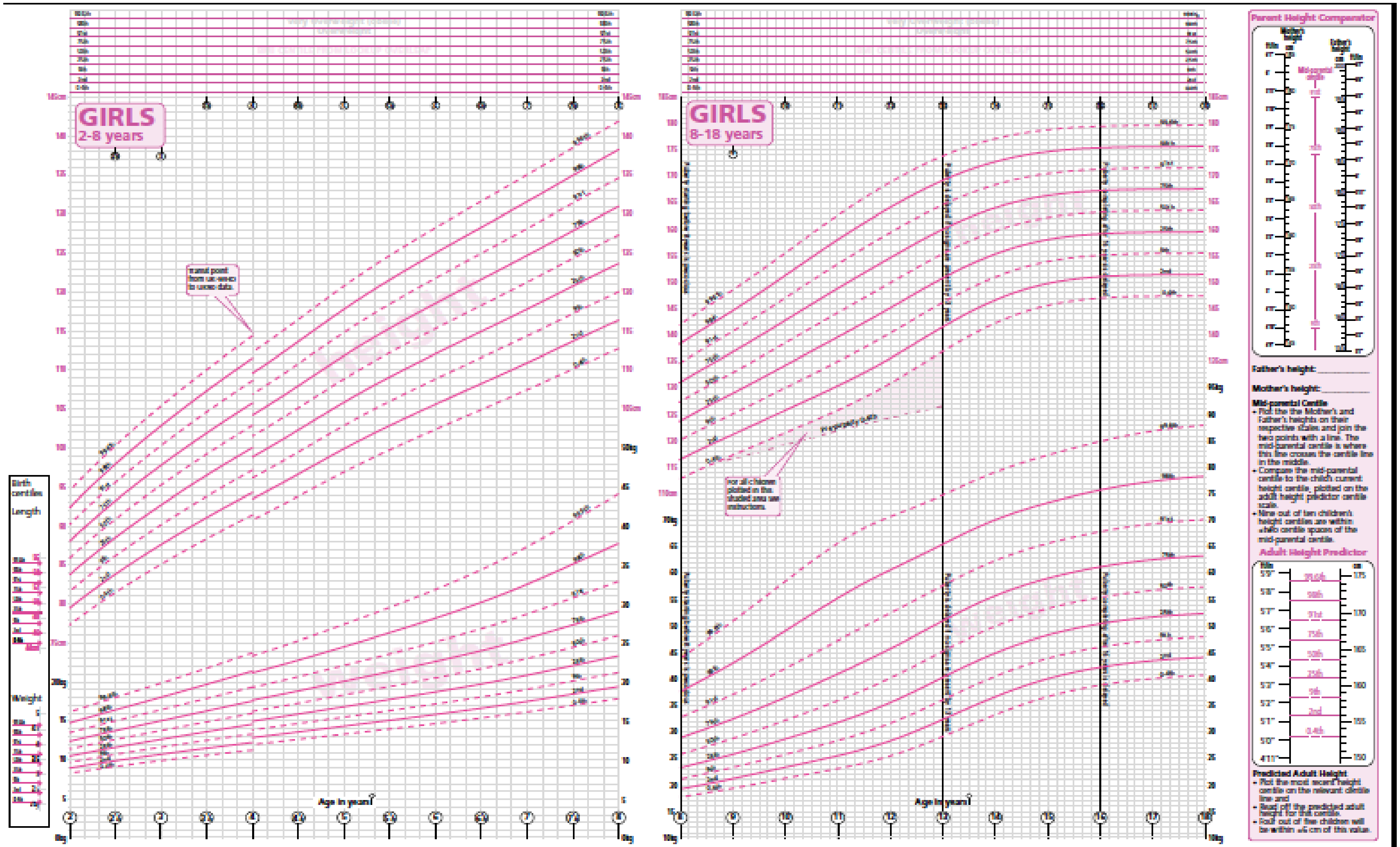


Figure 1.23: UK-WHO growth chart 2-18 years girls

(Davies, 2012)

1.9 The aims and objectives of the study

The aims of this study were

- To develop the age-specific (16 to 21 yr) and gender-specific growth centile curves for height, weight, SH, LL, BMI, WC, BF%, FM (kg), FFM (kg) and SMM (kg) for older adolescents and young adults from the SA background living in the UK.
- To characterise measures of body composition derived from BIA [BF%, FM (kg), FFM (kg) and SMM (kg)] in relation to age, gender and ethnicity (SA vs WE).
- To extend the work previously conducted within the group by integrating the 4 to15 yr age group centile data with the equivalent data set collected during this study and develop the full set of age and gender specific growth curves for this population.
- To compare the SMM (kg) growth curves resulting from this study with the SMM (kg) curve developed by McCarthy et al. 2013 and evaluate the differences in SMM (kg) between SA and WE children and adolescents.

To achieve the aims of the study, the objectives were:

- To collecting all the anthropometric measurements including height, weight, WC, SH and deriving some measurements i.e. BMI and LL in older adolescents and young adults aged between 16 and 21 years from SA background living in UK.
- To determine body composition by deriving relevant variables including BF%, FM (kg), FFM (kg), SMM (kg) using BIA in the same age and ethnic group living in UK.
- To calculating the age and gender specific z-scores for height, weight, SH, WC, BMI and BF% using LMS Growth software.
- To numerically compare the z-scores for height, weight, SH, WC, BMI and BF% between SA and WE.
- To generate the centile curves for 16 to 21 yr age group for all variables using LMS Chartmaker software, displaying the 0.4th, 2nd, 9th, 25th,50th, 75th, 91st, 98th and 99.6th centiles.
- To combine the data (anthropometric and BIA derived) collected from this study for 16 to 21 yr age group with the previously collected data for age 4 to15 yr.
- To generate the complete set of growth curves for 4-21 yr age group using LMS software displaying 0.4th, 2nd, 9th, 25th,50th, 75th, 91st, 98th and 99.6th centiles.

- To compare the SMM (kg) data from this study with the SMM (kg) data previously collected in this group on white European children.

CHAPTER 2 - Participants and Methods

2.1 Introduction

This chapter provides an overview of the standard operating procedures (SOP) which were used for the targeted measurement taken in the study. It also covers the procedures for the recruitment of the participants volunteered for this study followed by the statistical analysis used.

The chapter is divided into three main sections. First section describes the steps taken prior to the actual data collection including recruitment strategies. The second section covers the methods adopted for the collection of anthropometric measurements. Third section includes methods adopted to measure the body composition which were taken in order to perform analyses for body fat % (BF%), absolute fat mass (FM), fat-free mass (FFM) or skeletal muscle mass (SMM) using Bioelectrical Impedance Analysis (BIA). Last section describes the data handling techniques, statistical analyses procedures, including LMS (Cole and Green 1992) which was used to construct centile curves for height, weight, BMI, waist circumference, BF%, FM (Kg) and SMM (Kg).

2.2 Ethical Approval

As the study involved the collection and use of data from individuals, approval of the study was required by university's ethical review committee before starting any of the work related to the collection of the data. The participant information sheet (see appendix 1) was developed together with the informed consent form (see appendix 2). It was aimed that potential participants will be recruited from institutions such as schools, colleges, universities, mosques, temples, a generic introductory/invitation letter was also developed, so that a consistent and relevant information is provided to all institutions at the time of initial contact (see appendices 3 and 4).

The ethical review form was completed and submitted to the review committee together with other relevant documents which included Participant information sheet, Consent form, template letters for schools for their review and approval (documents included in appendices). The ethics committee approval (see appendix 5) was granted to conduct the study, after which the formal recruitment process was started.

2.3 Pre-recruitment preparations

In order to ensure that the data is collected with precision and to minimize the discrepancies within and between studies, and to enable the study to be effectively replicated, without compromising its validity, it was important that data acquisition is carried out in a standardized approach. (Bellisari and Roche 2005). The SOPs were written prior to data collection and the researchers (measurers – 2 in total including myself) were trained/familiarized with the SOPs.

The measurers (myself and another person) were trained on the use of relevant equipment at the university.

2.4 Recruitment Procedures

As the primary objective of the study was to collect anthropometric measurements and body composition of South Asian ethnic group of specific age range, healthy (apparently) population consisting of South Asian adolescents and young adults of both genders were recruited. An opportunistic sampling technique was applied. In order to perform clinically meaningful analysis and to obtain reliable results with minimum margin of error, around 500 to 600 participants (volunteers) were planned to be recruited for this study.

Keeping in view the objectives of study - to collect anthropometric measurements of adolescents and young adults of South Asian ethnic origin falling between the age group of 16 to 21 years - following selection criteria were applied

- Age group between 16 to 21 years (after 15th birthday and before 21st birthday)
- South Asian Ethnic origin (origin from India, Pakistan, Bangladesh, Nepal, Sri Lanka and Afghanistan)
- Resident of the UK
- Willingness to participate in the study after detailed information is being provided

The enrolment of the study was sequential i.e. anyone fulfilling the study eligibility criteria was invited to participate in the study. It was planned to recruit the study participants through different schools, colleges, mosques/temples in east and west of London. In order to conduct the recruitment at schools and college, the letters were sent to the schools seeking their permission. The schools were selected from areas rich in South Asian population i.e. Slough, Southall, Ilford, Walthamstow, etc.

Despite several attempts of contacting the school on phone calls, emails and personal visits, none of the schools allowed the data collection due to their data privacy policies or there were substantial procedural challenges leading to delay in data collection. Only few mosques / religious schools and cultural events allowed the data collection. Letters of invitation along with consent forms were distributed to interested institutions, with signed consent required by subjects who were more than 16.01 yrs old (past their 16th birthday) at the time of data collection and signed parental consent required for children < 16 yrs (who have not reached their 16th birthday) at the time of data collection.

Due to challenges faced from most of the institutions and to avoid further delays in data collection, we had to change our strategy for recruitment and decided to go to the public places (malls, parks, halls, high-street) which also needed formal approval/permission from relevant authorities. Due to population dynamics of Ealing council boroughs, we decided to target public places in that area and hence sought permission from Ealing Council. We are highly grateful to Ealing Council who granted us the permission for data collection for this study.

Data collection from public places such as parks had its own challenges such as suitable location (to set up the stadiometer) and in particular, power source needed to operate Tanita. The power source was managed by arranging a power bank, big enough to supply ample power to Tanita for its operations. Before we used this power bank for our study to ensure that performance of Tanita is not impacted by the different sources of power supply (AC vs DC current), validation was conducted by taking six reading (3 male and 3 female) using the power bank and by using direct current for the same subject under the same condition. The comparison was undertaken for BF% readings provided by the BIA system when operated by the two different sources of power supply. The mean and SD for BF% were 19.76 and 4.81 with coefficient of variation (CV) of 24.349 when operated via electric supply. The mean and SD for BF% (for the same participants) were 19.73 and 4.80 with CV of 24.343, when operated using the power bank. Hence the conclusion was drawn that there iswere nowas no significant difference in the outputs provided by BIA system using the different power sources.

2.5 Anthropometric Measures – accuracy and reliability

Anthropometry refers to the body measurement including its size (e.g. body weight and stature) and proportion (e.g. weight to height ratio, or sitting height ratio (Heyward and Wagner 2004). In addition to measuring the body size and proportionality, the anthropometric measures are also used as substitute markers of adiposity, such as BMI (Wt[kg]/Ht[m_2]), and WC. Different body composition assessment methods, such as BIA are also based on these measurements.

Accuracy and reliability are of key importance for any measurement process and are usually affected by the errors (Ulijaszek and Kerr 1999, Heyward and Wagner 2004). Error was minimized by following the standardized protocols.

Accuracy of measurement is usually defined as how ‘true’ the value of the measure is (Lohman et al. 1988). Low accuracy may be due to several factors including equipment error, participants’ error, or observer error i.e. due to lack of technician’s experience (Ulijaszek and Kerr 1999, Heyward and Wagner 2004). Thus, in order to increase accuracy, the measurer/observer was trained (as mentioned earlier) by the supervisor, the same observer undertook all required anthropometric measurements throughout the study by following standardized operating procedures and regular calibration of the equipment was carried out. Reliability refers to the fact that how reproducible the process is i.e. whether the repeated measures would give a similar result by following the same procedure under the same condition. It is impacted by either intra-observer (one observer) or inter-observer (more than one observer) differences (Ulijaszek and Kerr 1999). Reliability in our study was ensured as all study data was collected by one observer by following the standard operating procedure.

2.6 Anthropometric measurements

2.6.1 Height

A portable stadiometer (Leicester Height Measure - LHM) was used to measure the stature or standing height to the nearest 0.1cm. A firm and straight wall was used to position the stadiometer against that wall on the floor (with the firm, flat and levelled surface). With the stadiometer assembled, the head plate was raised to allow sufficient room for the participant to stand underneath it.

The consenting participants removed their shoes and stood with their feet flat on the centre of the base plate, feet together and heels against the rod. Their back was kept as straight as possible. Arms hanging loosely on either side of the body, with palms facing inwards, and shoulders relaxed. The head was held erect with eyes facing directly forward, ensuring the position of head was in Frankfort Plane. The Frankfort Plane is an imaginary line passing through the external ear canal and across the top of the lower bone of the eye socket, immediately under the eye (Lohman et al. 1988).

The head plate was then lowered until it touched the top of the head. At this point, the reading was be taken. Participant’s height was measure in centimetres, to one decimal place. Each height measurement was taken once. The measurements were recorded on the appropriate data collection notebook as well as entered into BIA system to measure the body composition. The LHM was regularly calibrated using a 1m rule.

2.6.2 Sitting Height

To measure the relative proportion of body, sitting height was also measured alongside standing height using the adapted Leicester Height Measure (Shah 2015). All measures were taken from the left side of the body following standard guidelines (Cameron et al. 1982). A suitable sitting tool (bench) was selected with a flat surface and suitably high enough to enable an average person to easily and comfortably sit on it so that their legs could freely hang. The stadiometer was assembled in a similar way as it was assembled for standing height, except that it was placed on the bench or table.

Subjects were requested to sit on the base of LHM, with the back of the knees aligned with the table edge, so that the legs could hang freely directly at the knee joint. Subjects were requested to sit as upright as possible, with shoulders relaxed and hands placed on the thighs. The measurer placed one hand at the base of the spine and the other at the top of the shoulder pressing it slightly backwards, prior to adjusting the head into the Frankfort Plane position as described above for measuring height. The participant was requested not to move their head to maintain the Frankfort Plane and was asked to take a deep breath but without any clenching of the buttocks (Lohman et al. 1988). The sliding top plate was then lowered and positioned directly onto the head, compressing any hair. SH was recorded using the same methodology as described for measuring height, to the nearest 0.1 cm. For every participant, the SH measurement was taken once.

2.6.3 Body weight

The Tanita BC418-MA (Tokyo, Japan) Bioelectrical Impedance Analyser (BIA) comprised of electronic digital scale was used to measure the body weight to the nearest 0.1kg. Due to the small electrical current generated by the BIA system, for the avoidance of any electromagnetic interference while using the body segmental analyser (as it uses electrical current) participants were asked if they have any cardiac pacemaker or implantable cardiac defibrillator. The scale was placed on a firm, flat surface and the level was adjusted (to be perfectly flat) using the adjusting wheels at the bottom. A correction factor of 0.5kg was applied to account for clothing.

The participant was asked to remove heavy items of clothing and jewellery and to wear shirt and trousers/skirt only. They were asked to empty their pockets and take off any other gadgets they are wearing such as headphones, bracelets, etc., and to remove their footwear (shoes, slippers, sandals, etc.) and socks. The participant then stepped onto the scales placing their bare foot on the metal plate, ensuring that the electrodes were covered. The weight was displayed on screen in kilograms (up to 1 decimal point). The scales were regularly calibrated and serviced according to the manufacturer's guidelines.

2.6.4 Waist Circumference

A flexible tape was used to measure the waist circumference to the nearest of 0.1 cm. As most of the data was collected in the outdoor environment, the measurement for waist circumference was taken with one layer of light clothing (shirt, blouse, vest or T-shirt). It was ensured that measurement was not taken over thick or bulky clothing. Coincidently, most of the data collection carried out in summer season, so we did not have to bother our participants too much by asking them to take off heavy clothing. The participant stood with their feet together with weight evenly distributed across both feet and arms slightly raised to the side of the body, breathing normally. The mid-point between inferior margin of the 10th rib and the crest of the ilium at the narrowest part of the trunk was located (Heyward and Wagner 2004).

The tension measuring tape was wrapped around the participant at the located mid-point. The measurement was taken (during expiration phase) to the nearest 0.1 cm, making sure to keep the measuring tape close but not tight enough to cause compression of the skin. The measurements were recorded on the appropriate data collection notebook.

2.6.5 Calculation of Body mass index

BMI was calculated using the formula of (body weight (kg)/height in m^2). in MS Excel.

2.7 Body composition

Body composition (BF%, FM, FFM and SSM) was measured via bioelectric impedance analysis using Tanita (BC-418 MA, Tokyo, Japan). The BC-418 8-contact electrode system (Tanita Corp., Tokyo, Japan) is developed in the way that do not need any usual gel electrodes for collecting multiple sets of impedance measurements for different body segments (arms, legs etc.,). It is based on step-on system where the subject needs to stand (bare-footed) on the steel rectangular footplates (left and right) which are internally connected to electrodes fastened to a metal platform. The BC-418 uses single frequency technique in which measurements are carried out at 50 kHz with a 0.8mA sine wave constant current (Pietrobelli et al. 2004).

2.7.1 Bioelectrical Impedance Analysis

The accuracy of a test involving a body composition analyser such as Tanita is dependent on the examinee and on the environment in which the test is conducted. To address this, following steps were following in order to assure accurate and consistent test results.

Tanita was placed on the ground with flat surface. It was ensured that it is stable and resting properly on the floor. The best horizontal level was achieved by moving the wheels at the bottom of the Tanita scale and guided by the spirit level. Subjects were requested to be in light clothing and empty their pockets and remove other accessories such as jewellery, headphones etc. Subjects were also requested to remove their socks or stockings before stepping on the footpad.

Personal details such as age, sex and height were recorded into the analyser. All subjects were entered as ‘standard’ body type, as none of the subjects recruited were considered to have an athletic build. Subjects were asked not to hold on to the handgrips or make any sudden moves while the body weight was being registered. Once the weight was registered, participants were asked to hold the hand electrode by putting the thumb on the top of the handgrip, while holding the bottom of the handgrip with other four fingers. Subjects were then asked to straighten out their elbows and leave some space between the armpits and body and keep the arms away from the legs at an approximate 45° angle and were requested to stand steadily while the Tanita measured the body composition. The output of the measured body composition was printed in the slips. With this output we got the values of variables i.e. BF%, FM, FFM, Wt., and appendicular SMM.

2.8 Data Handling & Statistical Procedures

To ensure confidentiality, no names were collected for the participants, rather the numerical codes were used for each participant at time of data collection. Participant’s date of birth, waist circumference, standing height (up to 0.1 decimal), sitting height (up to 0.1 decimal), data and place of data collection, were recorded in the notebook, while the other data (age, gender, height and their physical activity status – athlete vs standard) were entered directly in Tanita. While collecting the data all participants recruited in the study were standard from their physical activity perspective not athlete. The output slips from Tanita were saved in the file for subsequent data entry. All the data was entered into Excel

(Microsoft® Excel® for Mac 2011 version 14.4.9) and SPSS (IBM® SPSS® version 22 for Mac). Decimal age was collected by using the formula in excel spread sheet [formula = (date of data collection – date of birth)/365]

Specific scatter plots were generated for all variables. Prior to generate the centile curves, descriptive statistics of all variables were calculated. Normality of data was calculated in SPSS using Kolmogorov-Smirnov and Shapiro-Wilk tests at 5% margin of error where the data was found to be normally distributed.

2.8.1 Calculation of Z-Scores and construction of centile curves

Z-scores were calculated using LMS method which is based on the underlying assumption that the Box-Cox power transformation transfigure the date as normally distributed, hence normalizing the data at each age and summarizing it in terms of three smooth age specific curves called L (lambda), M (mu) and S (sigma) (Cole et al. 1995).

The M curve corresponds to the median of the variable at each age and the S curves correspond to the coefficient of variation of a particular variable at each age whereas the L curve allows for the substantial age dependent skewness in the distribution of the said variable. The values for L, M and S were tabulated for a series of ages. The points on each centile curve are defined in terms of the formula where L, M and S are values of the fitted curves at each age and z indicates the z score for the required centile (Cole et al. 1995). LMS Growth Software which takes the form of an Excel add-on which incorporates the UK1990 reference data for height, weight and BMI (https://www.healthforallchildren.com/shop-base/shop/software/lmsgrowth/). All anthropometric measures (Ht., Wt., WC, SH, BMI) and body fat percentage were converted to their corresponding Sex specific SD-scores (z-score) using the 1990 UK growth reference data (Cole et al. 1995), BF% reference data (McCarthy and Ashwell 2006) and WC reference data (McCarthy et al. 2001).

Centile curves for all variables (height, weight, sitting height, BMI, body fat%, fat mass, fat free mass and skeletal muscle mass) were created for each dataset for both genders using the LMS method as an underlying principle. The curves were constructed using the LMS Chartmaker software for sex specific curves for all variables. For constructing these curves, we imported all data from Microsoft Excel into this downloadable LMS Chart maker. The data was corrected/adjusted using the LMS method, to account for skewness and enable us determining the individual standard deviation scores (SDS; also referred to as centile or Z scores), which were used to assess the position of the child on the centile chart at the specific age (Cole and Green 1992, Gatineau and Mathrani 2011).

2.8.2 Combination of data already collected by previous research

In order to extend the full set of growth reference range from 4-21 years of age, the data collected during this thesis work was merged with equivalent data for children aged 4-15 years living in Greater London and neighbouring counties (schools) collected by previous research student (Shah et al, 2013) who took all the measurements on school premises. Dates of birth, gender and ethnicity information were collected at the same time as the anthropometric measurements. Due to time constraints during the school day, all measurements were conducted once. The two datasets were combined in MS Excel and z-scores and centile curves were generated for the full age spectrum using the methods described above.

CHAPTER 3 - General Descriptive Statistics

Table 3.1 summarises the participant's information for each country and by each gender. A total of 545 participants were recruited from different area. Around 40% of the study participants were from India followed by 34.5% from Pakistan, 11.6% from Sri Lanka and 8% from Bangladesh. The remaining 5% of the participants were from Nepal and Afghanistan in almost equal proportions. There were 2 participants with hybrid parental origin i.e. one of the parents were from SA countries. There were more males (55%) than females (45%) overall but few countries have more female participants than male participants.

Table 3.1: Participant information by country and gender

Country	Total		Gender	
	N	%	Male N (%)	Female N (%)
India	216	39.6	145 (48.3)	71 (29)
Pakistan	188	34.5	91 (30.3)	97 (39.6)
Bangladesh	43	7.9	21 (7)	22 (9)
Sri Lanka	63	11.6	32 (10.7)	31 (12.7)
Nepal	15	2.8	5 (1.7)	10 (4.1)
Afghanistan	18	3.3	5 (1.7)	13 (5.3)
Indian & Arabic	1	0.2	1 (0.3)	0 (0)
Pakistan & Mauritius	1	0.2	0 (0)	1 (0.4)
Total	545	100	300 (100)	245 (100)

Table 3.2 summarises the recruitment by age group. Around one third of the study participants were of 16 yrs of age, lowest numbers of participants in 19 yr age group. The number of male participants were more in each age group than females except for 21 years age group where females were more than males.

Table 3.2: Participant information by age group

Age	Male N (%)	Female N (%)	Total N (%)
16	114 (38)	71 (29)	185 (33.9)
17	52 (17.3)	37 (15.1)	89 (16.3)
18	35 (11.7)	26 (10.6)	61 (11.2)
19	24 (8)	25 (10.2)	49 (9)
20	25 (8.3)	20 (8.2)	45 (8.3)
21	50 (16.7)	66 (26.9)	116 (21.3)
Total	**300 (100)**	**245 (100)**	**545 (100)**

Table 3.3 summarises the general descriptive statistics of male population for key variables including Height, Weight, Sitting Height, WC, BMI and BF%, FM and FFM. This shows that for male population, mean and median height was 172.5. cm and 172 cm, respectively. Minimum height that measured was 153 cm and maximum height was 196 cm. Mean and median sitting height was 89.3 cm and 89.8 cm, respectively. The mean and median waist circumference (WC) were found to be almost similar i.e. 84.3cm and 84 cm, respectively. The minimum and maximum waist circumference was 62 cm and 115 cm respectively. The mean weight of male participants was 66.7 kg. It is interested to note that the minimum weight as low as 37.1 kg and maximum weight as high as 123.3 Kg in male participants. Mean BMI of male participants was 22.4. Minimum BMI was 14.6 while maximum BMI that was calculated was 34.7. Mean and median body fat % was 17.9% and 17.2% respectively. It is of note that minimum BF% in male participants was 2.3% while maximum BF% was 42%. Mean FM and FFM was 12.5kg and 54.2kg respectively. The minimum and maximum FM was 1.31kg and 42.7Kg respectively. The minimum and maximum FFM was 32.2 kg and 82.9 Kg respectively

Table 3.3: General descriptive statistics showing Age, Height, Sitting height, WC, Weight, BMI, BF, FM and FMM for males in study

General descriptive statistics (Males)									
	Age (Years)	Height (cm)	Sitting Height (cm)	WC (cm)	Weight (Kg)	BMI (Kg/m^2)	BF (%)	FM (Kg)	FFM (Kg)
Mean	17.4	172.5	89.3	84.3	66.7	22.4	17.9	12.5	54.2
5% Trimmed Mean	17.3	172.5	89.6	84.1	66.1	22.2	17.9	12.0	53.9
Median	16.8	172.0	89.8	84.0	64.4	21.7	17.2	10.7	53.4
Variance	3.6	44.5	22.3	102.8	161.6	14.2	42.3	44.7	62.4
Std. Deviation	1.91	6.67	4.72	10.1	12.7	3.8	6.5	6.7	7.9
Minimum	15.01	153	62.0	62.0	37.1	14.6	2.3	1.31	32.2
Maximum	21.6	196	100.0	115.0	123.3	34.7	42.0	42.7	82.9
Range	6.61	43	38.0	53.0	86.2	20.1	39.7	41.4	50.6
25^{th} percentile	15.7	168.0	87.0	77.0	57.5	19.6	13.7	8.1	48.9
75^{th} percentile	19.1	177.0	92.5	90.9	74.0	24.5	21.5	16.0	58.7
Interquartile Range	3.3	9	5.5	13.9	16.5	4.9	7.8	7.9	9.7
Skewness	0.57	0.02	-1.03	0.31	0.91	0.74	0.42	1.33	0.51
Kurtosis	-1.1	0.5	3.7	-.21	1.3	.32	0.7	2.4	0.7

Table 3.4 summarizes the general descriptive statistics of female population for Height, Weight, Sitting Height, WC, BMI and BF%, FM and FFM. The results show that for female population, mean and median height was 159.3 cm and 159.0 cm respectively. Minimum height measured was 142 cm and maximum height was 182 cm. Mean and median sitting Height were 84.2 cm and 84.5 cm, respectively. The mean and median waist circumference (WC) were found to be 81.5 cm and 81 cm, respectively. The minimum and maximum WC in female participants was 57 cm and 112 cm respectively. A slight difference in the mean (57.8 kg) and median (56.1 kg) weight was seen in female participants. It is interested to note that study found minimum weight as low as 33 kg and maximum weight as high as 99 kg in female participants. Mean BMI was 22.8 kg/m2. The minimum and maximum BMI in female participants was 13.1 kg/m2 and 35.3 kg/m2 respectively. Median body fat% was 29% with minimum and maximum BF% noted in female participants as 9.4% and 50.2% respectively. Mean FM and FFM was 17.5 kg and 40.3 kg respectively. The minimum and maximum FM was 3.8 kg and 44.4 Kg respectively. The minimum and maximum FFM was 29.2 kg and 55.2 Kg respectively.

Table 3.4: General descriptive statistics showing Age, Height, Sitting height, WC, Weight, BMI, BF, FM and FMM for females in study

General descriptive statistics (Females)									
	Age (Years)	Height (cm)	Sitting height (cm)	WC (cm)	Weight (kg)	BMI (kg/m^2)	BF (%)	FM (Kg)	FFM (Kg)
Mean	17.9	159.3	84.2	81.5	57.8	22.8	29.1	17.5	40.3
5% Trimmed Mean	17.9	159.2	84.5	81.3	57.4	22.6	29.2	17.1	40.2
Median	17.7	159.0	84.5	81.0	56.1	22.0	29.0	16.1	39.7
Variance	3.9	41.6	27.1	96.4	113.0	14.5	55.6	54.7	18.0
Std. Deviation	1.9	6.5	5.2	9.8	10.6	3.8	7.5	7.4	4.2
Minimum	15.0	142	63.0	57.0	33.0	13.1	9.4	3.8	29.2
Maximum	21.1	182	96.0	112.0	99.6	35.3	50.2	44.4	55.2
Range	6.1	40	33.0	55.0	66.6	22.2	40.8	40.7	25.9
25^{th} percentile	15.9	155.0	81.9	75.0	49.9	20.1	24.1	12.0	37.3
75^{th} percentile	20.0	163.8	87.5	87.8	64.6	25.2	34.4	22.3	43.0
Interquartile Range	4.1	9	5.7	12.8	14.6	5.0	10.3	10.3	5.7
Skewness	.11	0.20	-1.18	0.3	0.68	0.75	-0.05	0.84	0.42
Kurtosis	-1.5	0.1	2.7	0.4	1.0	0.6	-0.1	1.0	0.3

Table 3.5 shows the descriptive statistics for SDS of both male and female population for Height, Weight, Sitting Height, WC, BMI and BF%. SDS for height reflects that majority of the male population lies below the average height of the reference population (based on UK population data from 1990). Similar pattern was observed in the height of female population (SDS in -ve). Almost similar pattern of SDS score of sitting height was seen in both male and female population. The SDS height for female population was more negative compared with the male population, which was also consistent with the SDS sitting height pattern in both genders.

The female population was slightly below the SDS weight of reference population (UK 1990). The SDS for weight indicates that most of the male population is above the average weight of the reference population. The SDS for waist circumference (WC), BMI and BF% were found to be in positive values for both genders, meaning that majority of the population's WC, BMI and BF% is greater than the average WC, BMI and BF% for reference population in both genders.

Table 3.5: Descriptive statistics for SDS score of both male and female population for Height, Weight, sitting height, WC, BMI, and BF for all ages combined

Descriptive statistics of SDS score by gender												
Descriptive statistics	**SDS Height**		**SDS Weight**		**SDS Sitting height**		**SDS WC**		**SDS BMI**		**SDS BF%**	
	M	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
Mean	-0.32	-0.66	0.14	-0.04	-0.55	-0.85	1.34	2.23	0.40	0.38	0.48	0.63
Std Dev	0.94	1.07	1.17	1.25	1.08	1.36	1.04	1.13	1.22	1.18	1.22	1.32
Minimum	-3.36	-3.28	-3.53	-4.42	-6.30	-6.51	-1.40	-2.18	-3.17	-4.95	-5.53	-4.02
Maximum	2.69	2.96	3.82	3.34	1.98	2.36	3.47	4.21	3.02	3.04	4.02	3.70

3.1 Summary and discussion

The overall summary of the descriptive statistics shows that SA adolescents and young adults have low height and have higher value of WC, BMI and BF% compared to UK 1990 reference population among both genders.

It is worth mentioning that in the summary of descriptive statistics, for male participants the minimum value of BF is 2.3%, which is considered a very low BF%, considering we were targeting the population supposed to be healthy (absence of any medical condition). There are 11 male participants in our study who had body fat less than 5%. Four of them had less than 3% body fat and had BMI below 18.5 kg/m^2. According to BMI cut off for Asians, their BMI is falling under the underweight category which explains the less amount of fat in their body. Seven of them had BMI 18.5 kg/m^2 to 23 kg/m^2. All of these participants had WC below 90cm. According to WHO revised cut off for Asian (detail in section 1.8.1 Table 1.3) they were in ideal weight category (considering their WC criteria). The participants with BF% less than 5% were checked twice for their body composition readings via Tanita and same results were found on both readings. The reason for low BF% for the seven participants with BMI in the ideal range is not clear. It is believed that Tanita slightly under-estimates the body fat %age in SA which can possibly see in these participants or It may be their unique body composition (tendency of body to have low body fat). We don’t know if there is any limitation of Tanita to accurately calculate the body fat percentage below a certain value which may have been the case in these participants.

CHAPTER 4 - Height, Weight, Sitting Height and Leg length

4.1 Introduction

Height has long been used as a marker of linear growth and nutritional status. This linear growth varies between different population groups. In addition, the ICP (infancy– childhood–puberty) model of growth suggests that non- genetic factors that can affect growth rate are diet, growth hormone and sex steroids (Navti et al. 2014). Ethnic group differences in height and weight have been observed, with South Asian children being on average shorter and lighter compared to their white European counterparts (Whincup et al. 2010). Although there is a complex relationship between stature, obesity and metabolic risk, shorter stature individuals have a higher incidence of obesity-related co-morbidities compared to those who have a height within a normal range. Body weight corrected for age is the simplest anthropometric measure of nutritional status in infancy, childhood and adolescence. A higher birth weight is positively associated with increased adult BMI or overweight and obesity rates (Qiao et al. 2015, Zou et al. 2019).

However, weight alone does not provide much information on body composition, whereas the relative proportion of FM and FFM is much more informative. When used in conjunction with height, weight can determine BMI which is used to define overweight and obesity (as well as underweight and healthy weight) in different population groups. When used in paediatric settings, height, weight and BMI are usually compared with reference to indicate the relative position of that child to nationals norms (Koletzko et al. 2015, Whitney and Rolfes 2018).

The evaluation of child growth is greatly assisted by expressing height and weight in terms of z scores based on a reference population (Cole et al. 1995). Gender specific height and weight centile charts have been constructed to evaluate variation in growth in both epidemiological and clinical settings. Weight and height centile charts can be used to identify the individual who is underweight for age and short-for-age respectively and a change in z score is much easier to quantify and interpret than a change in centile position.

Additionally, children growth can also be evaluated by using sitting height as a parameter. Sitting height (SH) permits the evaluation of the relative proportions of leg length and trunk length in relation to overall stature. Indeed, it has been observed in adults that individuals with relatively short legs for their height are at a greater risk for cardiometabolic disease (Marcato et al. 2014). Although the precise reason why having shorter legs for height (disproportionality) is unclear, it may be due to nutritional disturbance at critical periods of growth either in utero or post-natally (Li et al. 2016, Perkins et al. 2016).

In addition, previous studies have shown that children who are classified as overweight/obese based on either BMI or WC have been shown to have relatively shorter legs for their height (Pliakas and McCarthy 2010). In addition, it has also been shown that individuals from a South Asian background also tend to have shorter legs in relation to their overall height (Bogin and Varela-Silva 2010).

The measurement of leg length (LL) and sitting height (SH) outside of the laboratory or clinic can be difficult to conduct due to technical and equipment-related difficulties. However, a range of techniques have been developed for use in the field, which very much relies on the portability, accuracy and precision of the assessment tool (Lukaski 1990, Kushner 1992, Ellis 2000, Dangour et al. 2002, Torres et al. 2003, Charbonneau-Roberts 2005, Mialich et al. 2014). In this research group (LondonMet), a lightweight, portable sitting height measure has been developed from a standard Leicester stadiometer which can be seated on a firm and secure table. In this study, we set out to develop references for height, weight, sitting height and leg length for the adolescent and young adult South Asian population to complement and add to the equivalent references for younger children.

4.2 Aims

The aims of this study were to develop sex-specific percentile curves of height, weight and sitting height for adolescents and young adults from SA background living in the UK.

4.3 Methodology

4.3.1 Height measurement protocol

All the measurements were taken to the nearest 0.1cm. Each time stadiometer was calibrated using a 1m rule and followed the same method as described in methodology section 2.6.1 of chapter 2.

4.3.2 Weight measurement protocol

Tanita BC418 system was used to measure the body weight. The body weight was taken in kg to 1 decimal point. The details of weight measurement protocol are described in section 2.6.3 of chapter 2.

4.3.3 Sitting height measurement protocol

Sitting height measurement was taken to the nearest 0.1cm and recorded the data on the data collection notebook. The details of sitting height measurement protocol are described in section 2.6.2 of chapter 2.

4.3.4 Leg Length measurement protocol

For calculating leg length (in cm) of study participants sitting height was subtracted from standing height.

4.4 Results

4.4.1 Height

Table 4.1 show the descriptive statistics of height for each age group (16-21yrs) and for both genders. Very little variation was observed in mean height of the males across different groups with a similar trend being seen in the females (16-21yrs). As a whole, male participants had a higher mean height compared to the female participants in all age group.

Table 4.2 show the descriptive statistics for z-score of height (16-21yrs). Overall male and female participants at each age group had a lower mean height compared to UK 1990 reference population (expressed as a negative z-score). Moreover, females had a greater negative mean z-score compared with the male participants for all age groups.

Table 4.1: Descriptive statistics (mean ± SD) of height for SA groups by age range and gender distribution

Descriptive statistics of height with age and gender distribution												
	16 years		17 years		18 years		19 years		20 years		21 years	
	M	F	M	F	M	F	M	F	M	F	M	F
Mean	171.4	158.8	172.8	159.4	173	159.9	175.4	158.4	172.3	160.5	173	159.8
Std Dev	6.78	6.43	5.92	6.50	6.53	5.99	8.09	5.48	6.22	6.86	6.11	6.97
Minimum	153	142	161	148	160	150	156	145.5	159	145.6	154	146
Maximum	189	171	191	177.1	186	172	196	170	185	173.4	189	181.5

Table 4.2: Descriptive statistics (mean ± SD) of Z-score for height for SA groups by age range and gender distribution

Descriptive statistics of Z-score for height with age and gender distribution												
	16 years		17 years		18 years		19 years		20 years		21 years	
	M	F	M	F	M	F	M	F	M	F	M	F
Mean	-0.03	-0.66	-0.32	-0.67	-0.53	-0.60	-0.26	-0.86	-0.72	-0.53	-0.63	-0.63
Std Dev	0.88	1.05	0.84	1.07	0.92	0.99	1.16	0.91	0.89	1.14	0.87	1.15
Minimum	-2.33	-3.28	-1.99	-2.55	-2.39	-2.23	-3.04	-3.00	-2.62	-2.99	-3.36	-2.92
Maximum	2.34	1.33	2.22	2.25	1.36	1.40	2.69	1.06	1.05	1.62	1.65	2.96

4.4.1.1 Scatter plots

Fig 4.1 and 4.2 show the scatterplots for height vs age in both genders suggest essentially a flat association between these variables indicating that adult stature was essentially been achieved by 15 y of age in both males and females. However, when the centile charts were constructed, it could be seen that in male, the median height increased from 171.6 cm at age 15y, to 178.2 cm at age 21.5 y. No extreme observations or outliers were noted at either end in both genders.

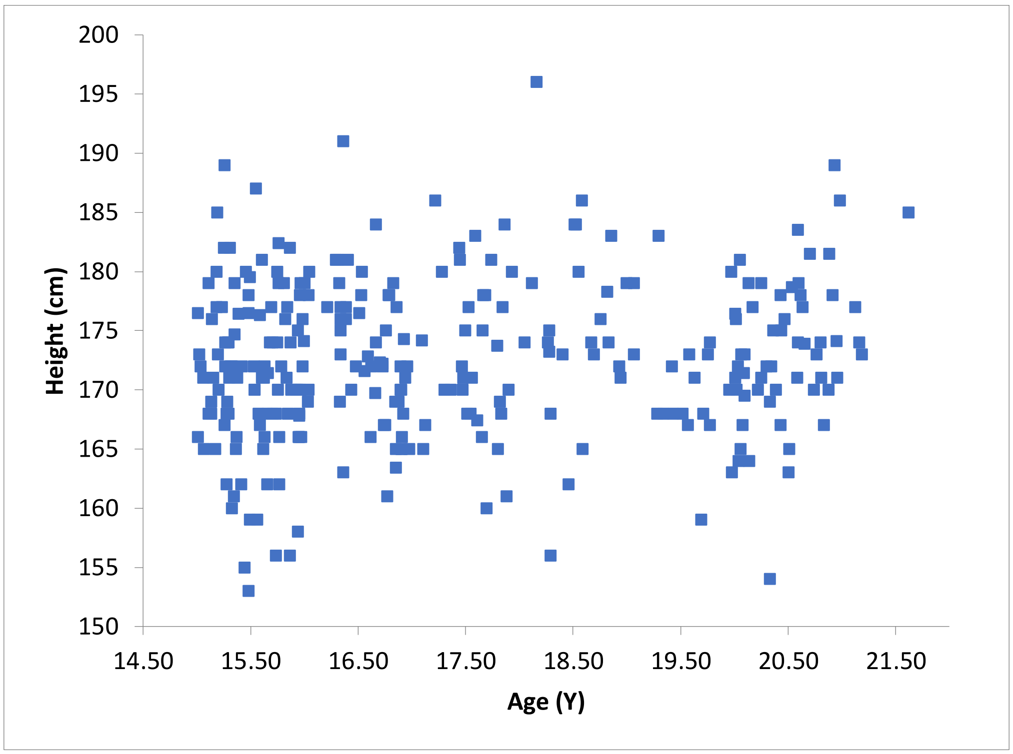


Figure 4.1: Scatterplot showing the distribution of the male height against age

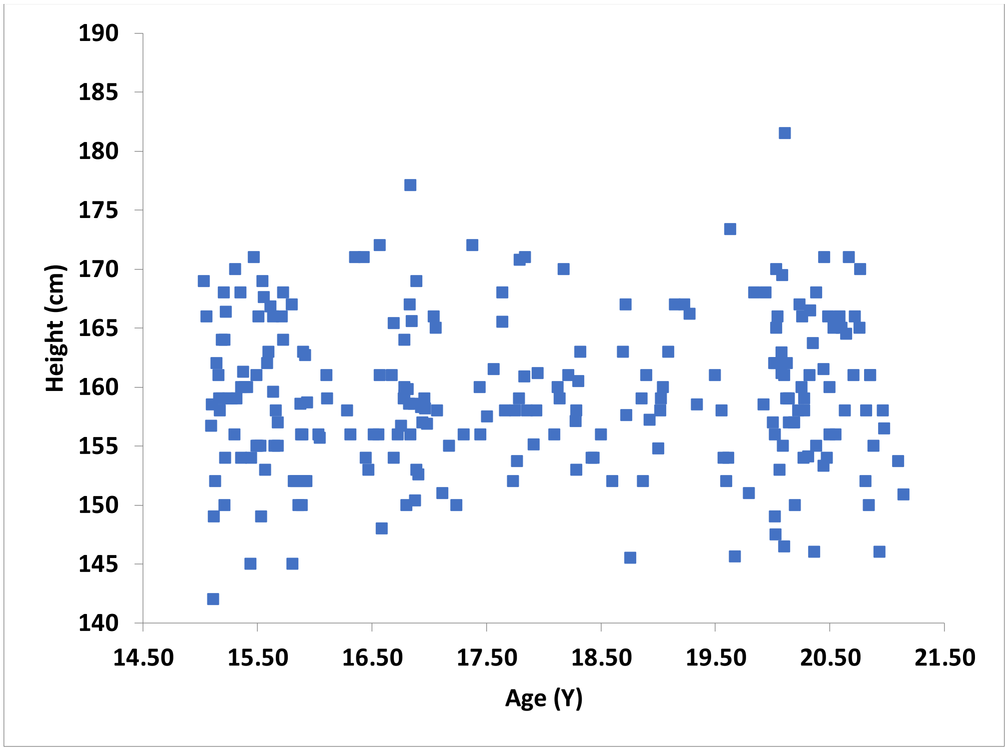


Figure 4.2: Scatterplot showing the distribution of the female height against age

4.4.1.2 Centile charts

In figure 4.3, the data was analysed at different centile points for male population. An age-related increase in mean height was seen in males between age 16 to 21 yrs. This trend was same for all the centiles. For 50th centile (Table 4.3) minimum height of 171.6 cm was seen in 15y of age while maximum height of 178.2cm was seen at 21.5 y among the studied age group. For 50th centile among male participants, a steady and small increase in height was seen from 15y onwards until 18.5y of age when it became plateaued till 20.5y of age and then increase in height was seen in subsequent age groups. This trend was almost similar in other centiles.

Table 4.3: Centiles of height by age and sex (male)

	0.4th	2nd	9th	25th	50th	75th	91st	98th	99.6th
Age	-2.6	-2.0	-1.3	-0.7	**0**	0.7	1.3	2.0	2.7
15	151.9	157.1	162.2	167	**171.6**	176	180.3	184.4	188.4
15.5	152.9	157.8	162.6	167.2	**171.7**	176.1	180.5	184.8	188.9
16	154.2	158.7	163.2	167.7	**172.1**	176.6	181	185.3	189.6
16.5	155.3	159.5	163.8	168.1	**172.5**	176.9	181.4	185.9	190.5
17	155.9	159.9	164	168.2	**172.5**	177	181.5	186.2	191
17.5	156.4	160.3	164.3	168.5	**172.8**	177.3	182	186.7	191.7
18	156.7	160.6	164.6	168.8	**173.1**	177.7	182.3	187.1	192.1
18.5	156.6	160.6	164.7	168.9	**173.1**	177.7	182.2	186.8	191.6
19	156.1	160.2	164.3	168.4	**172.7**	177	181.3	185.7	190.2
19.5	155.5	159.6	163.7	167.8	**172**	176.1	180.2	184.4	188.5
20	155.6	159.8	164	168	**172.1**	176	180	184	187.8
20.5	156.9	161.2	165.4	169.4	**173.4**	177.3	181.1	184.9	188.5
21	159.2	163.5	167.7	171.7	**175.6**	179.5	183.2	186.9	190.4
21.5	161.9	166.2	170.3	174.3	**178.2**	182	185.6	189.2	192.7

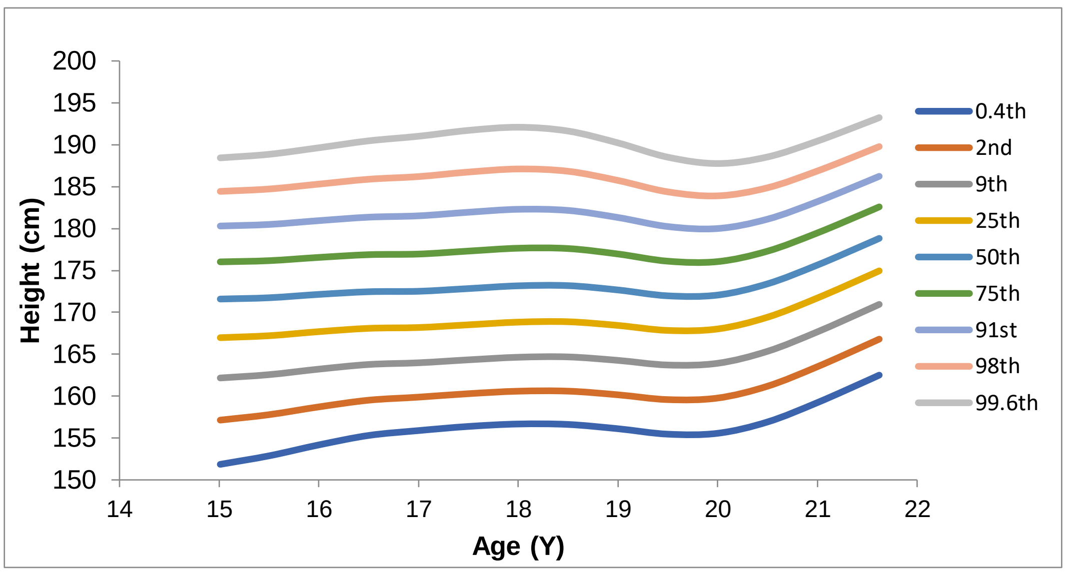


Figure 4.3: represents the height centiles of male at 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles

Similarly, the centile charts (Fig 4.4) were constructed for the female population which showed that height increases steadily from 15y onward till 17y of age after which there is little or no change in height of Asian females at all centiles. At 0.4th centile, increase in height can be observed from 15y to 17y and then the growth curve plateaued from 17y to 19y and then a downward trend was observed from 19y to 21y. Similar pattern was seen at 2nd and 9th centiles. No relationship was seen between age and height in female population at 25th, 50th, 75th and 91st centiles, which depict that the height is not increasing with age at those centiles. At 50th centile (Table 4.4), minimum height of 158.6 cm was seen at 16y and maximum height of 159.7 cm was seen at 20 and 20.5y of age.

Table 4.4: Centiles of height by age and sex (female)

	0.4th	**2nd**	**9th**	**25th**	**50th**	**75th**	**91st**	**98th**	**99.6th**
Age	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
15	139.4	145.0	150.2	155.0	**159.5**	163.8	167.8	171.6	175.3
15.5	141.7	146.1	150.4	154.7	**159.0**	163.2	167.5	171.6	175.8
16	143.3	146.9	150.7	154.5	**158.6**	162.8	167.2	171.8	176.6
16.5	144.7	147.8	151.1	154.7	**158.6**	162.8	167.4	172.4	177.9
17	145.6	148.5	151.6	155.0	**158.8**	163.0	167.7	173.0	179.0
17.5	146.1	148.9	152.0	155.3	**159.1**	163.2	168.0	173.4	179.7
18	146.1	148.9	152.0	155.4	**159.1**	163.3	168.0	173.4	179.7
18.5	145.5	148.5	151.7	155.1	**159.0**	163.2	168.0	173.3	179.4
19	144.9	148.1	151.5	155.2	**159.1**	163.5	168.2	173.5	179.3
19.5	144.3	147.7	151.4	155.2	**159.4**	163.9	168.7	173.9	179.5
20	143.6	147.3	151.2	155.3	**159.7**	164.2	169.0	174.2	179.6
20.5	142.6	146.7	150.9	155.2	**159.7**	164.3	169.1	174.1	179.2
21	141.0	145.4	149.8	154.4	**159.0**	163.7	168.4	173.2	178.1

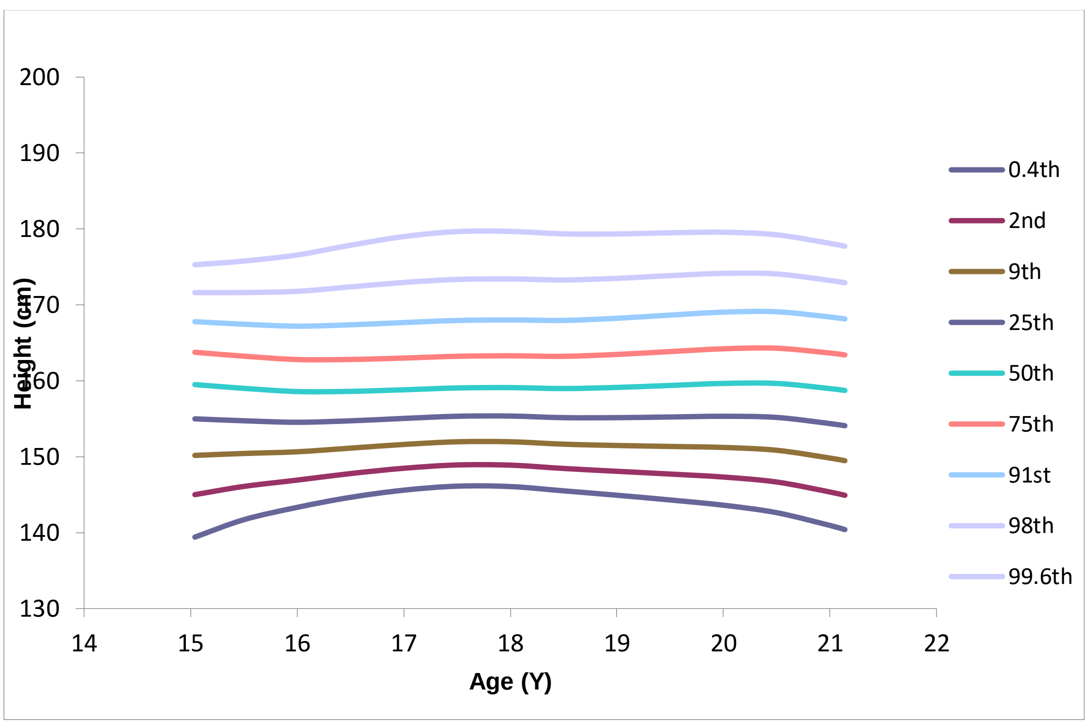


Figure 4.4: represents the height centiles of females at 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles

4.4.1.3 Merged centile curves

Figure 4.5 below shows the smoothed height centiles curves computed for 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for male. It is quite evident from the results that the mean height increased with age for all centiles. The increase in height was consistent and smooth from 4y till 16y after which there was minimal increase meaning that most of the height was achieved at the age of 16y. At 50th centile, minimum height of 105.1 cm was seen at 4 years of age and maximum height of 174.7 was seen at 21.5 years of age (Table 4.5).

Table 4.5: Merged centiles of height by age and sex (male)

	0.4th	**2nd**	**9th**	**25th**	**50th**	**75th**	**91st**	**98th**	**99.6th**
Age	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
4	91.9	95.7	99.1	102.2	**105.1**	107.8	110.4	112.7	115.0
4.5	93.0	96.8	100.3	103.4	**106.4**	109.1	111.7	114.1	116.5
5.0	95.8	99.5	103.0	106.2	**109.3**	112.2	114.9	117.5	120.0
5.5	98.6	102.3	105.7	109.1	**112.2**	115.2	118.1	120.9	123.6
6.0	101.3	105.0	108.5	111.9	**115.1**	118.3	121.4	124.4	127.3
6.5	104.1	107.7	111.2	114.7	**118.1**	121.4	124.6	127.8	130.9
7.0	106.8	110.4	114.0	117.5	**121.0**	124.5	127.9	131.3	134.6
7.5	109.5	113.1	116.7	120.3	**123.9**	127.5	131.1	134.7	138.3
8.0	112.2	115.8	119.4	123.1	**126.8**	130.5	134.3	138.1	142.0
8.5	114.9	118.5	122.1	125.8	**129.6**	133.5	137.5	141.5	145.6
9.0	117.6	121.1	124.8	128.6	**132.5**	136.5	140.7	144.9	149.3
9.5	120.3	123.9	127.6	131.5	**135.5**	139.6	143.9	148.3	152.9
10.0	123.0	126.6	130.4	134.4	**138.5**	142.7	147.1	151.8	156.6
10.5	125.8	129.5	133.3	137.3	**141.5**	145.9	150.5	155.2	160.3
11.0	128.6	132.4	136.3	140.4	**144.6**	149.1	153.8	158.7	163.9
11.5	131.5	135.3	139.3	143.5	**147.8**	152.4	157.2	162.2	167.6
12.0	134.4	138.3	142.3	146.6	**151.0**	155.7	160.6	165.7	171.1
12.5	137.3	141.2	145.4	149.7	**154.2**	159.0	163.9	169.1	174.6
13.0	140.0	144.1	148.3	152.7	**157.3**	162.1	167.1	172.4	177.9
13.5	142.7	146.8	151.1	155.6	**160.2**	165.1	170.2	175.4	180.9
14.0	145.1	149.3	153.7	158.2	**162.9**	167.8	172.9	178.2	183.7
14.5	147.4	151.7	156.1	160.6	**165.4**	170.3	175.3	180.6	186.1
15.0	149.4	153.7	158.2	162.8	**167.5**	172.4	177.5	182.7	188.1
15.5	151.1	155.5	159.9	164.6	**169.3**	174.2	179.2	184.4	189.7
16.0	152.5	156.9	161.4	166.0	**170.7**	175.6	180.6	185.7	190.9
16.5	153.6	158.0	162.6	167.2	**171.9**	176.7	181.6	186.6	191.7
17.0	154.5	158.9	163.4	168.0	**172.7**	177.5	182.3	187.2	192.2
17.5	155.2	159.6	164.1	168.7	**173.3**	178.0	182.8	187.6	192.5
18.0	155.6	160.1	164.6	169.1	**173.7**	178.3	183.0	187.7	192.5
18.5	156.0	160.4	164.9	169.4	**174.0**	178.5	183.1	187.7	192.4
19.0	156.3	160.7	165.2	169.6	**174.1**	178.6	183.1	187.6	192.1
19.5	156.5	160.9	165.4	169.8	**174.2**	178.6	183.0	187.4	191.8
20.0	156.7	161.1	165.5	169.9	**174.3**	178.6	183.0	187.2	191.5
20.5	156.9	161.3	165.7	170.1	**174.4**	178.7	182.9	187.1	191.2
21.0	157.2	161.6	166.0	170.3	**174.5**	178.7	182.9	186.9	191.0
21.5	157.4	161.9	166.2	170.5	**174.7**	178.8	182.8	186.8	190.8

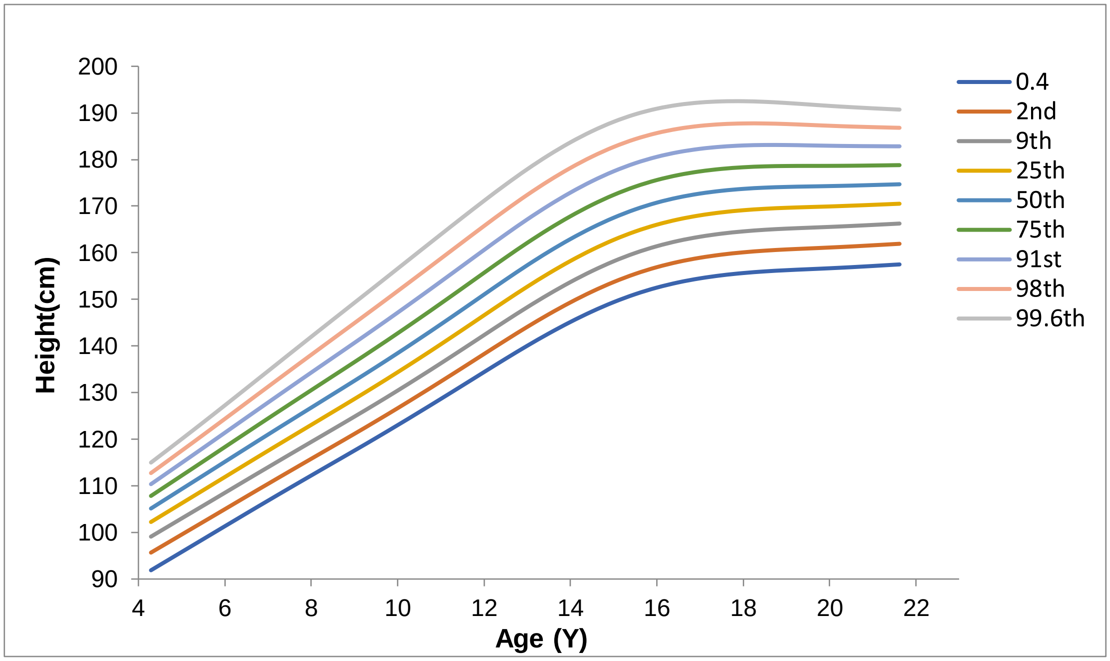


Figure 4.5: Smoothed computed height percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for male

The centile charts were constructed for female for combined age group (4 to 21 yrs of age) at same centile points. Similar trend was observed in centiles curves for female i.e. the results show that the mean height increased up to 16y for all centiles and then it became plateaued afterwards as seen among male.

Table 4.6: Merged centiles of height by age and sex (female)

	0.4th	**2nd**	**9th**	**25th**	**50th**	**75th**	**91st**	**98th**	**99.6th**
Age	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
4.0	91.7	94.0	96.5	99.2	**102.2**	105.5	109.2	113.4	118.1
4.5	93.2	95.6	98.2	100.9	**104.0**	107.4	111.1	115.3	120.0
5.0	96.0	98.5	101.2	104.1	**107.3**	110.8	114.6	118.8	123.4
5.5	98.8	101.4	104.2	107.3	**110.6**	114.1	118.0	122.2	126.9
6.0	101.5	104.3	107.3	110.4	**113.8**	117.5	121.4	125.7	130.3
6.5	104.1	107.1	110.2	113.6	**117.1**	120.8	124.8	129.1	133.6
7.0	106.7	109.9	113.2	116.6	**120.3**	124.1	128.2	132.4	136.9
7.5	109.3	112.6	116.1	119.7	**123.4**	127.4	131.5	135.7	140.2
8.0	111.8	115.3	118.9	122.7	**126.6**	130.6	134.7	139.0	143.4
8.5	114.3	118.0	121.8	125.7	**129.7**	133.7	137.9	142.2	146.6
9.0	116.7	120.6	124.6	128.7	**132.7**	136.9	141.1	145.4	149.7
9.5	119.1	123.3	127.4	131.6	**135.8**	140.0	144.3	148.5	152.8
10.0	121.5	125.9	130.2	134.5	**138.8**	143.1	147.3	151.6	155.8
10.5	123.7	128.4	132.9	137.4	**141.8**	146.1	150.4	154.5	158.7
11.0	126.0	130.8	135.6	140.2	**144.6**	149.0	153.3	157.4	161.5
11.5	128.1	133.2	138.1	142.8	**147.4**	151.8	156.0	160.1	164.1
12.0	130.0	135.4	140.4	145.3	**149.9**	154.3	158.5	162.6	166.5
12.5	131.7	137.3	142.5	147.4	**152.1**	156.5	160.7	164.8	168.7
13.0	133.3	139.0	144.3	149.3	**154.0**	158.4	162.6	166.6	170.5
13.5	134.5	140.4	145.8	150.8	**155.5**	160.0	164.2	168.2	172.0
14.0	135.6	141.6	147.1	152.1	**156.8**	161.3	165.4	169.4	173.2
14.5	136.6	142.6	148.0	153.1	**157.8**	162.3	166.4	170.4	174.1
15.0	137.4	143.4	148.8	153.9	**158.6**	163.0	167.2	171.1	174.9
15.5	138.1	144.0	149.4	154.5	**159.2**	163.6	167.7	171.7	175.4
16.0	138.7	144.6	149.9	154.9	**159.6**	164.0	168.1	172.1	175.9
16.5	139.3	145.0	150.3	155.2	**159.9**	164.2	168.4	172.4	176.2
17.0	139.8	145.4	150.6	155.4	**160.0**	164.4	168.6	172.6	176.4
17.5	140.3	145.7	150.8	155.6	**160.1**	164.5	168.7	172.7	176.6
18.0	140.7	145.9	150.9	155.6	**160.2**	164.6	168.8	172.8	176.8
18.5	141.1	146.1	151.0	155.7	**160.2**	164.6	168.8	172.9	176.9
19.0	141.4	146.3	151.1	155.7	**160.2**	164.5	168.8	173.0	177.0
19.5	141.7	146.5	151.1	155.7	**160.1**	164.5	168.8	173.0	177.2
20.0	142.0	146.6	151.2	155.7	**160.1**	164.5	168.8	173.1	177.3
20.5	142.3	146.7	151.2	155.6	**160.0**	164.4	168.8	173.1	177.4
21.0	142.5	146.8	151.2	155.6	**160.0**	164.3	168.7	173.1	177.5

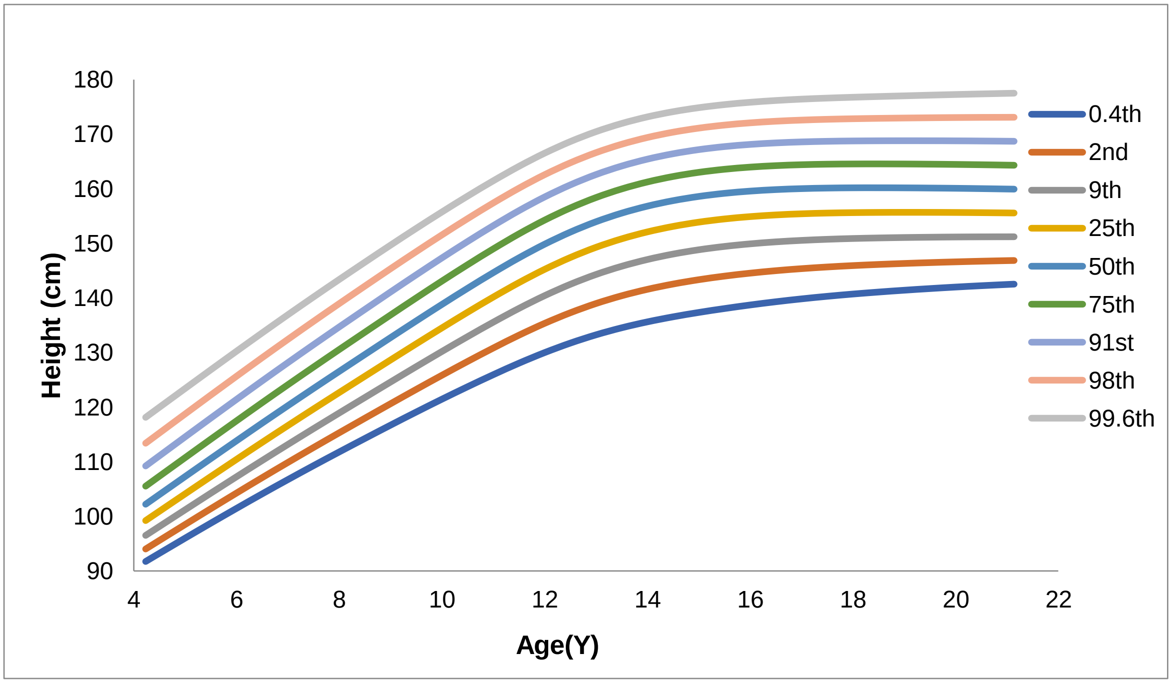


Figure 4.6: Smoothed computed height percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for female

4.4.2 Weight

Descriptive statistics (Table 4.7) were computed for weight in age group of 16 to 21y for both genders. In general, male was found have higher weight than female at all age group, though no specific related increase in weight was seen in both genders with increasing age. For example, amongst male, though minimum mean weight (62.8 kg) was seen at 16y age group but maximum weight of 70.7 kg was seen in 19y of age. Likewise, amongst female, minimum mean weight of 56.2 kg was seen at 16y age group while maximum mean weight of 61.1 kg was in 20y age group reflecting that weight has no specific relation with increasing age within the studied age group (16-21yrs).

Descriptive statistics for z-score of weight is presented in table 4.8 below. The results among 16 to 21yrs of age group shows that majority of the male and female population exists above average weight of UK 90 reference population. At all age groups, no specific trend is seen compared to reference population for both genders. For example, mean weight of 17y male was found above the average of reference population weight, while the opposite (below the average) is seen in female of same age group. The same pattern is seen at 19y of age group, however, the situation seemed to be reversed in 20- and 21-yrs age group i.e. male found to be below average weight from the respective gender of reference population compared to female. At the 18y age group, both males are female were found to be below the mean weight of male and female of the reference population.

Table 4.7: Descriptive statistics (mean ± sd) of weight for SA groups by age range and gender distribution

Descriptive statistics of weight with age and gender distribution												
	16 years		17 years		18 years		19 years		20 years		21 years	
	M	F	M	F	M	F	M	F	M	F	M	F
Mean	62.8	56.2	68.9	56.4	66.9	56.7	70.7	56.6	69.7	61.1	69.8	60.2
Std Dev	11.6	10.1	14.6	9.8	12.6	11.9	13.4	9.9	8.9	10.6	11.7	10.7
Minimum	37.1	35.1	46.8	33	44.9	44.1	51.6	44.3	52.3	45.2	47.1	40.3
Maximum	97.3	81	123.3	79.9	107.2	99.6	104.2	83.8	90.8	78	101.2	98.3

Table 4.8: Descriptive statistics (mean ± sd) of Z-score for weight of SA groups by age range and gender distribution

Descriptive statistics of Z-Score for weight with age and gender distribution												
	16 years		17 years		18 years		19 years		20 years		21 years	
	M	F	M	F	M	F	M	F	M	F	M	F
Mean	0.3	0.04	0.4	-0.2	-0.1	-0.3	0.1	-0.3	-0.1	0.2	-0.2	0.1
Std Dev	1.03	1.26	1.25	1.27	1.19	1.24	1.29	1.17	0.97	1.27	1.28	1.22
Minimum	-2.78	-3.40	-2.27	-4.42	-2.75	-2.01	-2.13	-2.02	-2.40	-1.92	-3.53	-2.90
Maximum	2.76	2.47	3.82	2.25	2.99	3.34	2.76	2.36	1.86	1.91	2.51	3.19

4.4.2.1 Scatter plots

Figure 4.7 & 4.8 below show the scatter plot of body weight plotted against age for both genders. No specific trend for weight in relation to age was seen for both genders and no particular outliers were seen in the data. One male within 17y of age group had a body weight of 123 kg, massively obese people are expected to have that range of weight.

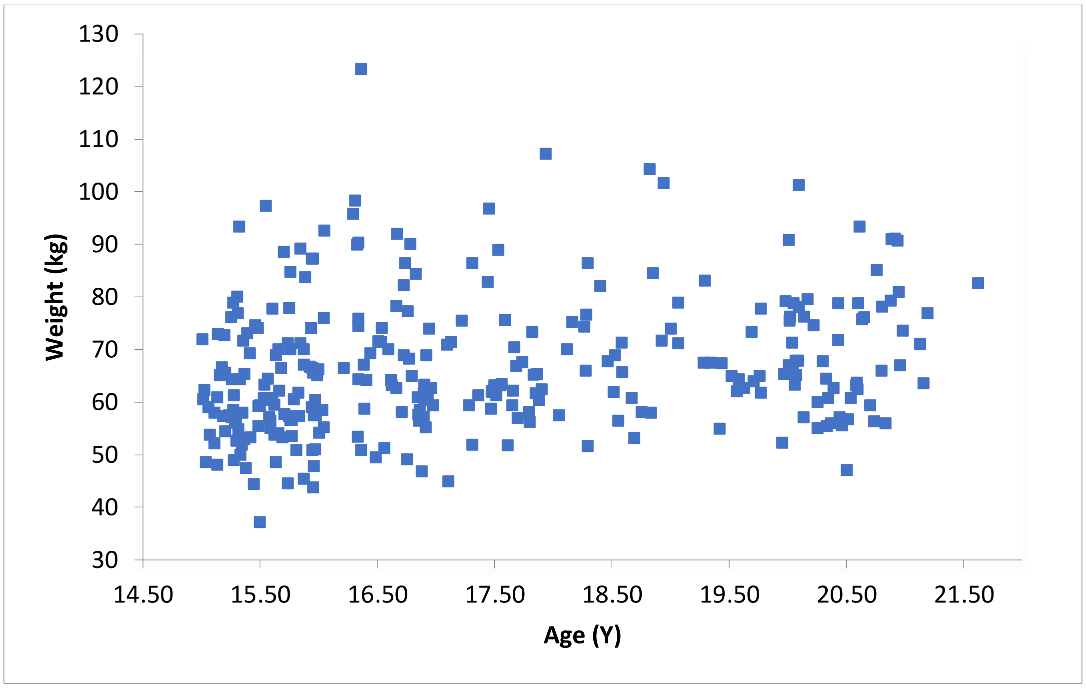


Figure 4.7: Scatterplot showing the distribution of the weight of male study participants against age

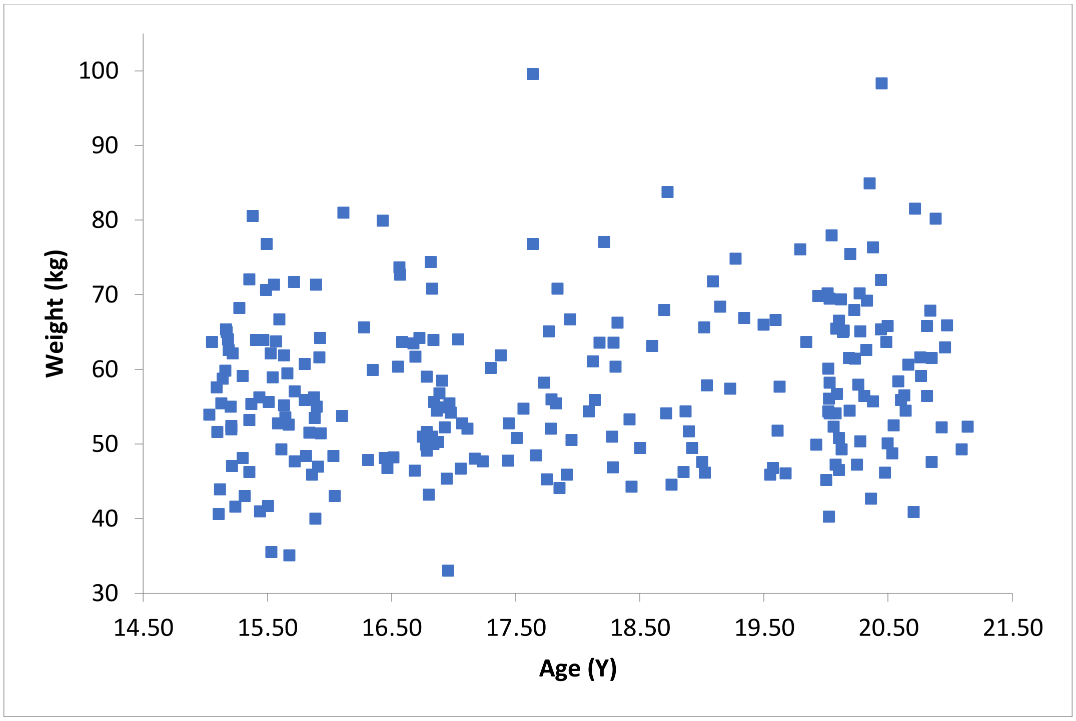


Figure 4.8: Scatterplot showing the distribution of the weight of female against age

4.4.2.2 Centile charts

The smoothed centile curves were plotted for weight for both male and female (Fig 4.9 and 4.10 respectively) for 9 different centile points (0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles). In male participants weight was increasing with age. At 50th centile for male (Table 4.9), minimum mean weight of 59.7 kg was seen in 15y age group while maximum mean weight of 74.1 kg was seen in 21.6y of age showed a gradual increase in body weight with increasing age.

Table 4.9: Centiles of weight curve by age and sex (male)

	0.4th	2nd	9th	25th	50th	75th	91st	98th	99.6th
Age	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
15.0	38.0	42.3	47.3	53.1	**59.7**	67.4	76.3	86.7	98.8
15.5	39.8	44.0	48.9	54.6	**61.4**	69.5	79.2	91.1	105.7
16.0	41.8	45.9	50.7	56.4	**63.3**	71.8	82.4	95.9	113.8
16.5	43.5	47.4	52.1	57.7	**64.7**	73.4	84.6	99.6	120.7
17.0	44.6	48.4	52.9	58.4	**65.2**	73.8	85.2	100.9	124.1
17.5	45.6	49.3	53.7	59.0	**65.7**	74.2	85.6	101.5	125.7
18.0	46.6	50.3	54.6	59.9	**66.5**	74.8	86.0	101.7	125.6
18.5	47.4	51.1	55.4	60.7	**67.2**	75.4	86.3	101.2	123.4
19.0	47.8	51.5	55.9	61.2	**67.7**	75.7	86.1	100.0	119.6
19.5	47.6	51.5	56.0	61.3	**67.7**	75.6	85.4	98.1	114.9
20.0	47.2	51.2	55.9	61.4	**67.9**	75.6	84.9	96.4	110.8
20.5	47.0	51.4	56.4	62.1	**68.7**	76.4	85.4	96.0	108.6
21.0	47.7	52.5	57.9	64.0	**70.9**	78.7	87.5	97.5	108.9
21.5	48.5	53.9	59.8	66.3	**73.5**	81.4	90.1	99.6	110.1
21.6	48.7	54.2	60.2	66.9	**74.1**	82.1	90.7	100.2	110.4

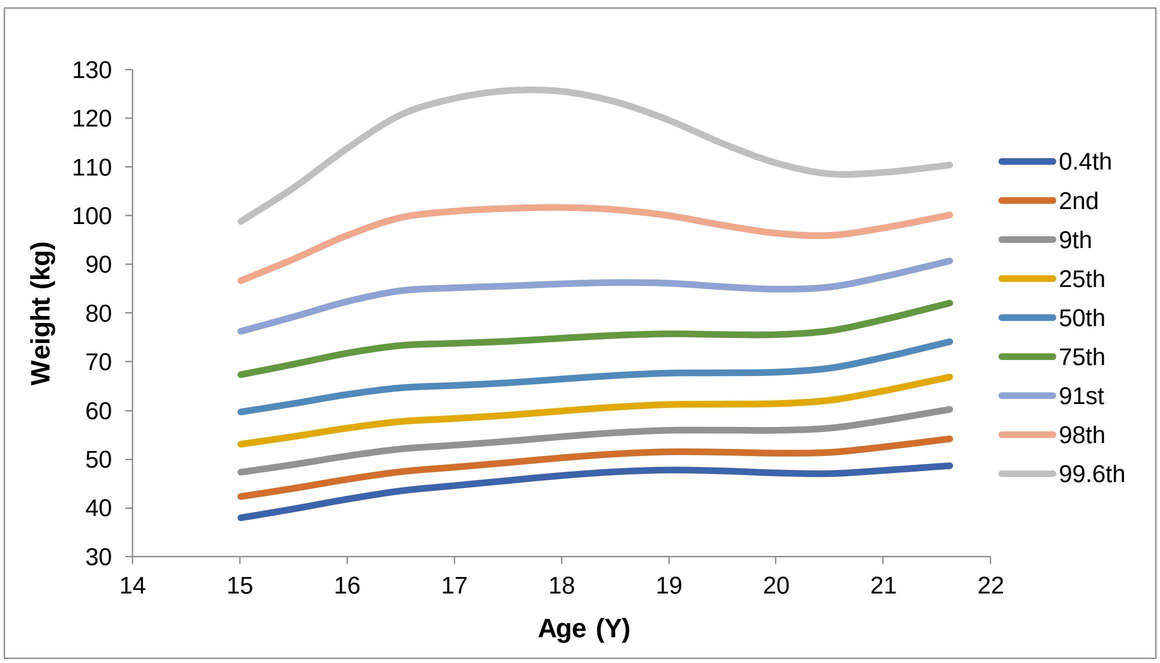


Figure 4.9: Weight centiles of male at 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles

In female participants slight increase in weight can be noticed from 16 to 21y with some variation at different age groups meaning that there is no relationship between age and weight in female participants (Table 4.10) It was observed that at 15y weight was higher and then it plateaued between age 16 to 18y. Minimum mean weight of 55.4kg was seen in 16.5y age group while maximum mean weight of 59.3 kg was seen in 21y of age.

Table 4.10: Centiles of weight curve by age and sex (female)

	0.4th	**2nd**	**9th**	**25th**	**50th**	**75th**	**91st**	**98th**	**99.6th**
Age	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
15.0	30.4	36.7	43.0	49.5	**56.0**	62.6	69.3	76.1	83.0
15.5	32.3	37.7	43.4	49.5	**56.0**	62.8	69.8	77.3	85.0
16.0	33.8	38.5	43.7	49.4	**55.7**	62.6	70.1	78.3	87.1
16.5	34.9	39.1	43.9	49.3	**55.4**	62.4	70.3	79.2	89.4
17.0	35.7	39.5	44.0	49.1	**55.0**	62.0	70.2	80.0	91.6
17.5	36.5	40.2	44.4	49.4	**55.3**	62.4	71.0	81.6	94.9
18.0	37.3	40.9	45.0	49.9	**55.9**	63.0	71.9	83.2	97.8
18.5	37.8	41.3	45.5	50.4	**56.3**	63.6	72.6	84.1	99.2
19.0	38.0	41.7	45.9	50.9	**56.9**	64.2	73.3	84.8	99.6
19.5	38.3	42.0	46.4	51.5	**57.6**	65.0	74.1	85.3	99.6
20.0	38.5	42.4	46.9	52.2	**58.4**	65.9	74.9	85.9	99.6
20.5	38.6	42.6	47.3	52.7	**59.0**	66.5	75.5	86.3	99.5
21.0	38.5	42.7	47.4	52.9	**59.3**	66.7	75.6	86.1	98.8

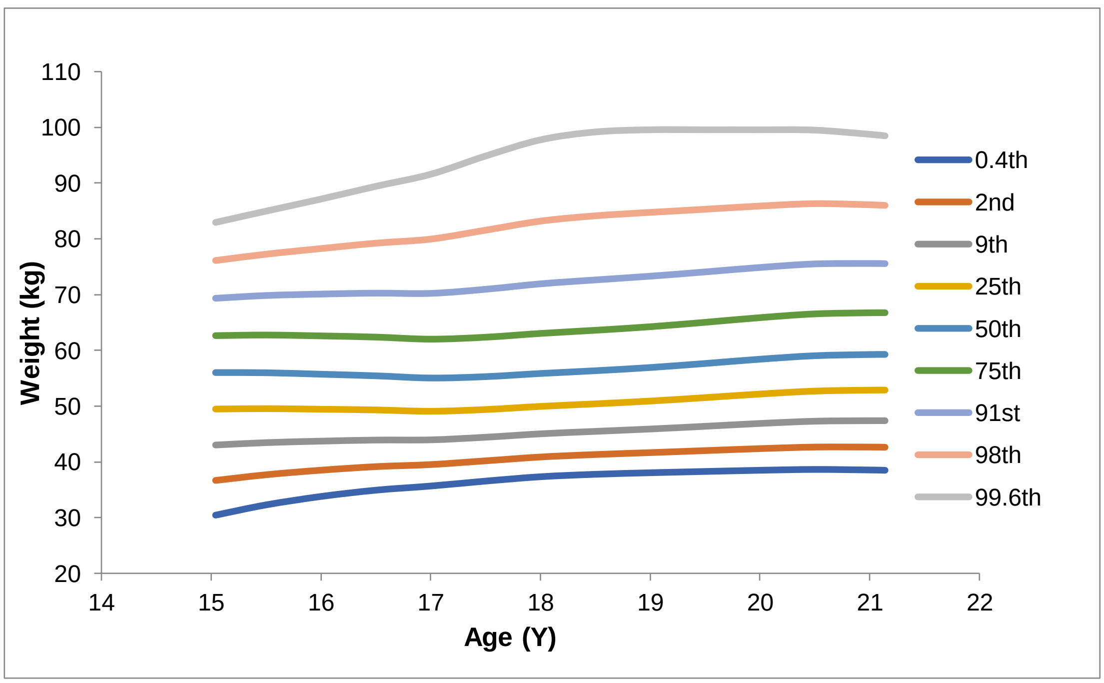


Figure 4.10: Weight centiles of females at 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, and 98th and 99.6th centiles

4.4.2.3 Merged centiles curve

Figure 4.11 shows centiles curves of 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th for male body weight for the merged data (4 to 21 yrs age group). A constant and gradual increase in the body weight was observed with increasing age and this trend was consistent for all the centile cut off points except for 99.6th percentile where the increasing trend became plateaued at the upper end of the age range in male. At 50th centile, minimum mean body weight of 16.4 kg was seen at 4.5y age group while maximum mean body weight of 72.9 kg was seen at higher age group (21.5) among the studied age range, reflecting the increasing trend of body weight at 50th centile (Table 4.11).

Table 4.11: Merged centiles of weight by age and sex (male)

	0.4th	2nd	9th	25th	50th	75th	91st	98th	99.6th
Age	-2.7	-2.0	-1.3	-0.7	0.0	0.7	1.3	2.0	2.7
4.5	11.8	12.7	13.7	14.9	16.4	18.3	20.6	23.8	28.1
5.0	12.4	13.3	14.5	15.8	17.5	19.5	22.2	25.8	30.8
5.5	12.9	14.0	15.2	16.7	18.5	20.8	23.8	27.9	33.7
6.0	13.5	14.7	16.0	17.6	19.6	22.1	25.5	30.1	36.9
6.5	14.2	15.4	16.8	18.6	20.8	23.6	27.3	32.6	40.5
7.0	14.9	16.2	17.7	19.6	22.0	25.1	29.3	35.2	44.4
7.5	15.6	17.0	18.7	20.8	23.4	26.8	31.5	38.1	48.6
8.0	16.4	17.9	19.7	22.0	24.9	28.6	33.8	41.2	53.2
8.5	17.3	18.9	20.9	23.3	26.4	30.5	36.2	44.6	58.2
9.0	18.2	20.0	22.1	24.8	28.2	32.6	38.9	48.2	63.4
9.5	19.3	21.2	23.5	26.3	30.0	34.9	41.7	51.9	68.9
10.0	20.5	22.5	25.0	28.0	32.0	37.3	44.7	55.8	74.3
10.5	21.7	23.9	26.6	29.9	34.2	39.9	47.8	59.8	79.6
11.0	23.1	25.4	28.3	31.8	36.4	42.5	51.1	63.8	84.7
11.5	24.5	27.0	30.1	33.9	38.8	45.3	54.4	67.8	89.5
12.0	26.0	28.7	32.0	36.1	41.3	48.3	57.8	71.8	94.1
12.5	27.6	30.5	34.0	38.4	43.9	51.2	61.2	75.7	98.5
13.0	29.3	32.4	36.1	40.7	46.5	54.2	64.6	79.5	102.6
13.5	31.0	34.2	38.2	43.0	49.2	57.1	67.9	83.2	106.3
14.0	32.7	36.1	40.3	45.3	51.7	60.0	71.1	86.6	109.7
14.5	34.4	38.0	42.3	47.6	54.2	62.8	74.1	89.7	112.6
15.0	36.1	39.8	44.3	49.8	56.6	65.3	76.8	92.5	115.0
15.5	37.7	41.6	46.2	51.8	58.8	67.7	79.2	94.8	116.9
16.0	39.2	43.2	47.9	53.7	60.8	69.7	81.3	96.8	118.3
16.5	40.5	44.6	49.5	55.4	62.6	71.6	83.1	98.3	119.1
17.0	41.8	46.0	50.9	56.9	64.1	73.1	84.5	99.4	119.4
17.5	42.9	47.1	52.2	58.2	65.5	74.4	85.7	100.1	119.2
18.0	43.9	48.2	53.3	59.4	66.7	75.6	86.6	100.6	118.8
18.5	44.8	49.2	54.4	60.5	67.7	76.5	87.4	100.9	118.2
19.0	45.7	50.2	55.4	61.5	68.7	77.4	88.0	101.0	117.4
19.5	46.5	51.0	56.3	62.4	69.6	78.2	88.5	101.0	116.6
20.0	47.3	51.9	57.2	63.3	70.4	78.9	88.9	101.0	115.8
20.5	48.1	52.7	58.0	64.2	71.3	79.6	89.4	101.0	115.0
21.0	48.9	53.6	58.9	65.0	72.1	80.3	89.8	101.0	114.3
21.5	49.8	54.5	59.8	65.9	72.9	81.0	90.2	101.1	113.7

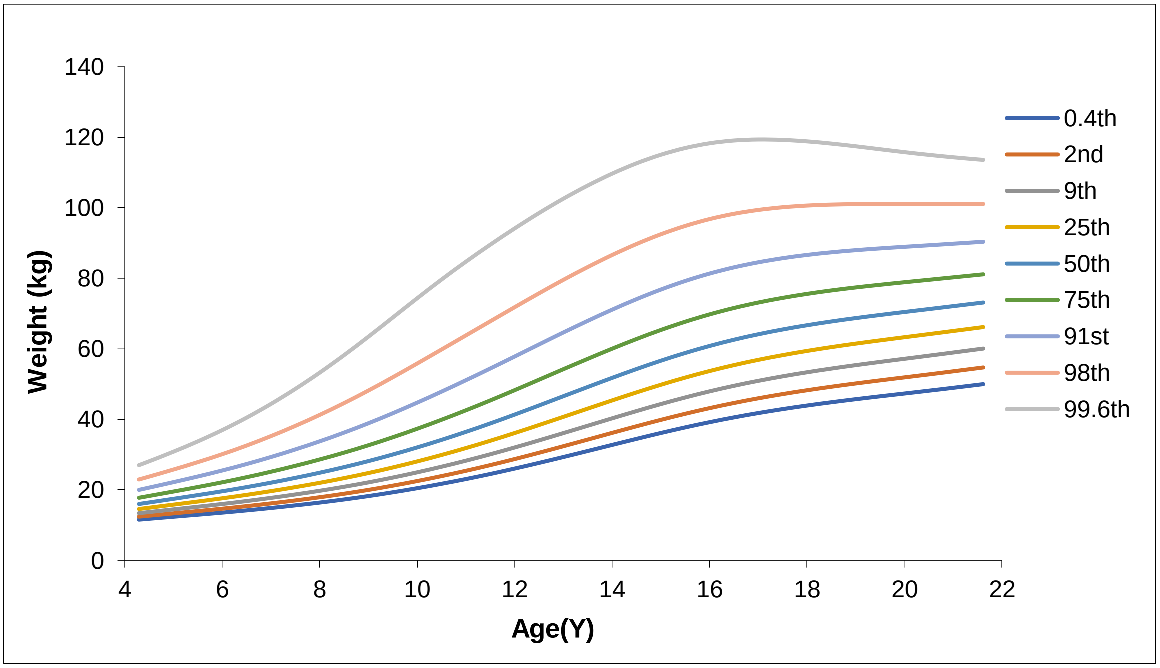


Figure 4.11: Smoothed computed weight centile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 9^{1st}, 98th and 99.6th centiles for male

The results in figure 4.12 represents female weight percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for the combined age range of 4-21 yrs of age. A steady increase in body weight has been observed with age in female population from 4y onwards but this trend became a bit less steep at later age groups. The results illustrated that both male and female had the same trend of increasing weight with age which describes that there is no substantial difference in gaining body weight with increasing age among both genders in studied age range. At 50th centile (Table 4.12), minimum and maximum mean body weight was seen in extreme lower and higher age groups in studied age range.

Table 4.12: Merged centiles of weight by age and sex (female)

	0.4th	**2nd**	**9th**	**25th**	**50th**	**75th**	**91st**	**98th**	**99.6th**
Age	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
4.5	10.3	11.1	12.2	13.4	**14.9**	16.8	19.4	22.9	28.2
5.0	11.1	12.0	13.2	14.6	**16.3**	18.4	21.3	25.3	31.1
5.5	11.8	12.9	14.2	15.7	**17.6**	20.1	23.3	27.7	34.1
6.0	12.6	13.8	15.2	16.9	**19.0**	21.7	25.3	30.1	37.1
6.5	13.3	14.6	16.2	18.1	**20.4**	23.4	27.3	32.6	40.1
7.0	14.0	15.5	17.2	19.3	**21.9**	25.2	29.4	35.1	43.2
7.5	14.7	16.3	18.2	20.5	**23.4**	27.0	31.6	37.8	46.3
8.0	15.5	17.2	19.3	21.8	**24.9**	28.9	33.9	40.5	49.4
8.5	16.2	18.1	20.4	23.2	**26.6**	30.8	36.2	43.3	52.6
9.0	17.0	19.1	21.6	24.7	**28.4**	33.0	38.8	46.2	56.0
9.5	17.9	20.2	22.9	26.2	**30.3**	35.2	41.4	49.3	59.5
10.0	18.8	21.3	24.3	27.9	**32.3**	37.6	44.2	52.6	63.1
10.5	19.8	22.5	25.8	29.7	**34.4**	40.2	47.2	55.9	66.9
11.0	20.8	23.8	27.4	31.6	**36.7**	42.8	50.3	59.4	70.8
11.5	22.0	25.2	29.0	33.6	**39.0**	45.5	53.3	62.9	74.5
12.0	23.1	26.5	30.6	35.5	**41.2**	48.1	56.3	66.1	78.0
12.5	24.1	27.8	32.2	37.3	**43.4**	50.5	59.0	69.1	81.1
13.0	25.2	29.1	33.7	39.1	**45.4**	52.8	61.5	71.7	83.8
13.5	26.2	30.3	35.1	40.7	**47.2**	54.8	63.7	74.0	86.1
14.0	27.1	31.4	36.4	42.2	**48.9**	56.6	65.6	76.1	88.1
14.5	28.1	32.5	37.6	43.6	**50.4**	58.3	67.4	77.8	89.9
15.0	29.0	33.6	38.8	44.8	**51.8**	59.7	68.9	79.3	91.3
15.5	29.9	34.5	39.9	46.0	**53.0**	61.0	70.2	80.6	92.5
16.0	30.8	35.5	40.9	47.0	**54.1**	62.1	71.2	81.6	93.4
16.5	31.6	36.4	41.8	48.0	**55.0**	63.0	72.1	82.5	94.2
17.0	32.4	37.2	42.6	48.8	**55.9**	63.8	72.9	83.1	94.7
17.5	33.2	38.0	43.4	49.6	**56.6**	64.5	73.5	83.7	95.2
18.0	34.0	38.8	44.2	50.3	**57.3**	65.1	74.0	84.1	95.5
18.5	34.8	39.5	44.9	51.0	**57.9**	65.7	74.5	84.4	95.7
19.0	35.5	40.3	45.6	51.6	**58.4**	66.2	74.9	84.7	95.8
19.5	36.3	41.0	46.3	52.2	**59.0**	66.6	75.2	84.9	95.9
20.0	37.0	41.7	46.9	52.8	**59.5**	67.0	75.5	85.1	95.9
20.5	37.8	42.4	47.6	53.4	**60.0**	67.4	75.8	85.3	95.9
21.0	38.5	43.1	48.2	54.0	**60.5**	67.9	76.1	85.4	95.9

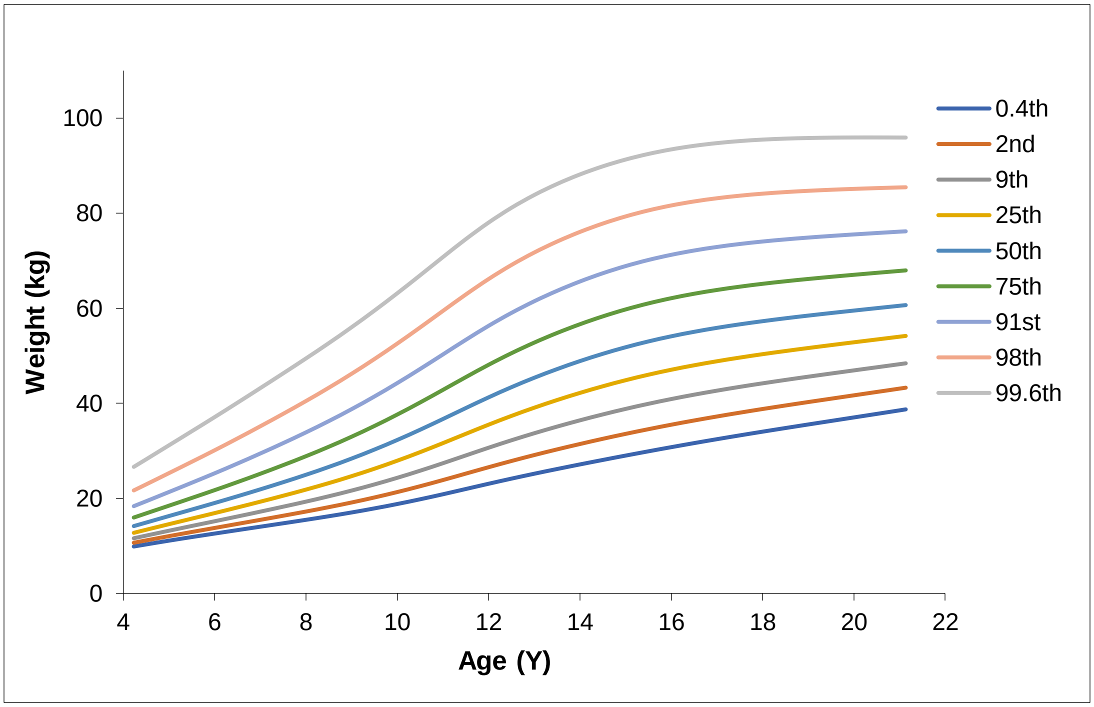


Figure 4.12: Smoothed computed weight percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for female

4.4.3 Sitting height

The results below in Table 4.13 shows the descriptive statistics of sitting height for both gender for each age group. As the sitting height is expected to be correlated with standing height, similar trend was seen the sitting height of male i.e. little variation in their sitting height with increasing age, through the trend was still increasing with minimum sitting height of 62 cm was seen in male of 16y of age group and maximum sitting of 100 cm was seen in male of 21y age group, though this maximum sitting height was observed in male from 17 and 19 yrs age groups too. Almost similar trends were seen in sitting height of female. Additionally, as with standing height, the mean sitting height among male were higher than female for all age groups.

Table 4.14 represents the descriptive statistics of z-score for male and female of all age range. The results of both genders show that majority of the South Asian population (for this age range) have average sitting height below the sitting height of a reference population. The sitting height for female was even lower than male with respect to the corresponding gender from the reference population for all age groups except 18y where both male and female have the same z-score of -0.7. No age specific trend was seen within the z-score in both genders.

Table 4.13: Descriptive statistics (mean ± sd) of sitting height for SA groups by age range and gender distribution

Descriptive statistics of sitting height with age and gender distribution												
	16 years		17 years		18 years		19 years		20 years		21 years	
	M	F	M	F	M	F	M	F	M	F	M	F
Mean	87.8	83.5	90.6	84.2	89.9	84.9	91.2	84.3	89.5	83.6	90.3	84.7
Std Dev	5.27	5.27	4.0	5.40	3.96	3.92	3.79	4.31	3.63	6.22	4.40	5.28
Minimum	62	67	80	68	81.5	72	84	69	80	63	81	64.5
Maximum	97	94	100	96	96	91.5	100	90.2	95	92	100	95

Table 4.14: Descriptive statistics (mean ± sd) of sitting height for SA groups by age range and gender distribution

Descriptive statistics of Z-Score for sitting height with age and gender distribution												
	16 years		17 years		18 years		19 years		20 years		21 years	
	M	F	M	F	M	F	M	F	M	F	M	F
Mean	-0.3	-0.8	-0.3	-0.8	-0.7	-0.7	-0.6	-0.9	-1.1	-1.2	-0.9	-0.9
Std Dev	1.24	1.40	0.94	1.42	0.89	1.02	0.84	1.12	0.80	1.62	0.97	1.37
Minimum	-6.30	-5.14	-2.75	-5.02	-2.63	-4.04	-2.15	-4.89	-3.15	-6.51	-2.95	-6.15
Maximum	1.88	2.14	1.98	2.36	0.74	1.00	1.42	0.63	0.20	1.03	1.19	1.72

4.4.3.1 Scatter plots

The sitting height data was analysed using scatter plots (Fig 4.13 and 4.14) for both genders to see any data trends or outliers in the data. No age specific association in sitting height was seen in scatter plots for either of genders. A sitting height of 62 cm was observed as the lowest and discrete observation among male at 16y age group. No such discrete observation was seen in the sitting height of female.

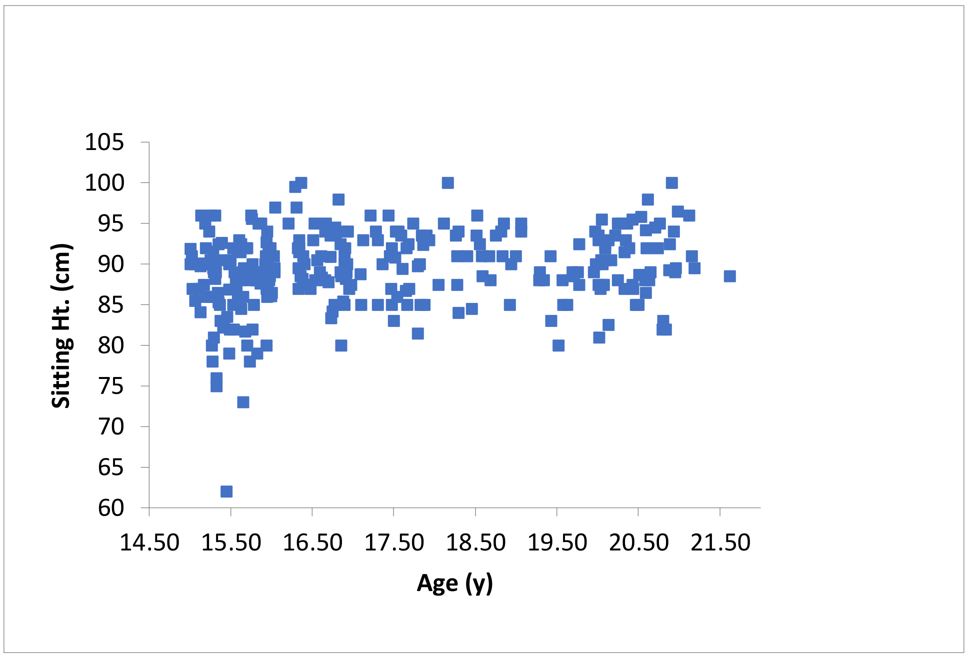


Figure 4.13: Scatterplot showing the distribution of the sitting height of male against age

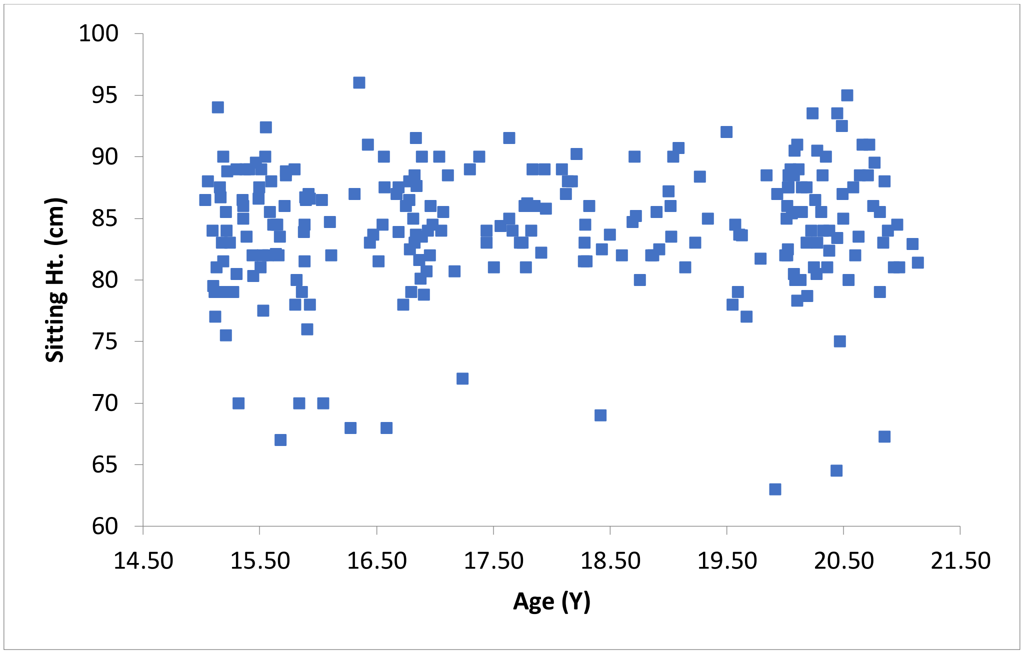


Figure 4.14: Scatterplot showing the distribution of the sitting height of female against age

4.3.2 Centile charts

Figure 4.15 shows the centile curves for sitting height for the male population at 7 different centiles. An age-related increase in mean sitting height was observed in males between age 16 to 21 yrs and this trend is consistent in almost all centiles. For the 50th centile (Table 4.15) a minimum sitting height of 88.1 cm was seen in 15y of age while maximum height of 91.6 cm was seen at 21.5y among the studied age group. According to the table, mean sitting height did not change between 17.5 and 18.5y of age. It then slightly decreases between ages 18.5 to 20y age group, a likely reflection of the limited number of participants in this particular age group.

Table 4.15: Centiles of sitting height curve by age and sex (male)

	2nd	9th	25th	50th	75th	91st	98th
Year	-2.0	-1.3	-0.7	0.0	0.7	1.3	2.0
15.0	72.4	79.9	84.6	**88.1**	90.9	93.3	95.3
15.5	75.9	81.3	85.4	**88.7**	91.4	93.8	96.0
16.0	78.5	82.8	86.4	**89.5**	92.2	94.7	96.9
16.5	80.3	84.0	87.2	**90.1**	92.8	95.3	97.6
17.0	81.3	84.5	87.6	**90.4**	93.0	95.5	97.8
17.5	81.8	84.9	87.8	**90.5**	93.1	95.5	97.9
18.0	82.0	85.0	87.9	**90.5**	93.1	95.5	97.8
18.5	82.0	85.0	87.8	**90.5**	93.0	95.4	97.6
19.0	81.7	84.7	87.5	**90.1**	92.6	95.0	97.2
19.5	81.3	84.4	87.2	**89.8**	92.3	94.7	96.9
20.0	81.3	84.4	87.3	**90.0**	92.6	95.0	97.3
20.5	81.6	84.8	87.8	**90.5**	93.2	95.6	98.0
21.0	81.9	85.2	88.2	**91.1**	93.8	96.4	98.9
21.5	82.2	85.5	88.7	**91.6**	94.4	97.1	99.6

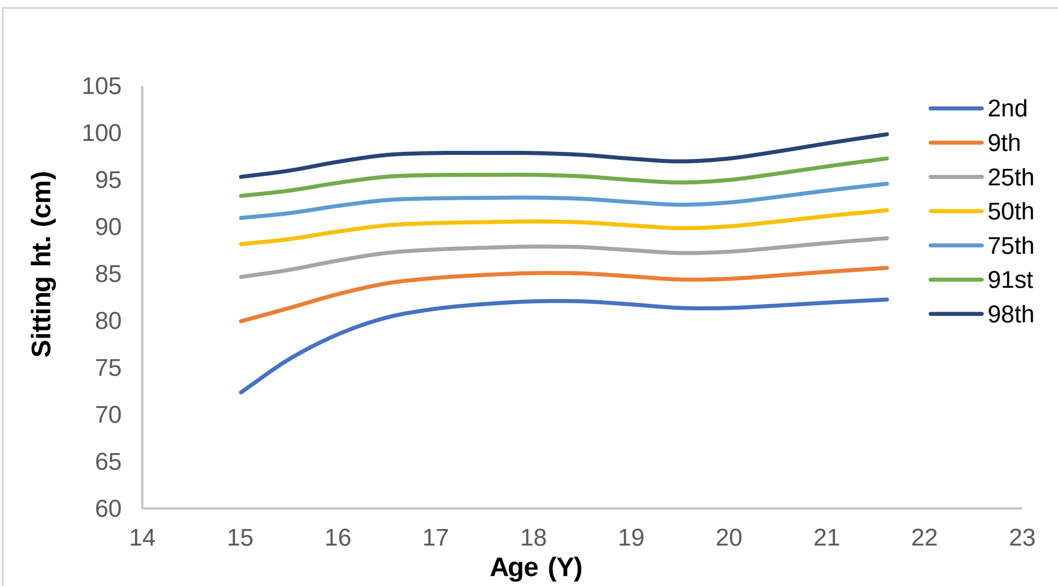


Figure 4.15: Sitting height centiles of male at 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, and 98th centiles

Similar centile curves of sitting height at 7 different centiles were constructed for the female population (Fig 4.16). No obvious age-related increase in mean sitting height was seen in female between age 16 to 21 yrs at all centiles.

This can also be seen in table 4.16 where at the 50th centile, there is little difference between the minimum sitting height (84.2 cm) and maximum sitting height (85.3 cm), indicating that sitting height minimally changes with increasing age.

Table 4.16: Centiles of sitting height curve by age and sex (female)

	0.4th	**2nd**	**9th**	**25th**	**50th**	**75th**	**91st**	**98th**	**99.6th**
Year	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
15.0	62.8	70.7	76.2	80.6	**84.2**	87.3	90.0	92.5	94.7
15.5	62.6	71.0	76.5	80.8	**84.3**	87.3	89.9	92.3	94.4
16.0	63.0	71.5	77.0	81.1	**84.5**	87.4	89.9	92.2	94.2
16.5	64.3	72.3	77.6	81.6	**84.8**	87.6	90.0	92.1	94.0
17.0	65.9	73.1	78.0	81.8	**84.9**	87.5	89.8	91.9	93.7
17.5	67.1	73.8	78.4	82.0	**84.9**	87.4	89.7	91.6	93.4
18.0	67.7	74.1	78.5	82.0	**84.9**	87.3	89.5	91.4	93.2
18.5	67.6	74.0	78.4	81.9	**84.8**	87.2	89.4	91.3	93.1
19.0	67.1	73.7	78.3	81.8	**84.8**	87.3	89.6	91.5	93.3
19.5	66.1	73.2	78.1	81.9	**85.0**	87.6	89.9	92.0	93.9
20.0	65.0	72.7	77.9	81.9	**85.2**	88.0	90.4	92.6	94.6
20.5	63.9	72.1	77.6	81.8	**85.3**	88.3	90.9	93.2	95.3
21.0	62.6	71.1	76.9	81.3	**84.9**	88.0	90.8	93.2	95.4

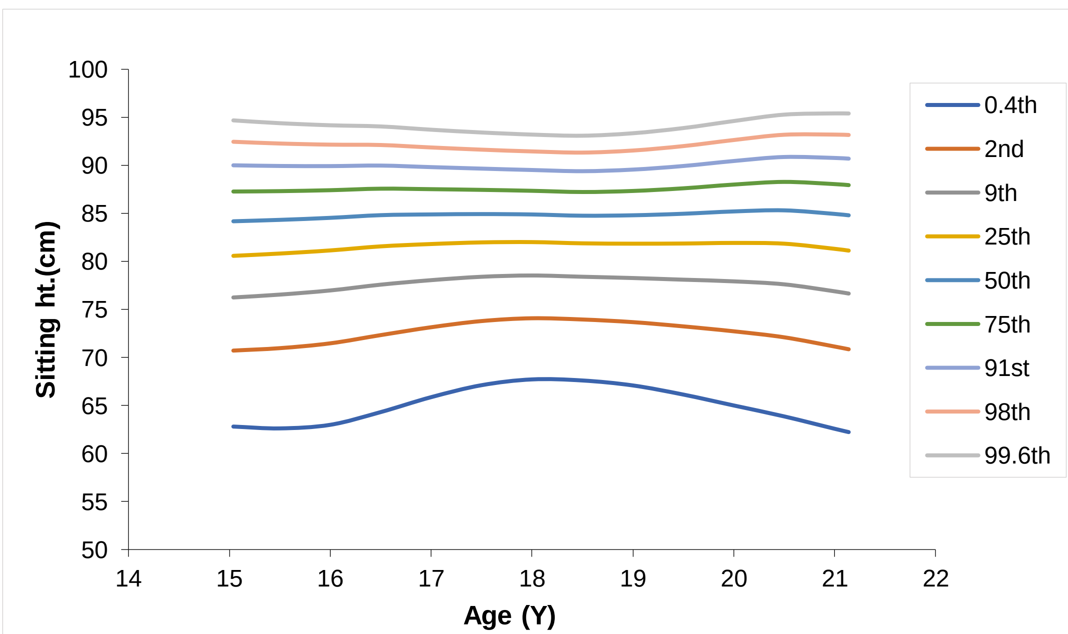


Figure 4.16: Sitting height centiles of female at 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles

4.4.4 Leg Length

Table 4.17 below includes the descriptive statistics of leg length for both genders for each age group. As the leg length is the counterpart of sitting height, hence also expected to be correlated with standing height and follow the same data trend as sitting height. There was no trend in data with increasing age. Mean leg length at age 16 was 83.6 which goes down to 82.3 at 17y and again goes up at age 18y. however, the increase in leg length was consistent in subsequent age groups. For example, in male, minimum average leg length of 82.7 cm was seen in 21y of age group and maximum mean leg length of 84.2 cm was seen in 19y age group. In female, there is small variation in mean leg length between age 16 and 19y. Minimum average leg length of 74 cm was seen in 19y of age group while maximum average leg length of 76.9 cm was observed in 20y of age group.

Table 4.18 represents the descriptive statistics of z score for leg length for male and female of all age range. The results of both gender show that the majority of the South Asian population (for this age range) have an average leg length below the average leg length of a reference population (UK 1990) except for 16y male group who found to be slightly higher leg length than the average of reference population. The result shows that all female have shorter leg length than male except for 20y of age group in which female were found to have slightly higher leg length than male.

Table 4.17: Descriptive statistics (mean ± sd) of leg length for SA groups by age range and gender distribution

Descriptive statistics of Leg length with age and gender distribution												
	16 years		17 years		18 years		19 years		20 years		21 years	
	M	F	M	F	M	F	M	F	M	F	M	F
Mean	83.6	75.3	82.3	75.2	83.0	75.0	84.2	74.0	82.8	76.9	82.7	75.1
Std Dev	5.7	5.2	4.3	4.6	5.2	5.0	5.6	4.7	5.7	7.2	5.1	6.6
Minimum	68.4	63	70.9	69	73	62.5	72	65.5	70	68.6	67	65
Maximum	98	89	92	90	93	84.6	96	85	96.5	95.5	95	97

Table 4.18: Descriptive statistics (mean ± sd) of leg length for SA groups by age range and gender distribution

Descriptive statistics of Z-Score for leg length with age and gender distribution												
	16 years		17 years		18 years		19 years		20 years		21 years	
	M	F	M	F	M	F	M	F	M	F	M	F
Mean	0.2	-0.3	-0.3	-0.4	-0.3	-0.5	-0.1	-0.7	-0.4	-0.1	-0.4	-0.5
Std Dev	1.3	1.3	1.0	1.1	1.1	1.2	1.2	1.1	1.2	1.8	1.1	1.6
Minimum	-3.2	-3.4	-2.8	-1.9	-2.5	-3.6	-2.7	-2.8	-3.1	-2.1	-3.8	-3.0
Maximum	3.4	3.1	1.8	3.2	1.8	1.9	2.5	2.0	2.5	4.5	2.2	4.9

4.4.4.1 Scatter plot

The leg length data was also plotted against age for both gender (Fig 4.17 and 4.18) to see any data trends or outliers in the data. No age specific association in leg length was seen in scatter plots for either of genders. The leg length data was clustered at 16, 17 and 21 yrs age group in both genders, showing higher number of participants in this age group.

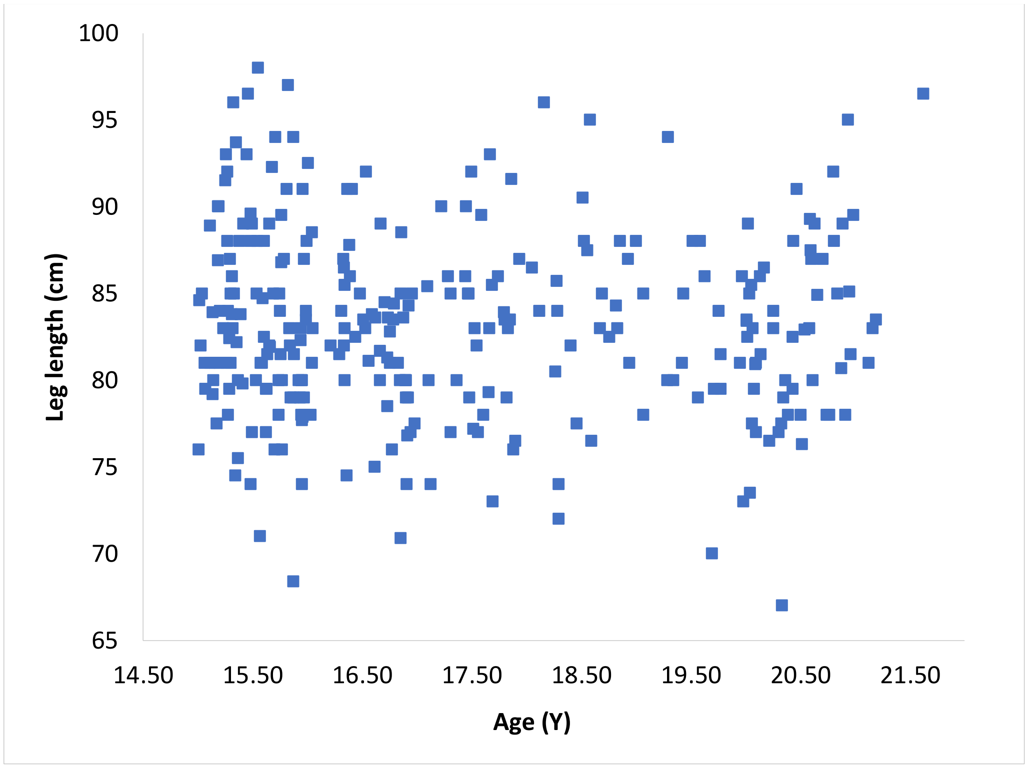


Figure 4.17: Scatterplot showing the distribution of the leg length of male against age

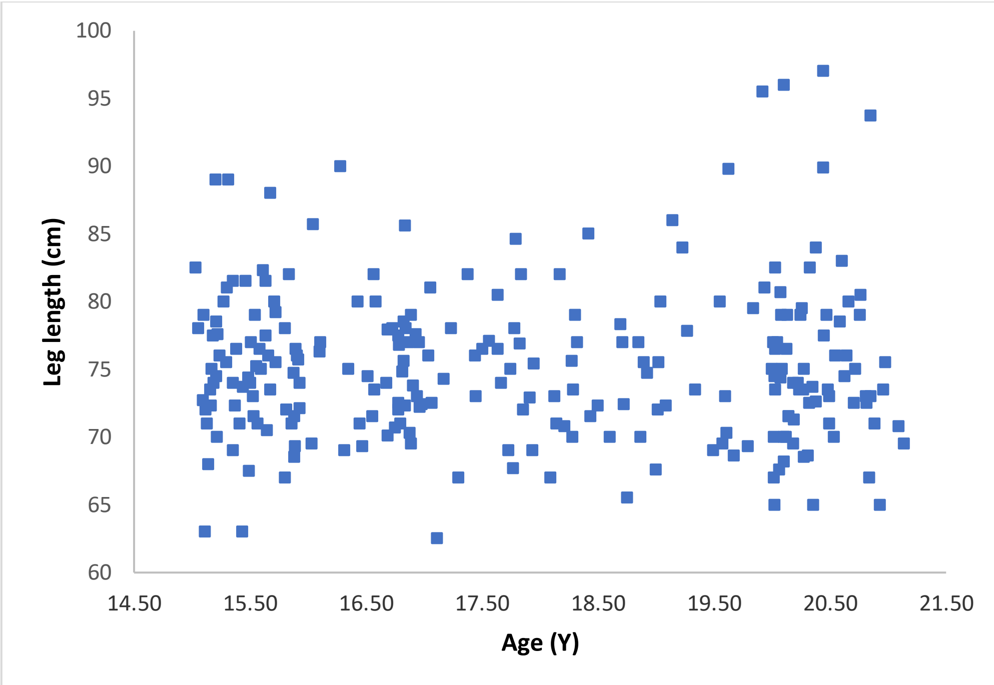


Figure 4.18: Scatterplot showing the distribution of the leg length of female against age

4.4.4.2 Centile charts

Figure 4.19 below showing the smoothed centile charts constructed for leg length for male. It was noticed that there is very little increase in the leg length after the age of 15y meaning that most of the leg length was achieved by the age of 15y and this pattern was generally seen in all centile groups. At 50th centile (Table 4.19), there was no consistent pattern of increasing and decreasing. however, the minimum mean leg length of 82.3 cm was observed in 17y age group, and maximum mean leg length of 86.5 cm was seen in 21.5y age group.

Table 4.19: Centiles of leg length curve by age and sex (male)

	0.4th	2nd	9th	25th	50th	75th	91st	98th	99.6th
Year	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
15.0	71.6	74.3	77.2	80.4	**83.9**	87.7	92.0	96.8	102.1
15.5	70.9	73.7	76.7	79.9	**83.4**	87.2	91.2	95.6	100.3
16.0	70.2	73.1	76.2	79.4	**82.9**	86.5	90.3	94.3	98.6
16.5	69.6	72.7	75.8	79.1	**82.5**	86.0	89.6	93.4	97.2
17.0	69.3	72.4	75.6	78.9	**82.3**	85.7	89.3	92.9	96.5
17.5	69.3	72.6	75.9	79.3	**82.7**	86.1	89.6	93.1	96.6
18.0	69.4	72.8	76.2	79.7	**83.1**	86.5	89.9	93.4	96.8
18.5	69.2	72.8	76.3	79.8	**83.2**	86.6	90.0	93.4	96.7
19.0	68.8	72.4	76.0	79.6	**83.0**	86.4	89.7	92.9	96.1
19.5	68.1	71.9	75.6	79.1	**82.5**	85.8	89.0	92.1	95.2
20.0	67.7	71.6	75.3	78.9	**82.3**	85.6	88.8	91.8	94.8
20.5	68.3	72.3	76.0	79.6	**83.1**	86.4	89.6	92.6	95.6
21.0	69.6	73.6	77.5	81.1	**84.6**	88.0	91.3	94.5	97.5
21.5	71.3	75.3	79.2	82.9	**86.5**	90.0	93.4	96.7	99.9

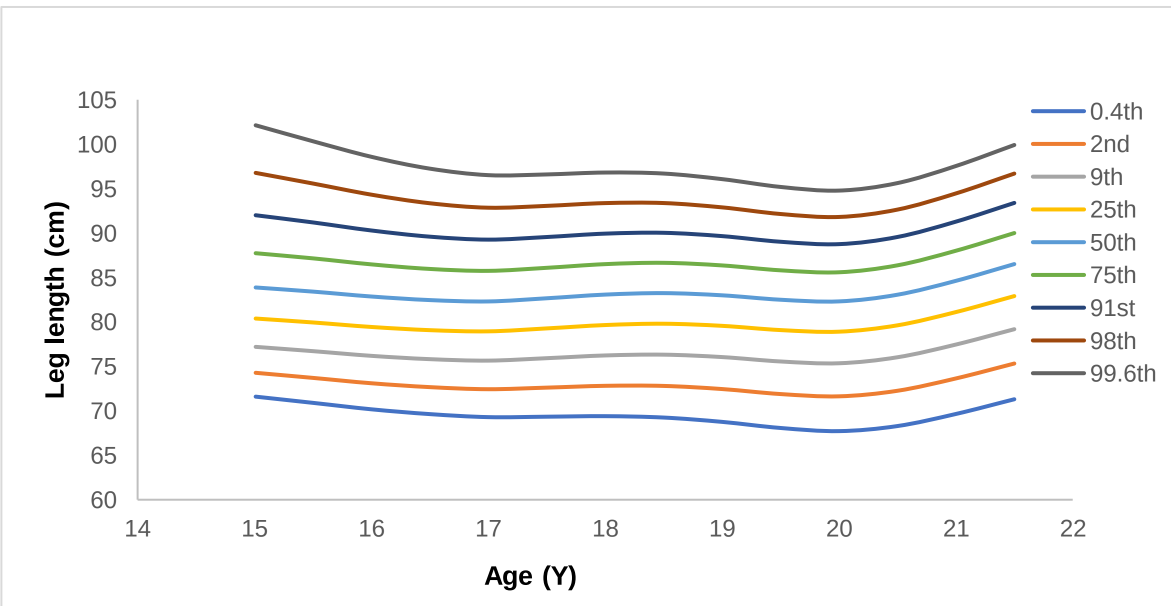


Figure 4.19: Leg length centiles of male at 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles

Figure 4.20 below showing the smoothed centile charts constructed for leg length for female. It was noticed that there was almost negligible change in leg length after the age of 15y in all centile groups. At 50th centile (Table 4.20), there was decreasing pattern of leg length i.e. at lowest age group, the mean leg length was noticed as 75.1 cm which was also the maximum mean leg length noticed at 50th centile, minimum mean leg length was noticed as 73.9 cm at highest age group.

Table 4.20: Centiles of leg length curve by age and sex (female)

	0.4th	**2nd**	**9th**	**25th**	**50th**	**75th**	**91st**	**98th**	**99.6th**
Year	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
15.0	62.5	65.4	68.4	71.7	**75.1**	78.7	82.6	86.7	91.1
15.5	63.0	65.8	68.7	71.8	**75.1**	78.6	82.4	86.5	90.9
16.0	63.5	66.1	68.9	71.8	**75.0**	78.5	82.2	86.2	90.5
16.5	63.7	66.2	68.9	71.8	**74.9**	78.3	81.9	85.8	90.1
17.0	63.7	66.2	68.8	71.7	**74.7**	78.0	81.6	85.5	89.8
17.5	63.7	66.1	68.7	71.5	**74.6**	77.9	81.5	85.5	89.9
18.0	63.7	66.0	68.5	71.3	**74.4**	77.7	81.5	85.8	90.6
18.5	63.7	65.9	68.4	71.1	**74.2**	77.7	81.8	86.5	92.1
19.0	63.7	65.9	68.3	71.0	**74.2**	77.9	82.3	87.7	94.5
19.5	63.8	65.9	68.3	71.0	**74.2**	78.1	83.0	89.3	98.0
20.0	63.9	65.9	68.2	71.0	**74.2**	78.3	83.7	91.2	103.0
20.5	64.0	65.9	68.2	70.9	**74.2**	78.5	84.4	93.3	110.6
21.0	63.7	65.6	67.8	70.5	**73.9**	78.3	84.8	95.7	126.4

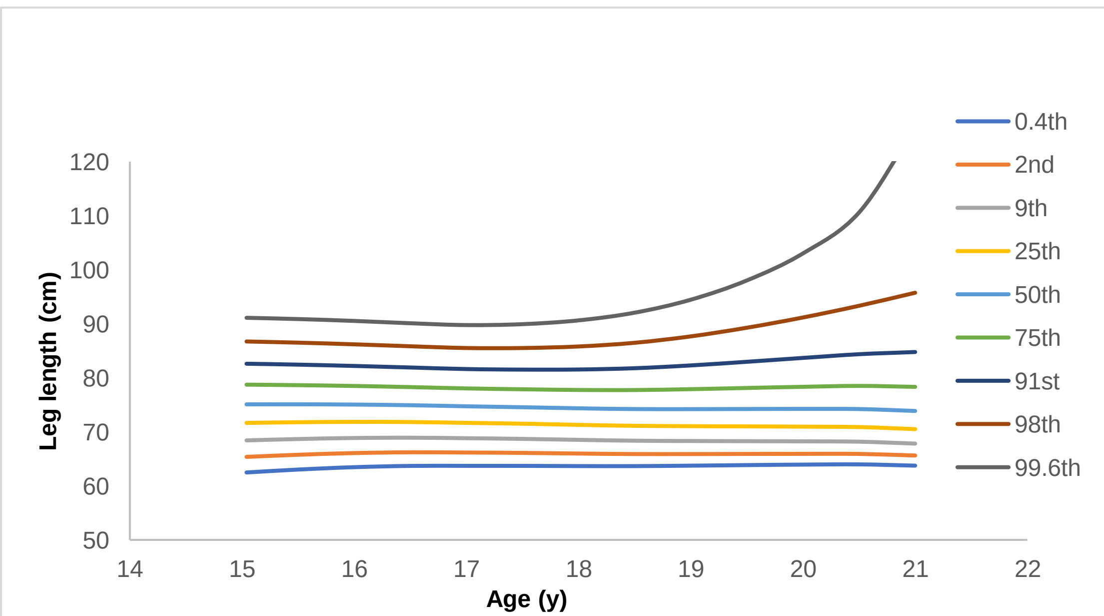


Figure 4.20: Leg length centiles of female at 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centile

4.5 Discussion

In this study, centile growth charts were constructed for height, weight, sitting height and leg length for the UK adolescent and young adult South Asian population (male and female). These are the first sets of curves generated for this population group, which has revealed important differences compared with the UK90 reference populations. In the 1990's, (Cole and Green 1992, Cole et al. 1995) established the reference centile curves for height and weight of UK children, adolescents and young adults. Only data from white Europeans were used in preparing these charts. These charts have been the foundation for nutritional assessment both clinically and epidemiologically for the past 30 years. Later on, since 2009, the RCPCH developed similar growth charts based on the WHO Child Growth Standards, which defined the optimum growth for healthy infants, children and adolescents from 2 to18 years of age. These growth charts were primarily developed to evaluate the growth of school age children and young people in primary or secondary health care. These charts also included advice on the onset age for puberty, adult height and BMI projections and a mid-parental height comparator (RCPCH, UK). Until now, it has been necessary to use these growth charts to assess the children and adolescents from a South Asian background. Despite secular increases in height and weight of UK South Asians which would have occurred between 1990 and the generation of these new curves, there is now the option to use these new charts specifically for this ethnic group.

One of the most useful and preferred methods for monitoring the growth of children is to plot the height and weight values of the children on standard centile charts. It is therefore important for each country to use its own populations as the reference group. However, this may not always represent the growth of other ethnic groups living in that country, especially in a country such as the UK where there is diverse ethnic makeup. Hence, the data on the growth of young adults living in UK from different ethnic groups are also needed for comparison with the national standards.

This study aimed to obtain anthropometrical measurements (weight, height and sitting height and derived leg length) from representative and randomly selected adolescents and young adults of a sufficient sample size. To what extent these aims have been fully achieved must be acknowledged and hence can be considered a limitation of this study (see section 4.6). This study demonstrated key differences between young adults from South Asian population and the UK reference population with respect to their height and weight measurements. The overall shorter height for age observed in this SA population compared to UK 1990 data is consistent with established observations of shorter height in this population group. However, despite this ethnic difference, within the population group there is variation in height for age with some individuals being short for their age and equally some being tall for their age. Tallness for age is linked with phases of growth and is characterised by centile curves in height growth charts (Cameron 2002). While height-growth restriction typically represents sub-optimal nutritional exposure at some stages of a child's development, this could be one of the possible explanations that participants in our study had lower mean height than UK population. More likely, this is due to a genetic element. In addition, parental height was not obtained in our study, and it is known that child height reflects parental height. Furthermore, height is also positively related to socio-economic status (McCarthy 2014). It was beyond the scope of this study to ascertain the income and employment background to the participants. Ideally a mix of all SES groups should be recruited in any study such as this one.

Variations in body measurements within South Asian population have also been examined in number of national surveys. One such example is the HSE 2004 (Sproston and Mindell 2006). This study demonstrated differences in height and weight among South Asian population compared to these measures of general population. A difference in height between South Asians has also been shown in the 2006-2007 National Child Measurement Programme (NCMP) (Dinsdale and Rutter 2008). This survey showed that Bangladeshi children were shorter than Indian and Pakistani children who were all shorter, on average than children from a white European background. Furthermore, a study on young children found that the greater height of Africans and Europeans compared to Indian children was explained by ethnicity (genetics) and not environmental and nutritional factors (Kuriyan et al. 2011).

When evaluating the findings on body weight, the current study showed that the weights of both male and female population more or less fell around the 50th centile (z-score = 0.0). However, given the age of the UK90 charts, contemporary while Europeans would on average fall above the 50th centile due to the know secular and dramatic increases in body weight over the past 30 years. When weight is incorporated into BMI (see chapter 1 section 1.7.1) this gives a clearer picture of the degree of excess weight in the South Asian population compared with the equivalent BMI references (Cole et al. 1995).

To date there are no published data related to sitting height measurements in South Asians UK residents. The only reference centile curves currently available for body proportions of children and adolescents in the UK were constructed more than 20 years ago by Dangour et al. (2002). The current study was designed to produce up-to-date sitting height centile curves for boys and girls specifically in South Asian population and this chapter contains contemporary cross-sectional data describing the sitting height of South Asian adults living in UK. The data set derived from a convenience sample and is therefore not necessarily nationally representative. As also reported by others, our participants showed an increase in sitting height with age, parallel to the increase in height (Grummer-Strawn et al. 2002). In the male, the increase in sitting height was found to be greater between studied ages as compared to female. Of greater interest, however, there are derived leg length curves.

Since this was the first study addressing the gap of anthropometric measurements in South Asian population living in UK, we were not able to compare results of our study with the results of other studies conducted in UK or any other country in Caucasian population, nor were we able to investigate the presence/absence of a trend with the historic data due to the same reason. There are studies which indicate that in past few decade in many countries the increase in height noted in general which is likely to be due to increase in limb length rather than in trunk length (Jantz and Jantz 1999, Dangour et al. 2002). This can be due to access to good diet or good monitoring tools (rather than actual increase in height) but it is difficult to say if the SA population living in UK has followed the same pattern of increase in height due to the lack of historic data. In conclusion, we believe this study, by providing references data on weight, height, and sitting height in South Asian young adults between 16 and 21 years, fulfils a need for clinicians and epidemiologists working in UK and will be useful in the diagnosis and follow-up of children with growth and weight-related issues.

An added feature of the centile charts generated in this study is that they have been extended beyond the adolescence range into young adulthood. Whilst centile charts have traditionally been used predominantly for the paediatric population, there is a growing interest in their use for the adult population. For example, centile charts have been constructed for blood pressure, head circumference and stature in adults.

4.6 Limitations

One of the short comings of the study is the limited amount of data collection as some key information such as socioeconomic status of the participants, which was not collected in this study, would have added some value

The validation of the sitting height technique was not the part of the study as this sitting height technique used for this study was completed by previous researcher. Also, the standard clinical equipment was not use as it was not portable and not suitable for field-based studies.

For studies involving measurements, ideally the measurements should be taken twice and mean of those measurements should be used. Due to limited resource and time and considering participants' inconvenience, anthropometric measures were taken once for this study

CHAPTER 5 – Body Mass Index and Waist Circumference

5.1 Introduction

A high BMI in adulthood is associated with increased morbidity, predominantly T2DM, hypertension and coronary heart disease (McCarthy 2017). For the estimation of obesity-related risk clustering among children and adolescents, BMI also has a very meaningful clinical utility. BMI is criticised as it represents only a crude proxy for body fatness and can result in significant misclassification of individuals with respect to metabolic risk (Katzmarzyk 2004). Even though the National Institute for Health and Care Excellence (NICE) UK recommends the use of BMI as the measure of overweight and obesity, it also emphasises that caution must be exercised when interpreting BMI as it is not a direct measure of adiposity (Willans et al. 2019).

The capacity of BMI to predict excess morbidity and mortality diverges between different ethnic groups, therefore BMI cut-offs calculated for Caucasians cannot necessarily be considered as an equivalent estimate of obesity-related risk in South Asians as the two ethnicities have distinctive obesity phenotypes. For example, the South Asian phenotype is characterised by a relatively lower skeletal muscle mass and a higher fat mass, with a tendency for the fat to be centrally distributed (Deurenberg et al. 1998, Mohan and Deepa 2006). Therefore, at equivalent BMIs, South Asians would be at a greater risk of metabolic disease due to this characteristic phenotype. Therefore, for getting more positive health outcome in South Asian population group some powerful strategies should make (Misra et al. 2011).

Therefore, lower obesity cut-off points are needed in South Asians to detect an equivalent plasma concentration of dysglycaemia and dyslipidaemia compared to White Europeans (Gray et al. 2011). In 2004, an expert consultation by the World Health Organisation (WHO) recommended revised BMI cut-off points in Asians for the classification of overweight (23 kg/m^2) and obesity (25 or 27.5 kg/m^2, depending on the specific Asian population (WHO expert consultation 2004). In support of this revision an evaluation of current studies conducted on Asian Americans by (Hsu et al. 2015) exposed the incidence of T2DM at a comparatively lower BMI cut-point compared with European Americans. These investigators clearly revealed that a BMI cut-off of 23 kg/m^2 is more appropriate for screening of T2DM in Asian populations living in the United States, and the same cut-off has been adopted in the position statement of 2015 by the American Diabetic Association (ADA). This is a major and much-needed health initiative for Asian populations (Hsu et al. 2015, Misra 2015). For South Asian children and adolescents, it had originally been suggested that there was no requirement to lower the centile cut-offs compared with Caucasians. However, more recently there has been a re-evaluation of this recommendation (Hudda et al. 2018).

WC measurement is recommended as an additional measure to BMI in the adult population to provide further evidence of obesity-related risk (Tran et al. 2018) As for BMI, it has been recommended that for South Asian adults, the cut-offs to define increased risk and very high risk are also lowered (de Wilde et al. 2013, Misra 2015). However, the NICE obesity guidelines express that WC is not recommended as a standard measure of obesity risk in young people, however they do suggest that it might be utilised in practice to provide additional evidence to metabolic risk alongside BMI (NICE 2006 obesity guidelines). It is acknowledged, however, that central obesity is more closely related with high risk of metabolic disease than the total obesity assessed by BMI (Després et al. 2001). Furthermore, there is substantial evidence that the WC measurement of central obesity is useful for envisaging the risk of hypertension, insulin resistance, T2DM, dyslipidaemia, non-alcoholic fatty liver and coronary heart disease (Chan and Woo 2010). Findings from the Bogalusa Heart Study revealed that there is a direct/positive correlation between abdominal or central fat distribution and adverse concentrations of triacylglycerol, LDL cholesterol, HDL cholesterol and insulin (Freedman et al. 1999). In addition, WC in obese children is an easy tool for assessment of systolic blood pressure and fatty liver (Deeb et al. 2018). In perspective of this close relationship between WC and central obesity, WC could be used as a substitute or as an additional measurement to BMI for assessment of CVD in children. Moreover, WC is a relatively simple, quick, non-invasive and inexpensive technique that can be used in the clinic or in the field (McCarthy et al. 2014). To this end, WC percentile curves have been generated for white British children (McCarthy et al. 2001) but, as yet, no such data have been produced for South Asian population living in UK.

Given the lowered BMI and WC cut-offs for South Asian adults, and the recommended lower BMI cut-offs for South Asian children, it is likely that the same would be recommended for WC. Indeed, to support this notion, a new set of WC percentile curves for the UK South Asian younger child and adolescent population aged 4-15y has recently been produced (Shah et al. 2019). However, for completeness, it would be beneficial both for clinical practice and epidemiology to extend these curves to cover the older adolescent and young adult South Asian population.

5.2 Aim of the study

The aim of this study was to fulfil the demand of centile curves of BMI and WC with different cut-off values for adolescents and young adults from South Asian background living in UK.

5.3 Methodology

The general study design and measurement protocols are presented in Ch.2 (Participants and methods). Data on height, weight, BMI and WC were collected as previously described. All data were entered onto an Excel spreadsheet. BMI was calculated by using formula (Wt./ Ht*Ht). The methodology for measuring waist circumference is described in section 2.6.4 of chapter 2. Descriptive statistics were produced for BMI and WC at each yearly age interval, expressed as raw values and as Z-scores. Scatterplots of BMI and WC against age were generated using Excel. LMS Chartmaker was then used to construct both BMI and WC centile charts for males and females aged 16-21y. Subsequently these data were merged with equivalent data previously collected for the 4-15 y age range to regenerate centile curves spanning the 4-21y age range.

5.4 Results

5.4.1 Body Mass Index (BMI)

Table 5.1 shows that in all age group, a narrow range (21.3 kg/m^2 – 23.7 kg/m^2) of average BMI has been observed in both gender with maximum standard deviation observed in 19y male (4.6 kg/m^2) and 20y female (4.0) probably due to lower number of participants in that group. Generally, the BMI was found to be increasing with age in both genders in the studied age group (16 – 21 yrs), though, among males, the maximum mean BMI of 23.5 was found in 20y age group and among females minimum mean BMI of 22.1 kg/m^2 was found in 17y age group and maximum mean BMI of 23.7 kg/m^2 was found in 20y of age group.

Z-scores for BMI was calculated for both male and female using UK 1990 data as reference population. Table 5.2 shows that mean z score for both genders at all age group included in the study are higher than average population meaning that BMI of studied population is higher than that of reference population. However, there was no specific trend in either gender in relation to increasing age. Among males, maximum z score of 0.70 was seen in 17y of age group while among females, maximum mean z score of 0.51 was found in 16y of age group.

Table 5.1: Descriptive statistics of BMI with age and gender distribution

Descriptive statistics of BMI with age and gender distribution												
	16 years		17 years		18 years		19 years		20 years		21 years	
	M (n=114)	F (n=71)	M (n=52)	F (n=37)	M (n=35)	F (n=26)	M (n=24)	F (n=25)	M (n=25)	F (n=20)	M (n=50)	F (n=66)
Mean	21.3	22.3	22.9	22.1	22.3	22.1	23.1	22.5	23.5	23.7	23.3	23.6
Std Dev	3.5	3.7	3.9	3.4	3.5	3.9	4.6	3.6	3.2	4.0	3.6	3.9
Minimum	14.7	14.6	16.4	13.1	16.5	17.2	17.4	18.3	18.1	18.3	17.2	15.8
Maximum	31.6	32.0	33.8	29.1	33.1	35.3	34.8	33.7	29.8	33.4	33.8	33.6

Table 5.2: Descriptive statistics of Z-Score for BMI with age and gender distribution

Descriptive statistics of Z-Score for BMI with age and gender distribution												
	16 years		17 years		18 years		19 years		20 years		21 years	
	M (n=114)	F (n=71)	M (n=52)	F (n=37)	M (n=35)	F (n=26)	M (n=24)	F (n=25)	M (n=25)	F (n=20)	M (n=50)	F (n=66)
Mean	0.40	0.51	0.70	0.30	0.35	0.16	0.31	0.23	0.42	0.48	0.17	0.38
Std Dev	1.21	1.18	1.19	1.25	1.09	1.14	1.40	1.08	1.08	1.21	1.29	1.18
Minimum	-3.17	-3.17	-2.26	-4.95	-2.26	-1.74	-2.04	-1.42	-1.93	-1.50	-2.62	-3.19
Maximum	2.84	2.74	3.02	2.19	2.83	3.04	2.98	2.79	2.14	2.70	2.80	2.71

5.4.1.1 Scatter plots

For the visual representation of the distribution of BMI values with respect to age, scatter plots were constructed. It was observed that a near maximum BMI was already achieved at the age of 15y in males and females, hence no age-related trend in data distribution was seen for BMI in either genders; additionally, no significant outliers in BMI was observed in either gender. Like other parameters, most of the data was found to be clustered around 16 and 21yrs age group, simply as there were higher number of participants in those two age groups. Figure 5.1 and 5.2 shows the scatter plot of BMI vs age for male and female participants respectively.

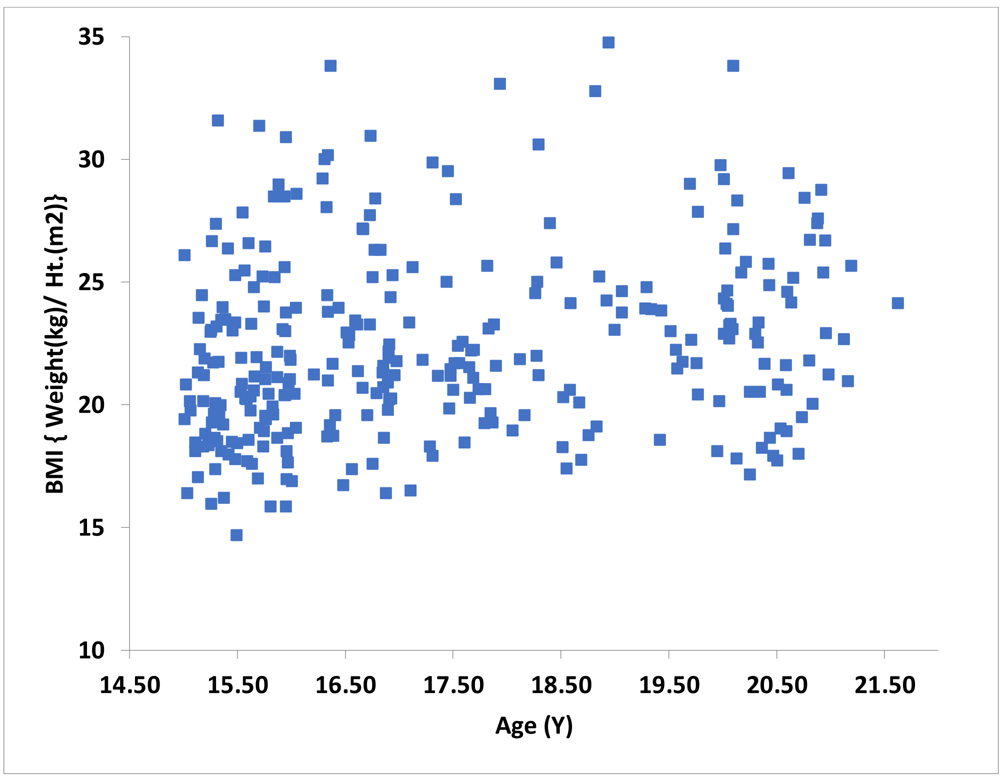


Figure 5.1: Scatterplot showing the distribution of BMI against age of male study participants

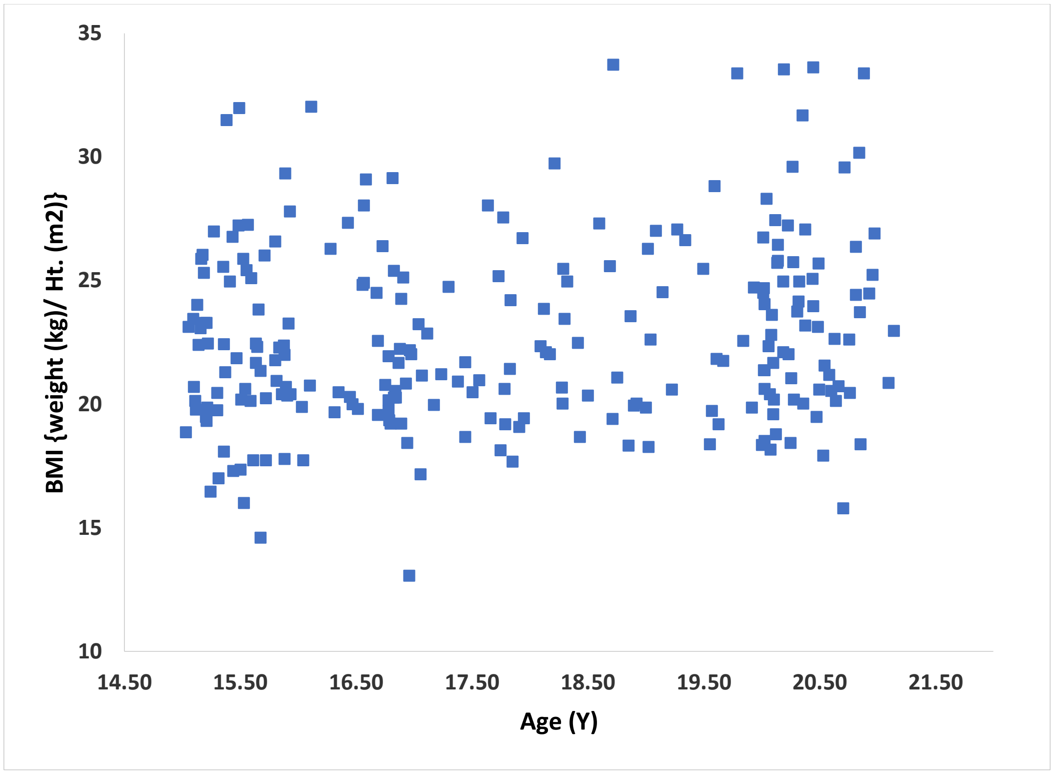


Figure 5.2: Scatterplot showing the distribution of BMI against age of female study participants

5.4.1.2 Centile curves

The centile curves were constructed for BMI for both genders for 9 different centile points at 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles. Figure 5.3 shows BMI was minimally increasing with age at most of the centile cut offs, though the higher centiles (98th and 99.6th) showed initial increase from 16y reaching a plateau at 18y followed by a dip. The increasing trend of BMI with age can be seen at 50th centile. The minimum mean BMI of 20.2 kg/m2 was seen at lowest age group (15y) and maximum BMI of 23.5 kg/m2 was seen at highest age group (21.5y) in the study (Table 5.3)

Table 5.3: Centiles of BMI by age and sex (male)

	0.4th	2nd	9th	25th	50th	75th	91st	98th	99.6th
Year	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
15.0	14.3	15.4	16.7	18.3	**20.2**	22.5	25.3	28.9	33.6
15.5	14.7	15.9	17.2	18.9	**20.8**	23.2	26.2	30.1	35.3
16.0	15.1	16.3	17.7	19.4	**21.4**	23.9	27.1	31.3	37.0
16.5	15.5	16.7	18.1	19.8	**21.9**	24.4	27.7	32.1	38.2
17.0	15.7	16.9	18.3	19.9	**22.0**	24.6	27.9	32.3	38.6
17.5	15.8	17.0	18.4	20.0	**22.1**	24.6	27.9	32.3	38.7
18.0	15.9	17.1	18.5	20.1	**22.2**	24.7	28.0	32.4	38.6
18.5	16.0	17.2	18.6	20.3	**22.4**	24.9	28.2	32.4	38.4
19.0	16.1	17.3	18.8	20.6	**22.6**	25.2	28.4	32.5	37.9
19.5	16.1	17.4	18.9	20.7	**22.9**	25.4	28.5	32.3	37.0
20.0	15.9	17.3	18.9	20.8	**22.9**	25.4	28.4	31.8	35.9
20.5	15.7	17.2	18.9	20.8	**23.0**	25.4	28.1	31.3	34.8
21.0	15.6	17.2	19.0	21.0	**23.2**	25.6	28.2	31.0	34.1
21.5	15.5	17.3	19.2	21.3	**23.5**	25.8	28.3	30.9	33.7

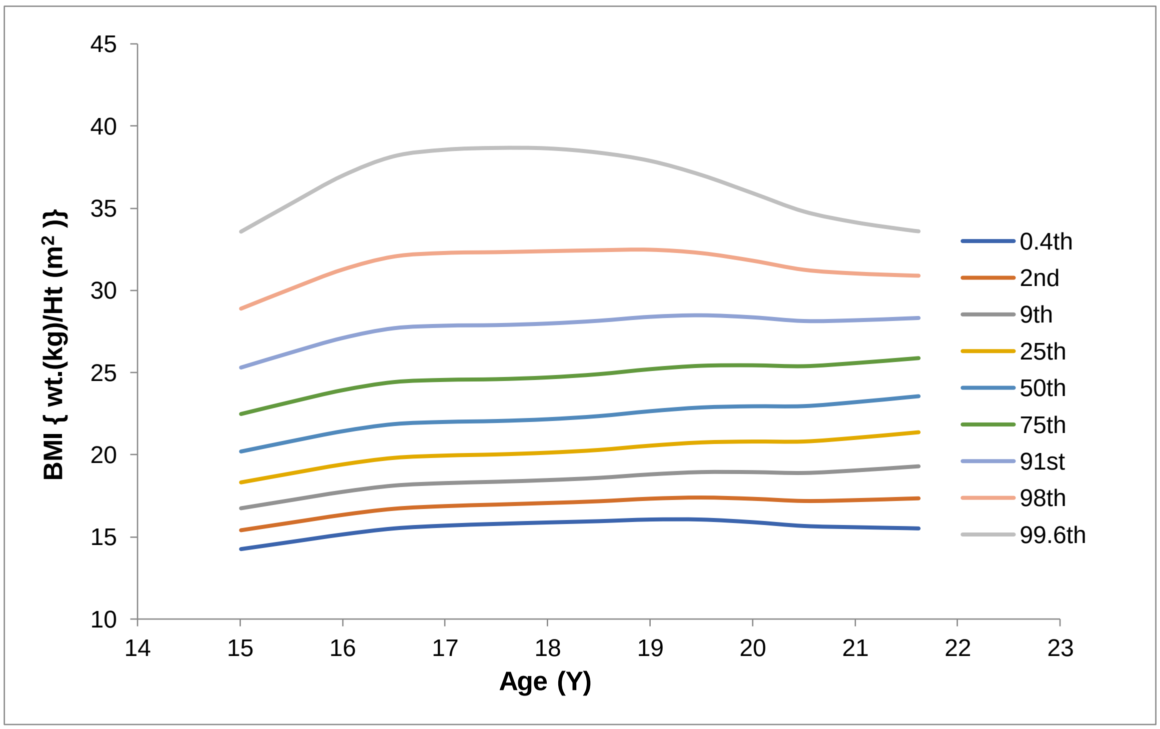


Figure 5.3: Smoothed calculated BMI percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for male

Figure 5.4 shows the BMI centile charts constructed for female participants for 9 different centile points. As seen in the centile chart for males, BMI increased with age at most of the centile cut offs. Compared to the 98th and 99.6th centiles for male, these centiles for female did not show any dip after achieving the peak value, rather an abrupt increase in the 99.6th centile curve was seen after the age of 18y. At the 50th centile (Table 5.4), the minimum mean BMI of 22 kg/m2 was seen in the 15y age group and the maximum mean BMI of 23.3 kg/m2 was seen in the 21y age group showing at consistent and modest increase in BMI with age.

Table 5.4: Centiles of BMI by age and sex (female)

	0.4th	**2nd**	**9th**	**25th**	**50th**	**75th**	**91st**	**98th**	**99.6th**
Year	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
15.0	14.1	15.8	17.7	19.7	**22.0**	24.4	27.1	30.0	33.2
15.5	14.3	15.9	17.8	19.8	**22.0**	24.5	27.2	30.3	33.7
16.0	14.5	16.1	17.8	19.8	**22.0**	24.5	27.3	30.4	34.0
16.5	14.7	16.2	17.8	19.7	**21.9**	24.4	27.2	30.5	34.2
17.0	14.8	16.2	17.8	19.6	**21.7**	24.2	27.0	30.4	34.4
17.5	15.1	16.4	17.9	19.7	**21.8**	24.2	27.2	30.8	35.2
18.0	15.5	16.7	18.2	20.0	**22.0**	24.5	27.6	31.5	36.4
18.5	15.7	17.0	18.4	20.2	**22.2**	24.8	27.9	32.0	37.5
19.0	15.9	17.1	18.6	20.3	**22.4**	25.0	28.2	32.4	38.2
19.5	16.0	17.2	18.7	20.5	**22.6**	25.2	28.5	32.8	38.6
20.0	16.0	17.3	18.8	20.6	**22.8**	25.5	28.8	33.1	38.8
20.5	16.0	17.3	18.9	20.8	**23.0**	25.8	29.1	33.4	38.9
21.0	16.0	17.4	19.1	21.0	**23.3**	26.1	29.5	33.7	38.9

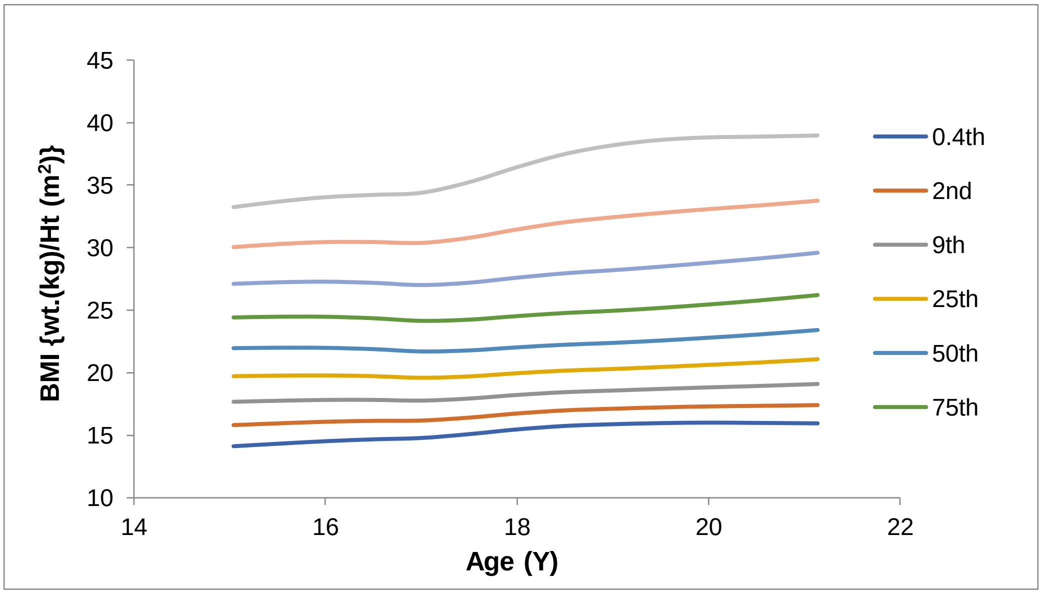


Figure 5.4: Smoothed calculated BMI percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for female

5.4.1.3 Merged centiles

As with the other parameters of anthropometric measurements, centile charts were constructed for males and females for 9 centile points after merging the BMI data for current study with the younger age groups. Figure 5.5 shows the merged BMI centile chart for male for 5 to 21 yrs age group. It was observed that BMI consistently increased with age from 4y up to age 21y at all centile points, though this increase was more obvious until the age of 14y after which only a slight increase in BMI was seen. Table 5.5 shows the BMI values at the 9 centiles for each age group (at 6-month intervals). At the 50^{th} centile, a minimum mean BMI of 14.6 kg/m^2 was seen at 4.5y age and maximum mean BMI of 23.6 kg/m^2 was seen at 21.5y age.

Table 5.5: merged centiles of BMI by age and sex (male)

	0.4th	**2nd**	**9th**	**25th**	**50th**	**75th**	**91st**	**98th**	**99.6th**
Year	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
4.5	12.0	12.5	13.1	13.8	**14.6**	15.6	16.8	18.5	21.1
5.0	11.9	12.5	13.1	13.8	**14.6**	15.7	17.1	19.1	22.1
5.5	11.8	12.4	13.0	13.8	**14.7**	15.9	17.4	19.6	23.2
6.0	11.7	12.3	13.0	13.8	**14.8**	16.0	17.8	20.2	24.4
6.5	11.7	12.3	13.0	13.8	**14.9**	16.3	18.1	20.9	25.8
7.0	11.7	12.3	13.0	13.9	**15.1**	16.5	18.6	21.7	27.2
7.5	11.7	12.3	13.1	14.1	**15.3**	16.8	19.0	22.4	28.8
8.0	11.7	12.4	13.2	14.2	**15.5**	17.2	19.5	23.3	30.4
8.5	11.8	12.5	13.4	14.4	**15.7**	17.5	20.1	24.1	32.0
9.0	11.9	12.6	13.5	14.6	**16.0**	17.9	20.6	24.9	33.5
9.5	12.0	12.7	13.7	14.8	**16.3**	18.3	21.2	25.7	34.8
10.0	12.1	12.9	13.9	15.1	**16.6**	18.7	21.7	26.5	35.9
10.5	12.2	13.1	14.1	15.3	**17.0**	19.1	22.2	27.1	36.7
11.0	12.4	13.2	14.3	15.6	**17.3**	19.5	22.7	27.7	37.2
11.5	12.5	13.4	14.5	15.9	**17.6**	19.9	23.2	28.3	37.6
12.0	12.7	13.6	14.8	16.2	**18.0**	20.4	23.7	28.8	37.8
12.5	12.9	13.9	15.1	16.5	**18.4**	20.8	24.2	29.3	38.0
13.0	13.1	14.1	15.4	16.9	**18.8**	21.2	24.7	29.7	38.1
13.5	13.3	14.4	15.7	17.2	**19.1**	21.7	25.1	30.1	38.2
14.0	13.6	14.7	16.0	17.6	**19.5**	22.1	25.6	30.5	38.3
14.5	13.9	15.0	16.3	17.9	**20.0**	22.6	26.0	30.9	38.4
15.0	14.1	15.3	16.6	18.3	**20.4**	23.0	26.5	31.3	38.4
15.5	14.4	15.6	17.0	18.7	**20.7**	23.4	26.9	31.6	38.4
16.0	14.6	15.8	17.3	19.0	**21.1**	23.8	27.2	31.8	38.4
16.5	14.8	16.1	17.5	19.3	**21.4**	24.1	27.5	32.0	38.3
17.0	15.0	16.3	17.8	19.6	**21.8**	24.4	27.8	32.2	38.1
17.5	15.2	16.5	18.0	19.8	**22.0**	24.7	28.0	32.3	37.9
18.0	15.4	16.7	18.2	20.1	**22.3**	24.9	28.2	32.4	37.7
18.5	15.5	16.9	18.4	20.3	**22.5**	25.1	28.4	32.4	37.5
19.0	15.6	17.0	18.6	20.5	**22.7**	25.3	28.5	32.4	37.2
19.5	15.7	17.2	18.8	20.7	**22.9**	25.5	28.6	32.4	37.0
20.0	15.8	17.3	19.0	20.9	**23.1**	25.7	28.7	32.4	36.7
20.5	15.9	17.4	19.1	21.0	**23.3**	25.8	28.8	32.4	36.5
21.0	16.0	17.6	19.3	21.2	**23.5**	26.0	28.9	32.3	36.3
21.5	16.1	17.7	19.4	21.4	**23.6**	26.2	29.0	32.3	36.1

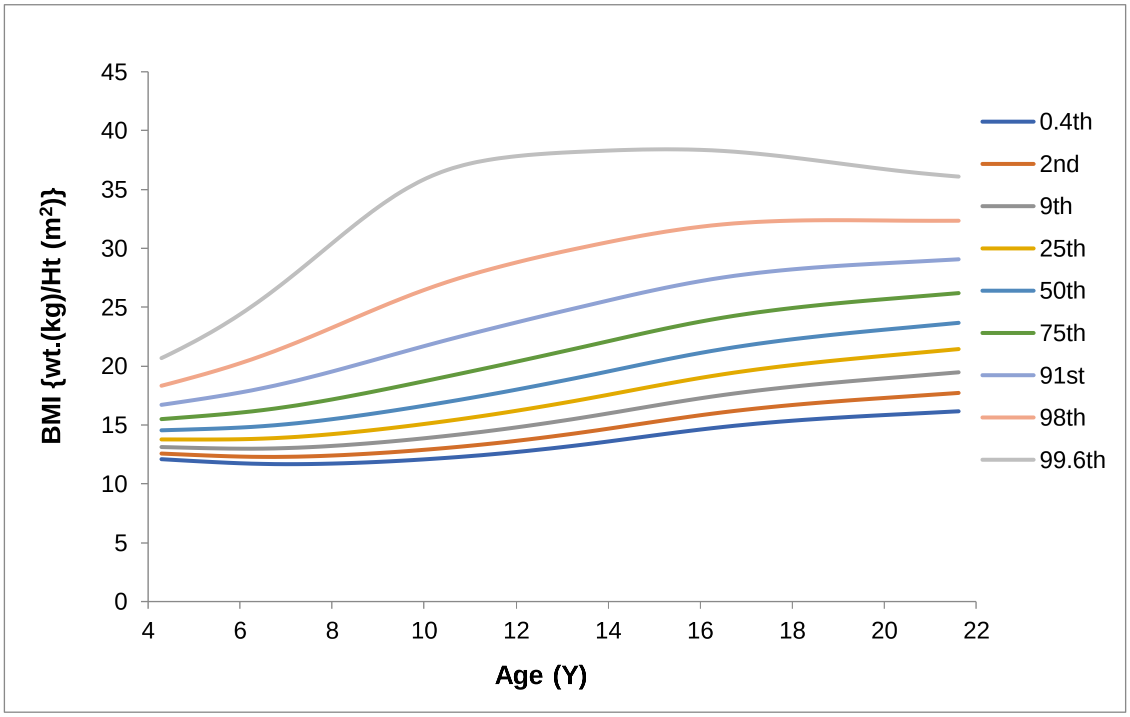


Figure 5.5: Smoothed computed BMI percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for male

Figure 5.6 shows the merged BMI centile chart for female for age 4.5 to 21y age groups. It was observed that BMI constantly increased with age from 4.5y up to age 21y and this was consistently seen at all centile points. Table 5.6 shows the BMI values at the 9 centiles for each age group (at 6-month intervals). At the 50th centile, a minimum mean BMI of 13.9 kg/m^2 was seen at 4.5y age and maximum mean BMI of 23.5 kg/m^2 was seen at age 21y.

Table 5.6: merged centiles of BMI by age and sex (female)

	0.4th	**2nd**	**9th**	**25th**	**50th**	**75th**	**91st**	**98th**	**99.6th**
Year	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
4.5	11.1	11.7	12.3	13.0	**13.9**	15.0	16.5	18.4	21.2
5.0	11.2	11.7	12.4	13.2	**14.1**	15.3	16.9	19.0	22.2
5.5	11.2	11.8	12.5	13.3	**14.4**	15.6	17.3	19.6	23.1
6.0	11.2	11.9	12.6	13.5	**14.6**	15.9	17.7	20.2	24.0
6.5	11.3	11.9	12.7	13.6	**14.8**	16.2	18.2	20.8	25.0
7.0	11.3	12.0	12.8	13.8	**15.0**	16.6	18.6	21.5	25.9
7.5	11.3	12.1	12.9	14.0	**15.2**	16.9	19.1	22.1	26.8
8.0	11.4	12.1	13.0	14.1	**15.5**	17.2	19.5	22.7	27.7
8.5	11.4	12.2	13.1	14.3	**15.7**	17.5	20.0	23.3	28.5
9.0	11.4	12.3	13.3	14.5	**16.0**	17.9	20.4	24.0	29.3
9.5	11.5	12.4	13.4	14.7	**16.3**	18.3	20.9	24.6	30.0
10.0	11.6	12.5	13.6	14.9	**16.6**	18.7	21.4	25.2	30.7
10.5	11.7	12.7	13.8	15.2	**17.0**	19.1	22.0	25.9	31.5
11.0	11.8	12.9	14.1	15.5	**17.4**	19.6	22.6	26.6	32.2
11.5	12.0	13.1	14.4	15.9	**17.8**	20.1	23.2	27.3	32.9
12.0	12.2	13.3	14.7	16.3	**18.2**	20.7	23.8	27.9	33.6
12.5	12.4	13.6	15.0	16.6	**18.7**	21.2	24.4	28.6	34.2
13.0	12.6	13.8	15.3	17.0	**19.1**	21.7	24.9	29.1	34.7
13.5	12.8	14.1	15.6	17.3	**19.5**	22.1	25.4	29.7	35.2
14.0	13.0	14.3	15.9	17.7	**19.9**	22.6	25.9	30.2	35.6
14.5	13.3	14.6	16.2	18.1	**20.3**	23.0	26.4	30.6	36.0
15.0	13.5	14.9	16.5	18.4	**20.7**	23.4	26.8	31.0	36.4
15.5	13.7	15.1	16.8	18.7	**21.0**	23.8	27.2	31.4	36.7
16.0	13.9	15.4	17.0	19.0	**21.3**	24.1	27.5	31.7	37.0
16.5	14.1	15.6	17.3	19.3	**21.6**	24.4	27.8	32.0	37.2
17.0	14.3	15.8	17.5	19.5	**21.9**	24.7	28.1	32.2	37.3
17.5	14.5	16.0	17.7	19.7	**22.1**	24.9	28.3	32.4	37.5
18.0	14.7	16.2	17.9	20.0	**22.3**	25.2	28.5	32.6	37.6
18.5	14.9	16.4	18.1	20.2	**22.5**	25.4	28.7	32.8	37.7
19.0	15.1	16.6	18.3	20.4	**22.7**	25.5	28.9	32.9	37.8
19.5	15.3	16.8	18.5	20.6	**22.9**	25.7	29.1	33.0	37.9
20.0	15.4	17.0	18.7	20.7	**23.1**	25.9	29.2	33.2	38.0
20.5	15.6	17.1	18.9	20.9	**23.3**	26.1	29.4	33.3	38.0
21.0	15.8	17.3	19.1	21.1	**23.5**	26.3	29.5	33.4	38.1

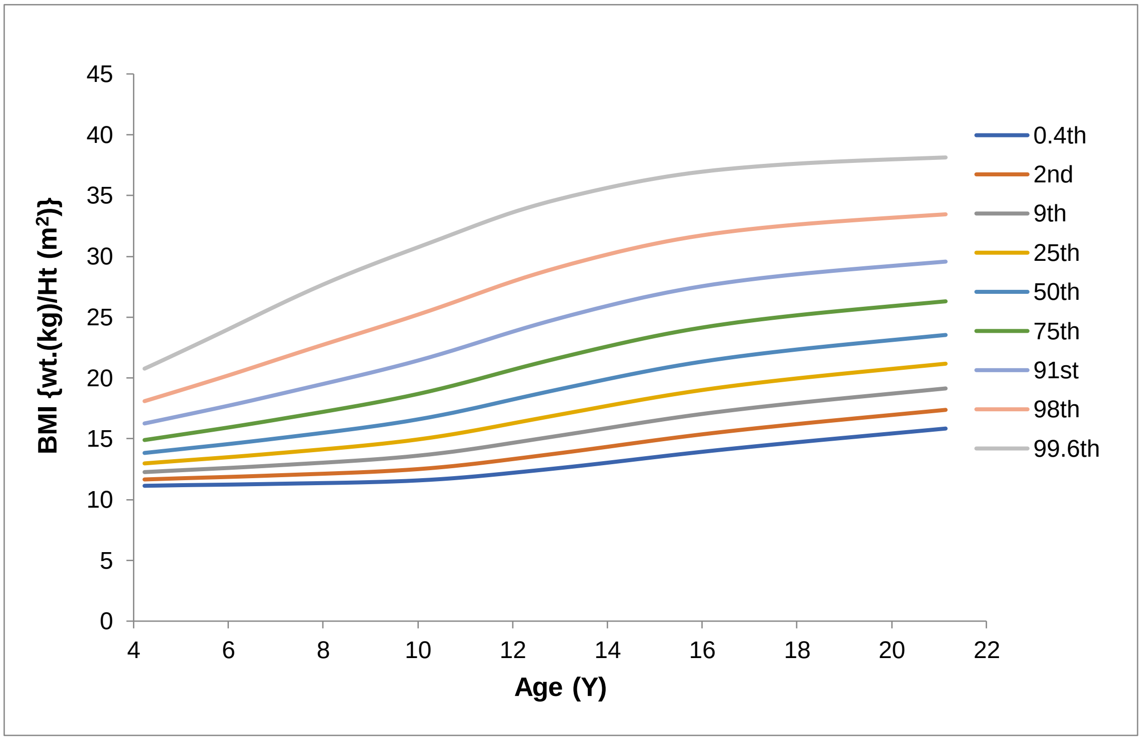


Figure 5.6: Smoothed computed BMI percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for female

5.4.2 Waist circumference

Descriptive statistics of waist circumference (WC) with age and gender distribution has been shown in the table 5.7. It was observed that waist circumference is not affected by age, however the waist circumference was consistently found to be higher in males compared to females for all age groups. Among males, the minimum mean WC of 82.3 cm was observed in 16y age group and maximum mean WC of 88.6 cm was seen in 19y age group. Among females, the minimum mean WC of 80.3 cm was noticed in 18y age group and maximum mean WC of 83.5 cm was seen in 20y age group.

The Z-score was also calculated for waist circumference for both males and females using the UK 1990 reference data for 16y and 17y age group only as no reference data was available for rest of the age group (Table 5.8). For both age groups and for both genders, the SDS was found to be higher, meaning that

South Asians males and females in their 16 and 17 y of age have higher WC than British population in 1990 compared to their respective genders and respective age group. It was also noticed that females have much higher SDS than males at both age groups.

Table 5.7: Descriptive statistics of waist circumference with age and gender distribution

Descriptive statistics of waist circumference (WC) with age and gender distribution												
	16 years		17 years		18 years		19 years		20 years		21 years	
	M (n=114)	F (n=71)	M (n=52)	F (n=37)	M (n=35)	F (n=26)	M (n=24)	F (n=25)	M (n=25)	F (n=20)	M (n=50)	F (n=66)
Mean	82.3	81.3	84.6	80.45	82.7	80.3	88.6	81.6	86.6	83.5	86.3	82.2
Std Dev	10.0	8.4	10.9	10.3	11.15	10.69	9.96	10.36	7.61	8.90	8.44	10.38
Minimum	63	61	64	57	62	60	74	62	75	66	66	58
Maximum	107	104	112	104	112	112	115	112	105	97.5	102	108

Table 5.8: Descriptive statistics of Z-Score for waist circumference with age and gender distribution

Descriptive statistics of Z-Score for waist circumference with age and gender distribution												
	16 years		17 years		18 years		19 years		20 years		21 years	
	M (n=114)	F (n=71)	M (n=52)	F (n=37)	M (n=35)	F (n=26)	M (n=24)	F (n=25)	M (n=25)	F (n=20)	M (n=50)	F (n=66)
Mean	1.36	2.33	1.31	2.04	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Std Dev	1.02	0.97	1.09	1.36	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Minimum	-1.16	-0.92	-1.40	-2.18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Maximum	3.27	4.20	3.47	4.21	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

5.4.2.1 Scatter plots

The waist circumference values were plotted against age for a scatter plot to look at data distribution and scatter of the data for both male and female (Fig 5.7 and 5.8). No data trend was seen in both scatter plots implying that age has no effect on the WC for the studied age group. No specific outlier was also seen. The data was clustered at 15 and 21 yrs age indication more observations (participants) in those age groups.

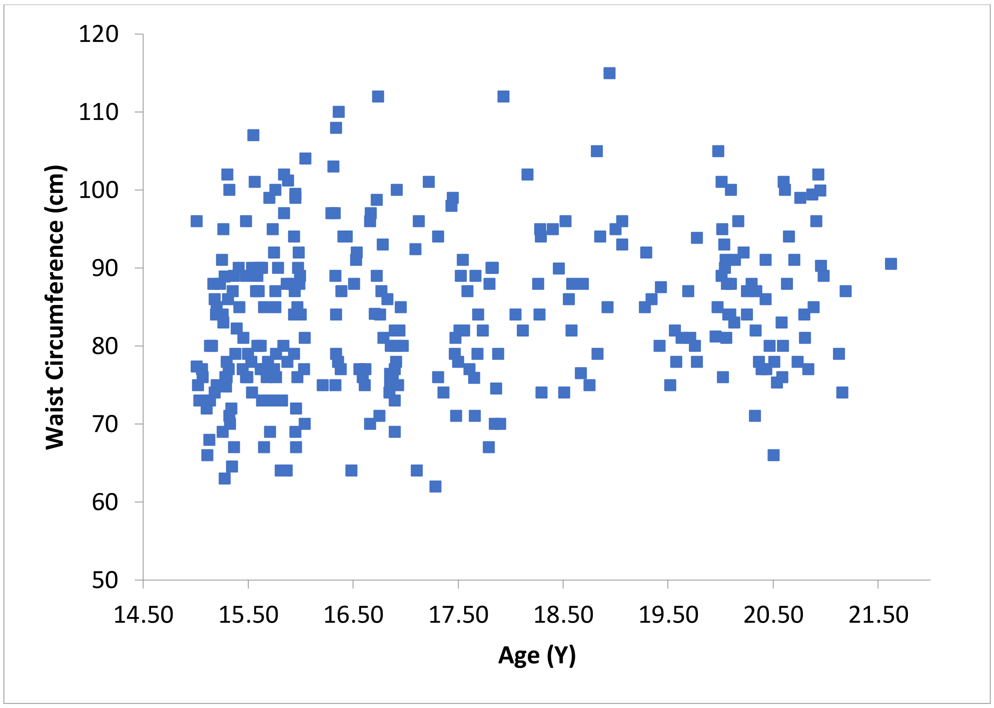


Figure 5.7: Scatterplot showing the distribution of WC against age of male study participants

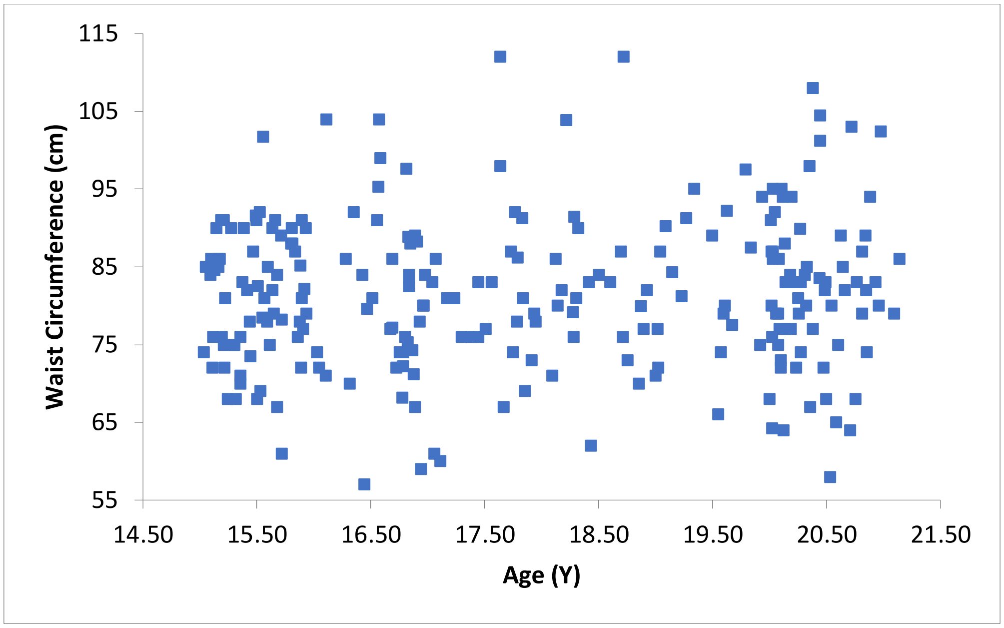


Figure 5.8: Scatterplot showing the distribution of WC against age of female study participants

5.4.2.3 Centile curves

The centile curves were constructed for waist circumference (WC) for both genders for 9 centile points at 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles. Figure 5.9 shows there was a minimal increase in WC with increasing age at most of the centile cut offs, though the higher centiles (98th and 99.6th) showed initial increase from 16y reaching a plateau at 18y followed by a dip. The increasing trend of WC with age can be seen at 50th Centile. The minimum mean WC of 79.2 cm was observed in 15y age group and maximum WC of 87.1 cm was seen at highest age group (21.5y) in the study (Table 5.9)

Table 5.9: Centiles of WC by age and sex (male)

	0.4th	2nd	9th	25th	50th	75th	91st	98th	99.6th
Year	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
15.0	58.0	62.6	67.6	73.1	**79.2**	85.8	93.2	101.2	110.2
15.5	59.5	64.2	69.4	75.2	**81.5**	88.4	96.1	104.6	114.1
16.0	60.6	65.4	70.7	76.6	**83.1**	90.3	98.2	107.1	117.0
16.5	61.0	65.8	71.1	76.9	**83.4**	90.7	98.8	107.8	118.0
17.0	61.0	65.7	70.9	76.7	**83.1**	90.2	98.2	107.2	117.4
17.5	61.6	66.1	71.2	76.9	**83.2**	90.2	98.1	107.0	117.1
18.0	62.9	67.4	72.4	77.9	**84.1**	91.0	98.8	107.6	117.5
18.5	64.5	69.0	73.9	79.3	**85.4**	92.1	99.7	108.3	118.0
19.0	65.7	70.1	74.9	80.3	**86.2**	92.7	100.0	108.2	117.4
19.5	66.1	70.5	75.3	80.5	**86.2**	92.5	99.4	107.0	115.5
20.0	66.2	70.6	75.4	80.6	**86.1**	92.2	98.7	105.8	113.5
20.5	66.2	70.7	75.5	80.6	**86.1**	91.9	98.1	104.7	111.8
21.0	66.4	71.1	76.0	81.1	**86.5**	92.2	98.2	104.4	110.9
21.5	66.8	71.6	76.6	81.7	**87.1**	92.6	98.3	104.2	110.2

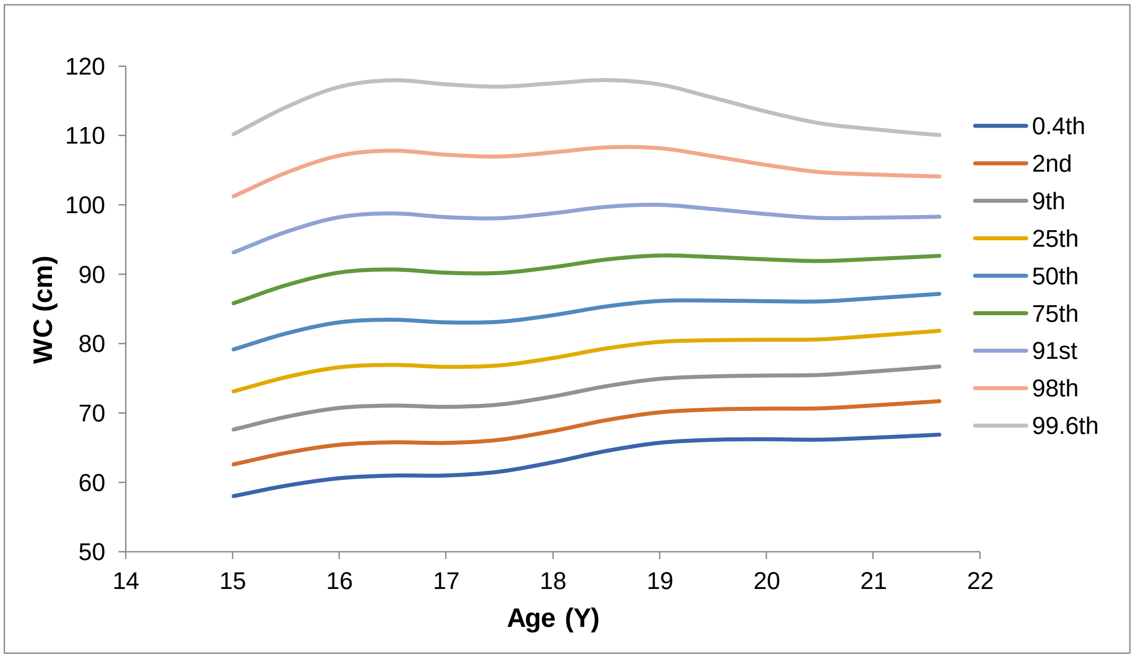


Figure 5.9: Smoothed computed waist circumference percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for male

Figure 5.10 shows the WC centile curves constructed for female participants for 9 different centile points. As seen in the centile chart for males, WC was slightly increasing with age at most of the centile cut offs, though this increase was more at the 98th and 99.6 centiles for male, these centiles for female did not show any dip after achieving the peak value, rather an abrupt increase in the 99.6th centile curve was seen after the age of 17y. The increasing trend of WC with age can be seen at 50th Centile. The minimum mean WC of 80 cm was seen in 17y age group and maximum WC of 82.5 cm was seen at highest age group (21y) in the study (Table 5.10)

Table 5.10: Centiles of WC by age and sex (female)

	0.4th	**2nd**	**9th**	**25th**	**50th**	**75th**	**91st**	**98th**	**99.6th**
Year	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
15.0	58.6	64.5	70.2	75.7	**81.1**	86.4	91.5	96.6	101.6
15.5	57.9	63.8	69.7	75.4	**81.2**	86.9	92.5	98.2	103.7
16.0	57.3	63.1	69.0	75.0	**81.1**	87.2	93.4	99.7	106.0
16.5	56.8	62.4	68.3	74.3	**80.6**	87.0	93.7	100.5	107.6
17.0	56.7	62.0	67.7	73.7	**80.0**	86.6	93.7	101.1	108.9
17.5	57.5	62.5	68.0	73.9	**80.2**	87.1	94.5	102.5	111.0
18.0	58.4	63.2	68.6	74.4	**80.8**	87.8	95.4	103.8	113.1
18.5	58.9	63.7	69.0	74.8	**81.2**	88.2	96.0	104.6	114.0
19.0	59.0	63.8	69.2	75.0	**81.4**	88.5	96.2	104.7	114.0
19.5	58.7	63.7	69.2	75.2	**81.6**	88.7	96.3	104.6	113.5
20.0	58.0	63.4	69.1	75.2	**81.8**	88.8	96.3	104.3	112.9
20.5	57.3	62.9	68.9	75.3	**82.0**	89.0	96.5	104.3	112.5
21.0	56.7	62.7	69.0	75.6	**82.5**	89.6	97.0	104.6	112.5

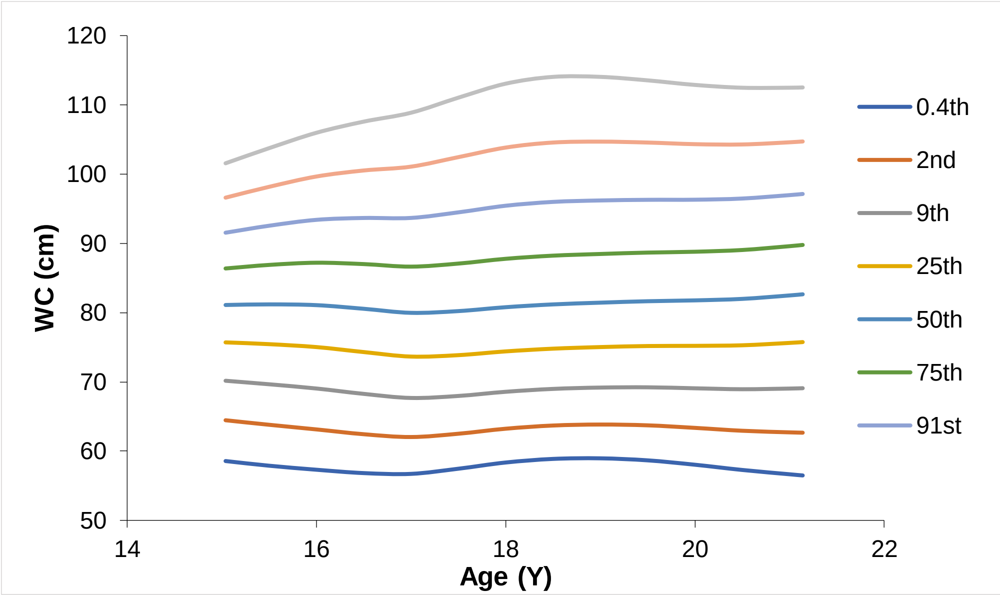


Figure 5.10: Smoothed computed waist circumference percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for female

5.4.2.4 Merged Centiles

The data was statistically analysed for waist circumference centiles curves for 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for male and female (Fig 5.11 and 5.12) respectively. Similar trend was observed where WC slightly increased with age, as the absolute increase has not been noticed between the both genders, although it can be seen at earlier stage of age in boys for 99.6th percentile, which became plateau at later stage. A horizontal trend can also be seen at later stage of the age range (17y) for said centiles in both population and this probably reflected that there is no gender-specific influences on waist circumference.

Table 5.11: Merged centiles of WC by age and sex (male)

	0.4th	2nd	9th	25th	50th	75th	91st	98th	99.6th
Year	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
4.5	43.7	44.9	46.2	47.7	**49.5**	51.8	54.7	58.6	64.6
5.0	44.0	45.3	46.7	48.4	**50.4**	52.9	56.2	60.8	68.1
5.5	44.3	45.7	47.2	49.0	**51.2**	54.0	57.7	63.0	72.0
6.0	44.6	46.1	47.7	49.7	**52.1**	55.1	59.2	65.3	76.1
6.5	45.0	46.5	48.2	50.3	**52.9**	56.3	60.9	67.7	80.6
7.0	45.3	46.9	48.8	51.1	**53.9**	57.5	62.5	70.3	85.4
7.5	45.7	47.4	49.4	51.9	**54.9**	58.8	64.3	72.9	90.4
8.0	46.2	48.0	50.1	52.7	**55.9**	60.2	66.2	75.6	95.4
8.5	46.7	48.6	50.8	53.6	**57.1**	61.6	68.1	78.4	100.4
9.0	47.2	49.2	51.6	54.6	**58.2**	63.1	70.0	81.1	104.9
9.5	47.8	49.9	52.5	55.6	**59.5**	64.6	72.0	83.8	108.8
10.0	48.4	50.7	53.3	56.6	**60.7**	66.2	73.9	86.2	111.9
10.5	49.1	51.4	54.3	57.7	**62.1**	67.8	75.8	88.6	114.0
11.0	49.8	52.3	55.3	58.9	**63.4**	69.4	77.7	90.7	115.3
11.5	50.5	53.2	56.3	60.1	**64.8**	71.0	79.6	92.6	116.1
12.0	51.3	54.1	57.4	61.4	**66.3**	72.7	81.5	94.4	116.6
12.5	52.2	55.1	58.6	62.7	**67.9**	74.5	83.3	96.1	117.0
13.0	53.1	56.2	59.8	64.2	**69.5**	76.3	85.2	97.8	117.3
13.5	54.1	57.4	61.2	65.7	**71.2**	78.2	87.1	99.5	117.6
14.0	55.2	58.6	62.6	67.3	**73.0**	80.1	89.1	101.1	118.1
14.5	56.3	59.9	64.1	69.0	**74.8**	82.0	91.0	102.7	118.6
15.0	57.4	61.2	65.5	70.6	**76.6**	83.9	92.9	104.2	119.1
15.5	58.4	62.4	66.9	72.1	**78.3**	85.6	94.5	105.5	119.5
16.0	59.4	63.5	68.2	73.5	**79.8**	87.2	96.0	106.6	119.7
16.5	60.2	64.5	69.3	74.8	**81.1**	88.5	97.2	107.4	119.8
17.0	60.9	65.3	70.3	75.9	**82.3**	89.7	98.1	108.0	119.6
17.5	61.5	66.1	71.2	76.9	**83.4**	90.6	98.9	108.4	119.3
18.0	62.1	66.8	72.0	77.8	**84.3**	91.5	99.6	108.6	118.9
18.5	62.6	67.5	72.8	78.6	**85.1**	92.2	100.1	108.8	118.4
19.0	63.1	68.0	73.5	79.4	**85.8**	92.8	100.5	108.8	117.9
19.5	63.5	68.6	74.1	80.1	**86.5**	93.4	100.8	108.8	117.4
20.0	63.9	69.1	74.7	80.7	**87.1**	93.8	101.1	108.7	116.9
20.5	64.2	69.6	75.3	81.3	**87.6**	94.3	101.3	108.7	116.4
21.0	64.6	70.1	75.9	81.9	**88.2**	94.8	101.6	108.6	116.0
21.5	65.0	70.7	76.5	82.6	**88.8**	95.2	101.8	108.6	115.6

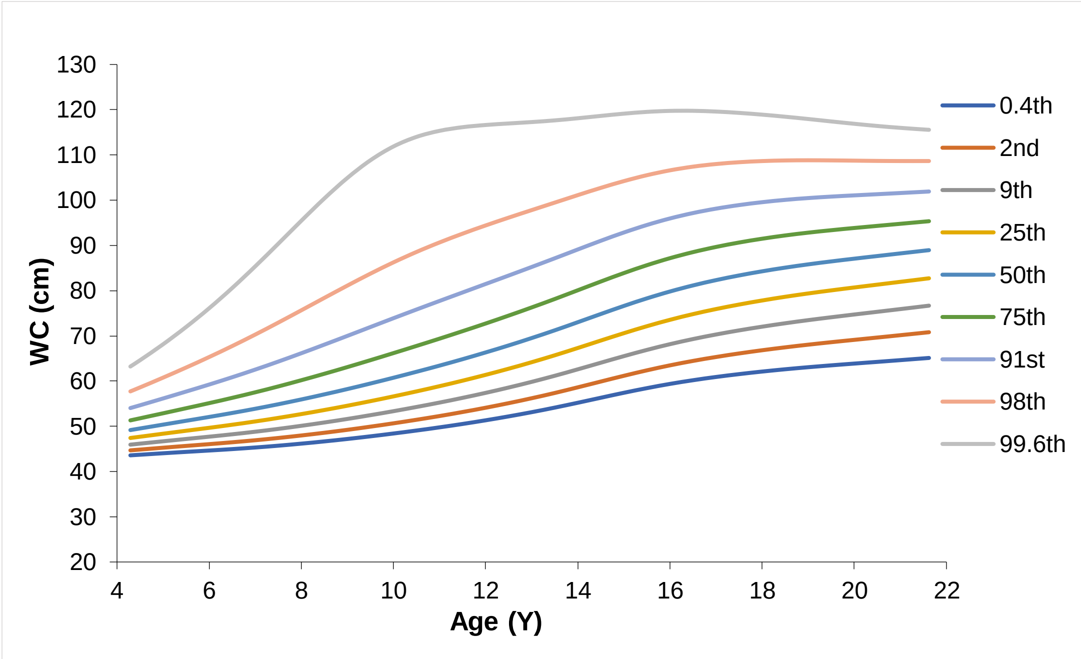


Figure 5.11: Smoothed computed waist circumference percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th for male

Table 5.12: Merged centiles of WC by age and sex (female)

	0.4th	**2nd**	**9th**	**25th**	**50th**	**75th**	**91st**	**98th**	**99.6th**
Year	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
4.5	41.3	42.6	44.1	45.9	**48.0**	50.6	54.0	58.7	66.1
5.0	41.9	43.3	44.9	46.8	**49.0**	51.9	55.6	60.9	69.2
5.5	42.5	43.9	45.6	47.7	**50.1**	53.2	57.2	63.0	72.3
6.0	43.0	44.6	46.4	48.5	**51.2**	54.5	58.8	65.1	75.5
6.5	43.5	45.2	47.1	49.4	**52.2**	55.7	60.4	67.2	78.6
7.0	44.0	45.7	47.7	50.2	**53.2**	56.9	62.0	69.3	81.6
7.5	44.4	46.2	48.4	50.9	**54.1**	58.1	63.5	71.3	84.4
8.0	44.7	46.7	48.9	51.6	**55.0**	59.2	64.9	73.2	87.0
8.5	45.0	47.1	49.4	52.3	**55.8**	60.3	66.3	75.0	89.3
9.0	45.3	47.4	49.9	53.0	**56.7**	61.4	67.7	76.7	91.4
9.5	45.5	47.8	50.5	53.6	**57.5**	62.5	69.0	78.4	93.3
10.0	45.8	48.2	51.0	54.3	**58.4**	63.6	70.4	80.0	94.9
10.5	46.2	48.7	51.6	55.1	**59.4**	64.8	71.8	81.6	96.5
11.0	46.7	49.3	52.4	56.1	**60.5**	66.1	73.4	83.3	98.0
11.5	47.2	50.0	53.3	57.1	**61.8**	67.6	75.1	85.1	99.5
12.0	47.9	50.8	54.2	58.3	**63.2**	69.2	76.8	86.9	100.9
12.5	48.6	51.7	55.3	59.6	**64.6**	70.9	78.6	88.7	102.2
13.0	49.3	52.6	56.4	60.9	**66.2**	72.6	80.5	90.5	103.6
13.5	50.2	53.7	57.7	62.4	**67.9**	74.5	82.5	92.4	105.0
14.0	51.0	54.8	59.0	63.9	**69.6**	76.4	84.5	94.3	106.5
14.5	51.9	55.9	60.3	65.5	**71.4**	78.3	86.5	96.2	107.9

15.0	52.8	57.0	61.7	67.0	**73.1**	80.2	88.4	98.0	109.4
15.5	53.6	58.0	62.9	68.5	**74.8**	81.9	90.2	99.6	110.6
16.0	54.2	58.9	64.0	69.8	**76.2**	83.5	91.7	101.0	111.7
16.5	54.8	59.6	65.0	70.9	**77.5**	84.9	93.1	102.2	112.5
17.0	55.2	60.3	65.8	71.9	**78.7**	86.1	94.2	103.2	113.1
17.5	55.5	60.8	66.6	72.8	**79.7**	87.1	95.2	104.0	113.6
18.0	55.8	61.3	67.2	73.6	**80.5**	88.0	96.0	104.6	113.9
18.5	55.9	61.6	67.8	74.3	**81.3**	88.7	96.7	105.1	114.0
19.0	56.0	61.9	68.2	74.9	**82.0**	89.4	97.3	105.5	114.1
19.5	56.0	62.2	68.7	75.5	**82.6**	90.0	97.8	105.8	114.2
20.0	55.9	62.4	69.1	76.0	**83.2**	90.6	98.2	106.1	114.2
20.5	55.8	62.6	69.5	76.5	**83.8**	91.2	98.7	106.4	114.2
21.0	55.7	62.7	69.8	77.0	**84.3**	91.7	99.2	106.7	114.3

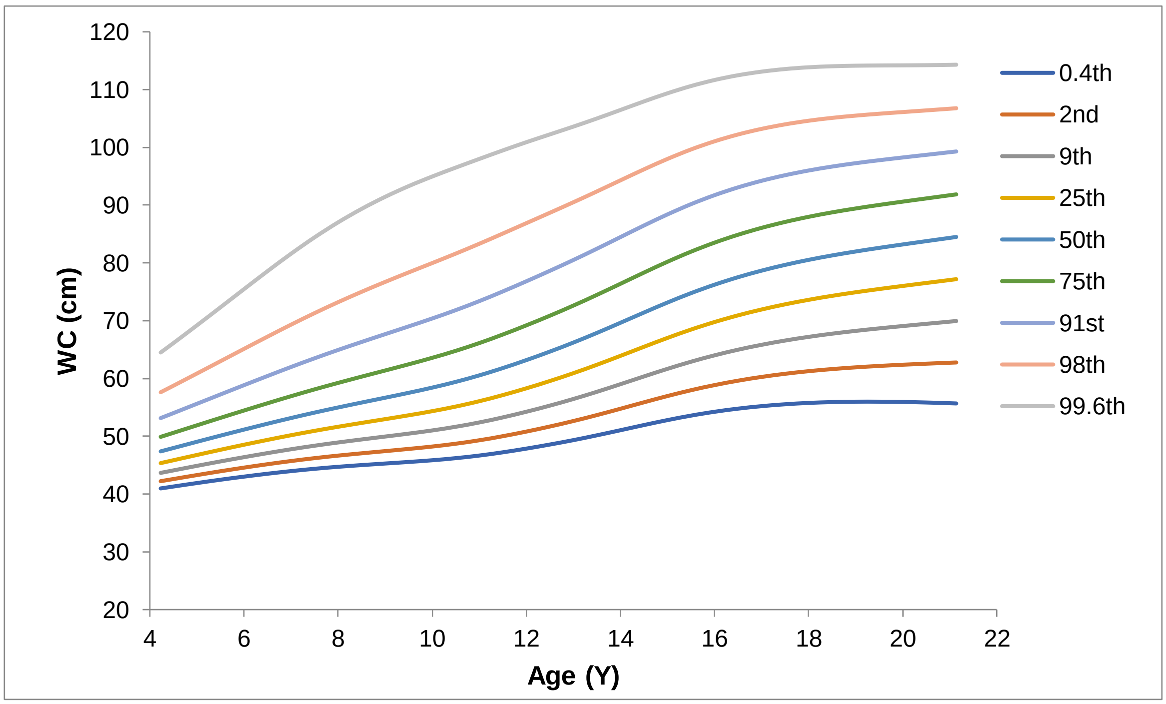


Figure 5.12: Smoothed computed waist circumference percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for female

5.5 Discussion

The development of centile charts for BMI and WC have been reported in different ethnic population including Italian, Cuban, British and Spanish children (Martinez et al. 1994, Zannolli and Morgese 1996, Moreno et al. 1999, McCarthy et al. 2001). Mushtaq et al. (2011) first time develop the reference curve of WC for Pakistani school aged children 5 to 12 years of age and compare the 50th centile with five different countries. In this study they concluded that at 50th centile Pakistani children have higher WC as compared to UK and Hong Kong, therefore a Broad worldwide reference values are needed to define central obesity in this country. In (2012) reference curve of BMI for Pakistani school aged children 5 to 12 years of age was developed, and it was found that Pakistani school-aged children significantly differed from the WHO and USCDC (US Centre for Disease Control and Prevention 2000) references (Mushtaq et al. 2012).

To our knowledge, this is the first study to develop the complete set of growth centile curves for the UK SA population in the age range of 5 y to 21 y where we have been able to describe the mean and distribution of BMI and WC at each age. Even though, there has always been a need to produce reference centiles for children, adolescents and young adults for the South Asian ethnic group, to date their development has been challenging due to difficulties in accessing the specific population at the required sample size and no study has reported the reference data for South Asian in UK. The present study was designed with the aim to address this gap by generating growth reference curves in South Asians from age 4y to 21y. showing that flattening of BMI means all BMI has been achieved.

As previously stated, BMI is the most widely used tool for assessing overweight and obesity, yet it remains that BMI underestimates total body fat (BF) in South Asians (SA) as this population group tends to have a lower BMI for a given body fatness compared with the whites population (WHO expert consultation 2004). However, our study has indicated a higher BMI for age compared with the reference population (UK 1990 study). This can be explained by the secular increase in BMI across all population groups in the UK since the establishment of the UK1990 references (Moody and Neave 2016). Nevertheless, given the clear differences in BMI and body fat distribution between ethnicities, there is justification for the development of South Asian-specific centile curves for various anthropometric measurements with ethnic-specific thresholds for overweight and obesity in SA children. Using the same dataset for the 4.5-15y in this study, Shah et al., 2019 compared the WC reference centiles developed by (McCarthy et al. 2001) with SA children aged 4.5 to 15 y. Overall, they observed that WC (in both genders) was higher in SA at each age. This became evident in boys from age 8y whereas in girls this increment started at age 9y. This difference between SA and the UK reference can also be explained by secular trends since the data that was used for construction of the WC references was collected in 1977 in boys and 1987 in girls. Consequently, if we compare any recent or current population, including white children will be greater due to historical and secular change in weight and body composition (Lee et al. 2014). However, a unique feature of the WC curves in this study is that they have been extended beyond age 18y up to age 21y. The purpose of this was to establish at what point WC began to plateau as well as being able to use these charts into the younger adult age range.

The centile charts developed in our study will facilitate practitioners and researchers to evaluate the body size, dimensions and composition in the South Asian ethnic group. Furthermore, these charts should also facilitate the identification of individuals who are at an increased risk for metabolic disease without the risk of under-estimation or over-estimation when using the UK1990 references. Several UK studies have recommended that BMI cut-offs for classifying overweight and obesity in SA adults needs to be lower than those for WEs (Gray et al. 2011, Batterham 2014), hence providing substantial rationale for developing the ethnic-specific centile charts. Akin to the IOTF cut-offs which pass through the adult values of 25 and 30 at age 18y (Cole et al. 2000), it would be possible to replicate these cuts-offs for SA curves to pass through BMI 23, 25 or 27.5 at the same age. However, to develop these cut-offs is beyond the scope of this thesis.

5.6 Limitations

As with other parameters, the BMI and WC charts constructed in this study would not be appropriate for use with other Asian populations such as Chinese children. As children from different ethnic groups show variations in their rate of proportional growth and fat patterning (Goran et al. 1997) while these charts were constructed for South Asian populations.

Likewise, the anthropometric measurements were taken once from all the study participants instead of duplicate measurements.

CHAPTER 6 – Body fat percentage and Fat mass

6.1 Introduction

The dramatic increase in childhood obesity has warranted the justification for having better assessment tools, which can evaluate obesity and furthermore, characterise the risk of obesity related co-morbidities (McCarthy et al. 2014). Body mass index (BMI) is routinely used as a measure for evaluation of both thinness and obesity (Kalra et al. 2013). As outlined in Ch. 5 BMI is associated with limitations for determining meaningful adiposity, particularly in the SA population who have greater percent body fat for the same body mass index (BMI) compared with white Caucasians (Pasco et al. 2012). By knowing the susceptibility of SA to develop adiposity-related disorders, it is important to determine the method which can accurately assess body fatness %BF and FM (kg) in this population (Kalra et al. 2013). It has always been a challenge to calculate FM outside the laboratory but innovations in bioelectrical impedance (BIA) have made the estimation of fat and lean masses easier into the clinical and public health settings (McCarthy et al. 2014). BIA is relatively inexpensive, portable, rapid and simple to use but it is less accurate than any other more sophisticated methods such as DXA and ADP (Kuriyan et al. 2018).

Over the past 2 decades, various paediatric body-composition reference data have been reported, including BIA data in Turkey (Kurtoglu et al. 2010), South Asian (Eyre et al. 2017) and the Iranian children (Jeddi et al. 2014). These data represent an advance over BMI (Wells et al. 2012). Various previous studies on the body composition of children reported that there are ethnic differences among white, black, Hispanic, and South Asians (Freedman et. 2008).

One set of references for percentage body fat (BF%) in the form of centile charts has been available for white British children since 2006 (McCarthy and Ashwell 2006). The BF% centile charts represent gender differences in fat accumulation that is not reflected in BMI percentile curves. Specific cut-offs were identified to characterise under-fat, healthy, over-fat and obese. Since it has been known that ethnic-specific differences in body composition exist (particularly the hydration of the fat-free mass), these percentile references cannot used for children of another ethnicity. After recognising the importance of body fat assessment, body fat centile charts have emerged in other paediatric populations, e.g. in Turkish children (Kurtoglu et al. 2010). To date, equivalent charts have not been generated for the UK South Asian children and adolescent population.

6.2 Aim of the study

Given the lack of equivalent charts for the South Asian child population, the aim of this study was to fulfil the demand for centile curves of BF% and FM (kg) in this population group.

6.3 Methodology

Body fat percentage and fat mass were measured via the bioelectric impedance analysis by using Tanita (BC-418 MA, Tokyo, Japan), the details have been described in section 2.7 of chapter 2.

6.4 Results

6.4.1 Percentage Body fat (BF%)

Table 6.1 shows the descriptive statistics of both the male and female population for body fat %age. Female participants have shown higher body fat compared to male participants in all age group. Among males, minimum body fat was noted as low as 2.3% was observed in the 21y age group while among female participants, minimum body fat of 9.4% was also noted in similar age group (21 years). Among male participants, body fat % was found to be increasing up to the age of 17 years, noted a static mean value for 18 and 19 yrs age group and then a gradual decline in the body fat% was seen from years onwards until the age of

21 years. Very little variation was seen in the mean body fat% of female participants within the studied age group.

Z-score for BF% calculated using the UK 1990 reference data is shown in table 6.2. This is shown for all age groups except 21y age group as the reference data was not available for that age group. BF% was found to be higher compared to the reference population in both genders and all age groups except for 20y male age group which found to have lower body fat percentage compared to reference population (see section 3.1 for explanation). Female participants were found to have higher mean z-scores at all age groups (except at age 17y) compared to male participants meaning that females had higher body fat percentage compared to the respective reference population.

Table 6.1: Descriptive statistics of body fat (%) with age and gender distribution

Descriptive statistics of body fat (%) with age and gender distribution												
	16 years		17 years		18 years		19 years		20 years		21 years	
	M	F	M	F	M	F	M	F	M	F	M	F
Mean	18.9	28.2	19.7	27.8	18.4	28.3	18.7	30.1	14.9	31.7	14.8	30
Std Dev	5.68	7.72	5.87	7.13	4.58	6.69	8.08	6.29	6.89	7.81	7.36	7.52
Minimum	8.5	9.7	10.7	11.4	11.2	16.1	6.6	19.9	2.8	19.4	2.3	9.4
Maximum	36.7	46.7	38.7	40.6	31.2	44.6	42	45.6	29.3	50.2	28.8	45.2

Table 6.2: Descriptive statistics of z-score of body fat (%) with age and gender distribution

Descriptive statistics of Z-Score for body fat (%) with age and gender distribution												
	16 years		17 years		18 years		19 years		20 years		21 years	
	M	F	M	F	M	F	M	F	M	F	M	F
Mean	0.5	0.6	0.7	0.5	0.6	0.6	0.4	0.8	-0.51	1.0	N/A	N/A
Std Dev	1.11	1.51	1.03	1.25	0.95	1.08	1.62	1.00	1.80	1.23	N/A	N/A
Minimum	-2.9	-4.0	-1.6	-3.0	-1.3	-1.7	-3.5	-0.9	-5.5	-1.0	N/A	N/A
Maximum	2.8	3.3	3.1	2.5	2.7	3.0	4.0	3.1	2.7	3.7	N/A	N/A

6.4.1.1 Scatter plot

The scatterplot for BF% vs. age in males (Fig 6.1) suggested a relatively flat association between these variables. It also suggested that the maximum body fatness was essentially achieved by 15y of age, although the BF% was found to be decreasing after the age of 18y. However, in females, the scatter plot (Fig 6.2) suggested a possible age-related increase in BF% from 16 to 21 yrs of age. No extreme observations (outliers) were observed at either end in both genders. However, among males, a number of very low values of BF% was observed at 20 and 21 yrs age group which has been discussed in detail in section 3.1.

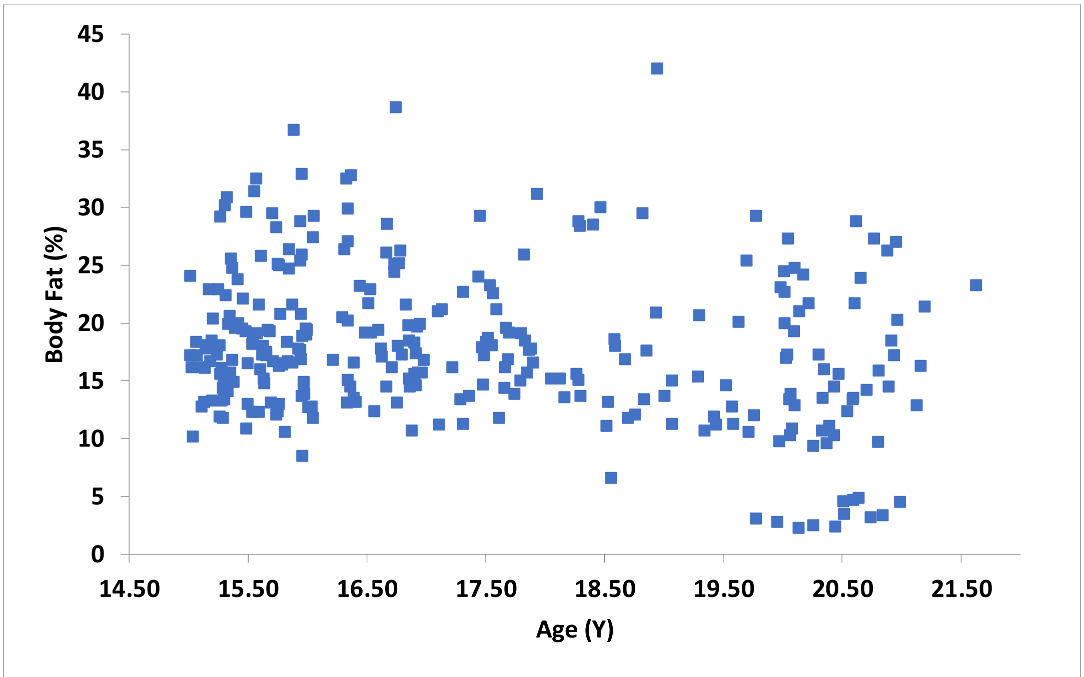


Figure 6.1: Scatterplot showing the distribution of the male BF (%) against age

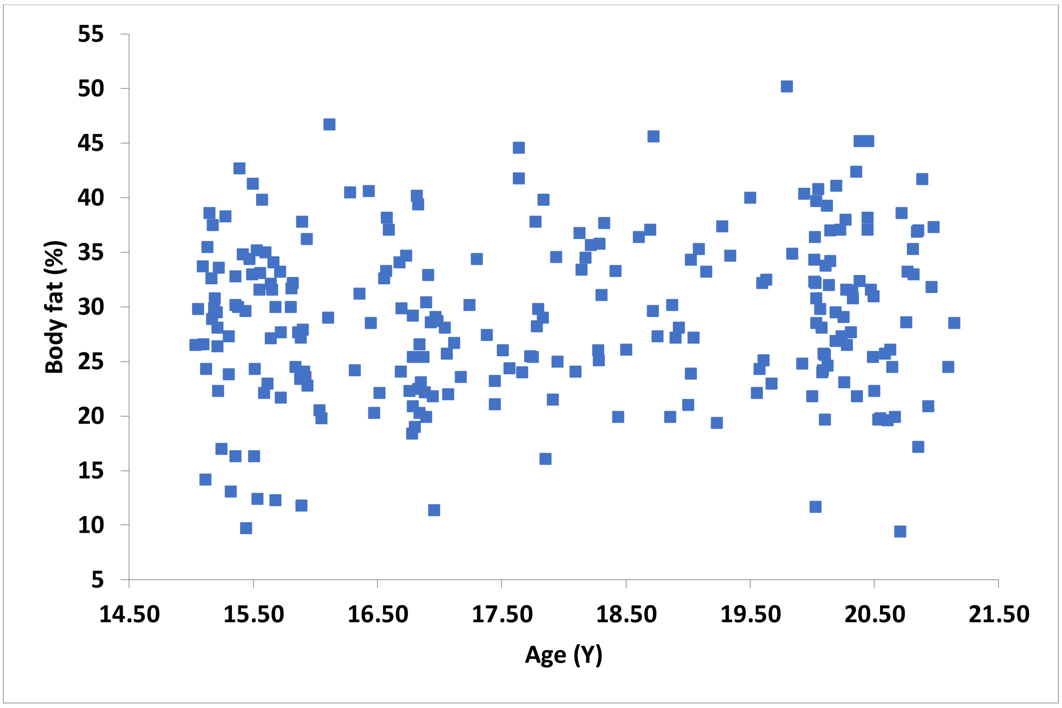


Figure 6.2: Scatterplot showing the distribution of the female BF (%) against age

6.4.1.2 Centile curves

Figure 6.3 shows the centile curves constructed for 7 different centile points (2nd, 9th, 25th, 50th, 75th, 91st and 98th centiles) for the male population. As some male participants with a very low BF% were seen in the scatter plot at the 20y and 21y age group, the same was reflected in the centile curves for 2nd and 9th centiles. For 50th centile, body fat percentage was seen to be increasing from 15y onward until maximum value was achieved at 16.5y age group. Body fat percentage remained almost the same for 17y and 18y age groups and then starts decreasing slightly after the age of 18y. At the lower centiles, (2nd and 9th), the decrease in body fat percentage was seen in all age groups and was more pronounced after the age of 18y till dropped to very low values.

This can be seen in table 6.3 (showing the absolute BF% values for different centiles) that for the 50th centile, the peak mean BF% occurred at age 16.5y age group while the minimum body fat of 14.5 % was seen in 20.5y age group.

Table 6.3: Centiles of BF% by age and sex (male)

	2nd	9th	25th	50th	75th	91st	98th
Year	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0
15.0	10.6	12.3	14.4	**17.1**	20.5	25.0	30.9
15.5	10.9	12.7	15.0	**17.9**	21.6	26.4	32.8
16.0	11.0	12.9	15.3	**18.4**	22.3	27.4	34.1
16.5	10.9	12.9	15.4	**18.5**	22.5	27.7	34.6
17.0	10.6	12.6	15.1	**18.2**	22.3	27.5	34.3
17.5	10.0	12.1	14.7	**17.9**	22.1	27.4	34.2
18.0	9.2	11.4	14.1	**17.5**	21.9	27.3	34.3
18.5	8.1	10.4	13.3	**16.9**	21.4	27.1	34.1
19.0	6.8	9.2	12.3	**16.2**	20.9	26.5	33.3
19.5	5.2	7.9	11.3	**15.4**	20.2	25.8	32.1
20.0	3.5	6.6	10.4	**14.8**	19.7	25.2	31.1
20.5	1.4	5.2	9.7	**14.5**	19.6	24.9	30.4
21.0	1.4	3.6	9.1	**14.6**	19.9	25.2	30.5
21.5	1.4	0.7	8.6	**14.8**	20.4	25.7	30.7

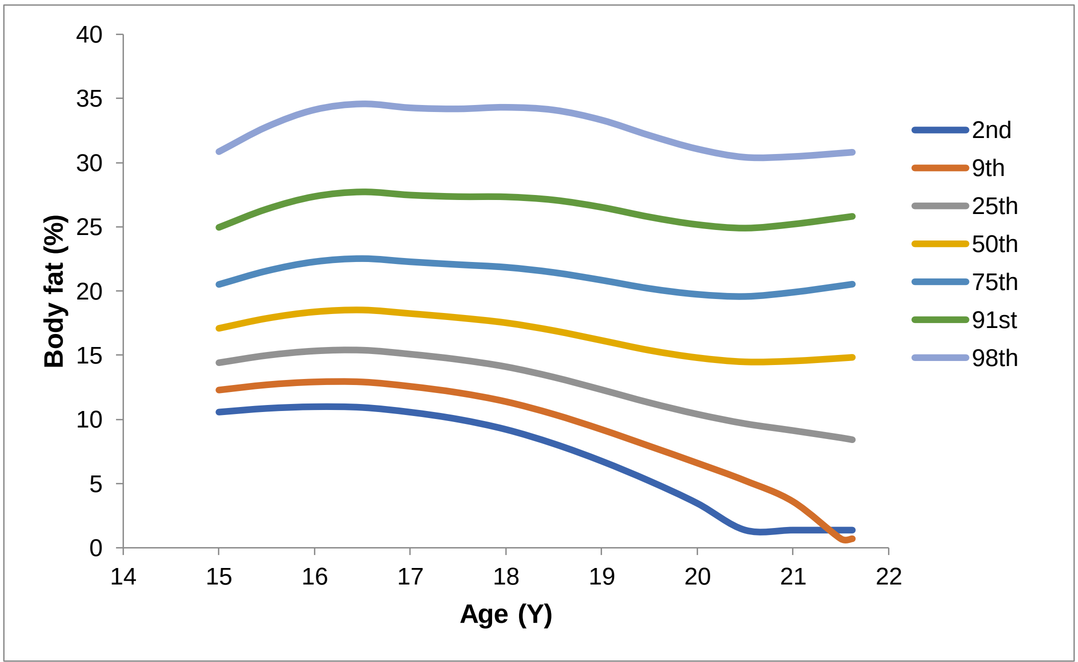


Figure 6.3: Body fat (%) centiles of male at 2nd, 9th, 25th, 50th, 75th, 91st and 98th centiles

At 0.4th and 2nd centile cut-offs, body fat percentage for female participants (Fig 6.4) showed that BF% modestly increases from age 15 to 18.5y and then BF% decreased at higher age groups after reaching the maximum BF% at 18.5y age group, however, the rest of the centiles did not show the similar trend. At 50th centile (Table 6.4) there was no specific trend in BF% was seen with increasing age. It decreased from 28.9% at the age 15y and reached to the minimum BF% of 27.6% at 17y age group and then after that age BF% increased to the maximum BF% of 30.4% at 20y age group and then decreased to 29.8% at 21 y age group.

Table 6.4: Centiles of BF% by age and sex (female)

	0.4th	2nd	9th	25th	50th	75th	91st	98th	99.6th
Year	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
15.0	3.6	9.1	17.4	23.6	**28.9**	33.6	37.9	42.0	45.8
15.5	3.6	11.8	18.1	23.6	**28.7**	33.4	38.0	42.3	46.4
16.0	8.2	13.5	18.6	23.5	**28.4**	33.1	37.8	42.4	47.0
16.5	10.4	14.6	18.9	23.3	**27.9**	32.6	37.4	42.2	47.2
17.0	11.6	15.2	19.1	23.2	**27.6**	32.2	37.0	42.0	47.3
17.5	12.7	16.0	19.7	23.7	**28.1**	32.7	37.7	43.0	48.5
18.0	13.5	16.8	20.5	24.5	**29.0**	33.7	38.8	44.3	50.1
18.5	13.8	17.2	21.0	25.2	**29.7**	34.5	39.7	45.3	51.2
19.0	13.6	17.2	21.2	25.4	**30.1**	35.0	40.2	45.7	51.5
19.5	12.9	16.8	21.1	25.6	**30.3**	35.3	40.5	45.9	51.5
20.0	11.5	16.0	20.7	25.5	**30.4**	35.5	40.6	45.8	51.0
20.5	9.3	14.7	20.0	25.1	**30.2**	35.2	40.2	45.1	50.0
21.0	5.8	12.9	19.0	24.6	**29.8**	34.8	39.6	44.2	48.7

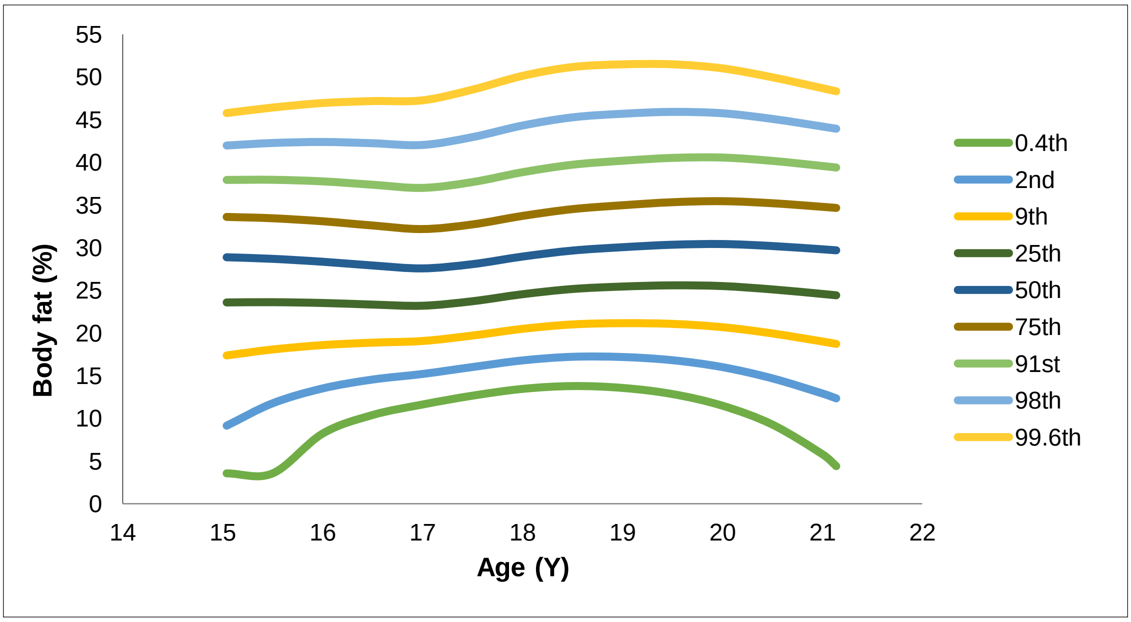


Figure 6.4: Body fat (%) centiles of females at 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles

6.4.1.3 Merged centile curve

The data collected from this study was merged with data collected by previous researcher for South Asian ethnic group to construct the growth curves extending from age 4y up to 21y age groups. The centile curves for

BF% for male (Fig 6.5) showed that age has not much influence in the growth of body fat as compared to other anthropometric measures such as height or weight. Looking at the mean population i.e. 50_{th} centile (Table 6.5), the mean body fat percentage varied between 15.1% to 19.6% and these 2 (min and max) values were not observed in extreme age groups either i.e. 4y or 21y age group respectively. At 50_{th} centile, for 4.5y age group, the mean BF% of 17.9% was noted and for 21.5y age group, a mean BF% of 15.1% was noted, reflecting that body fat percentage is independent of age in the age group of 4y or 21y males. It was observed that mean BF% increase from age 4.5 to 11.5 year and then starts decreasing after that age.

Table 6.5: Centiles of BF% by age and sex (male) – merged data

	2nd	**9th**	**25th**	**50th**	**75th**	**91st**	**98th**
Year	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0
4.5	14.2	15.2	16.4	**17.9**	19.7	22.0	25.2
5.0	14.0	15.1	16.4	**18.0**	20.0	22.7	26.3
5.5	13.9	15.0	16.4	**18.1**	20.3	23.3	27.4
6.0	13.7	14.9	16.4	**18.3**	20.7	23.9	28.7
6.5	13.6	14.8	16.4	**18.4**	21.0	24.6	30.0
7.0	13.4	14.8	16.4	**18.6**	21.4	25.4	31.3
7.5	13.3	14.7	16.5	**18.8**	21.8	26.1	32.7
8.0	13.2	14.7	16.5	**18.9**	22.2	26.9	34.2
8.5	13.1	14.6	16.6	**19.1**	22.6	27.6	35.6
9.0	13.0	14.6	16.6	**19.3**	23.0	28.3	36.9
9.5	12.9	14.5	16.6	**19.4**	23.3	28.9	38.0
10.0	12.7	14.4	16.6	**19.5**	23.5	29.5	39.0
10.5	12.5	14.3	16.5	**19.6**	23.7	29.9	39.7
11.0	12.3	14.1	16.4	**19.5**	23.8	30.2	40.2
11.5	12.1	13.9	16.3	**19.5**	23.9	30.3	40.4
12.0	11.8	13.7	16.1	**19.4**	23.8	30.3	40.4
12.5	11.6	13.5	15.9	**19.2**	23.7	30.3	40.2
13.0	11.3	13.2	15.7	**19.1**	23.6	30.1	39.9
13.5	11.0	13.0	15.5	**18.9**	23.5	29.9	39.4
14.0	10.7	12.7	15.3	**18.7**	23.3	29.7	38.9
14.5	10.4	12.4	15.1	**18.5**	23.2	29.5	38.4
15.0	10.1	12.2	14.9	**18.4**	23.0	29.3	37.9
15.5	9.8	11.9	14.6	**18.2**	22.9	29.1	37.4
16.0	9.4	11.6	14.4	**18.0**	22.7	28.8	36.9
16.5	9.0	11.3	14.2	**17.8**	22.5	28.6	36.3
17.0	8.6	10.9	13.9	**17.6**	22.3	28.3	35.7
17.5	8.2	10.6	13.6	**17.4**	22.1	27.9	35.1
18.0	7.7	10.2	13.3	**17.1**	21.8	27.5	34.4
18.5	7.1	9.7	13.0	**16.9**	21.6	27.1	33.7
19.0	6.6	9.3	12.6	**16.6**	21.3	26.7	32.9
19.5	5.9	8.8	12.2	**16.3**	20.9	26.2	32.1
20.0	5.3	8.3	11.9	**16.0**	20.6	25.7	31.3
20.5	4.6	7.8	11.5	**15.7**	20.3	25.3	30.6
21.0	3.8	7.2	11.2	**15.4**	20.0	24.8	29.8
21.5	2.8	6.7	10.8	**15.1**	19.7	24.3	29.1

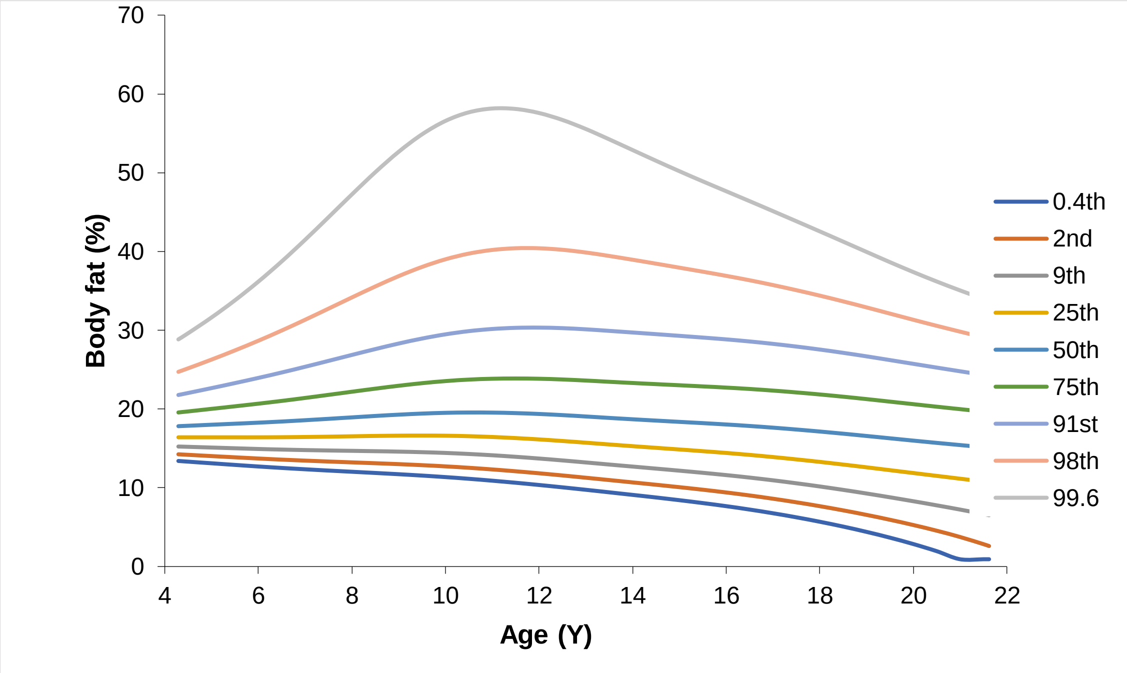


Figure 6.5: Body fat (%) centiles of male at 2nd, 9th, 25th, 50th, 75th, 91st and 98th centiles – merged data

The merged centile charts for females from 4 to 21 yrs age (Fig 6.6) reflected gender related difference in BF%. At 50th centile (Table 6.6), the BF% was seen to be steadily increasing from 4y onwards, while in male it starts decreasing after age 11.5y. The minimum mean BF% of 19.8% was seen in 4.5y age group and maximum mean BF% of 30.6% was seen in 21y age group. In female this increasing trend was same for almost all centiles except 0.4th and 2nd centile where the BF% decreased after initial few years.

Table 6.6: centiles of BF% by age and sex (female) – merged data

	0.4th	**2nd**	**9th**	**25th**	**50th**	**75th**	**91st**	**95th**	**98th**
Year	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
4.5	15.0	15.9	17.0	18.3	**19.8**	21.8	24.4	28.0	33.6
5.0	15.0	16.0	17.1	18.5	**20.2**	22.3	25.1	29.1	35.3
5.5	15.0	16.0	17.2	18.7	**20.5**	22.8	25.9	30.2	37.0
6.0	15.0	16.0	17.3	18.9	**20.8**	23.3	26.6	31.3	38.6
6.5	14.9	16.0	17.4	19.0	**21.1**	23.7	27.3	32.3	40.1
7.0	14.8	16.0	17.4	19.2	**21.4**	24.2	27.9	33.3	41.5
7.5	14.7	16.0	17.5	19.3	**21.6**	24.6	28.5	34.1	42.7
8.0	14.6	15.9	17.5	19.4	**21.8**	25.0	29.1	34.9	43.6
8.5	14.4	15.8	17.5	19.5	**22.1**	25.3	29.7	35.6	44.4
9.0	14.2	15.7	17.5	19.6	**22.3**	25.7	30.2	36.3	45.0
9.5	14.1	15.6	17.5	19.7	**22.5**	26.1	30.7	36.8	45.4
10.0	13.9	15.5	17.5	19.9	**22.8**	26.5	31.2	37.4	45.8
10.5	13.8	15.5	17.6	20.1	**23.2**	27.0	31.8	38.0	46.2
11.0	13.6	15.5	17.7	20.4	**23.6**	27.6	32.5	38.7	46.5
11.5	13.5	15.5	17.9	20.7	**24.1**	28.2	33.2	39.3	46.9
12.0	13.4	15.5	18.0	21.0	**24.6**	28.8	33.8	39.9	47.2
12.5	13.2	15.5	18.2	21.3	**25.0**	29.4	34.5	40.4	47.5
13.0	13.0	15.4	18.3	21.6	**25.5**	29.9	35.0	40.9	47.6
13.5	12.7	15.4	18.4	21.9	**25.9**	30.4	35.5	41.3	47.8
14.0	12.4	15.3	18.5	22.2	**26.3**	30.9	36.0	41.7	47.9
14.5	12.1	15.1	18.6	22.4	**26.7**	31.4	36.5	42.1	48.1
15.0	11.7	15.0	18.6	22.7	**27.0**	31.8	36.9	42.4	48.2
15.5	11.3	14.8	18.7	22.9	**27.4**	32.2	37.3	42.7	48.4
16.0	10.9	14.7	18.7	23.1	**27.7**	32.6	37.7	43.0	48.6
16.5	10.5	14.5	18.8	23.3	**28.1**	33.0	38.1	43.3	48.7
17.0	10.1	14.4	18.9	23.5	**28.4**	33.3	38.4	43.6	48.9
17.5	9.7	14.2	18.9	23.7	**28.7**	33.7	38.8	43.9	49.1
18.0	9.2	14.1	19.0	24.0	**29.0**	34.0	39.1	44.2	49.4
18.5	8.7	13.9	19.0	24.2	**29.3**	34.4	39.4	44.5	49.6
19.0	8.2	13.7	19.1	24.4	**29.6**	34.7	39.8	44.8	49.8
19.5	7.6	13.5	19.1	24.6	**29.8**	35.0	40.1	45.1	50.0
20.0	6.9	13.3	19.2	24.7	**30.1**	35.3	40.4	45.4	50.2
20.5	6.1	13.0	19.2	24.9	**30.4**	35.6	40.7	45.6	50.4
21.0	5.1	12.7	19.2	25.1	**30.6**	35.9	41.0	45.9	50.6

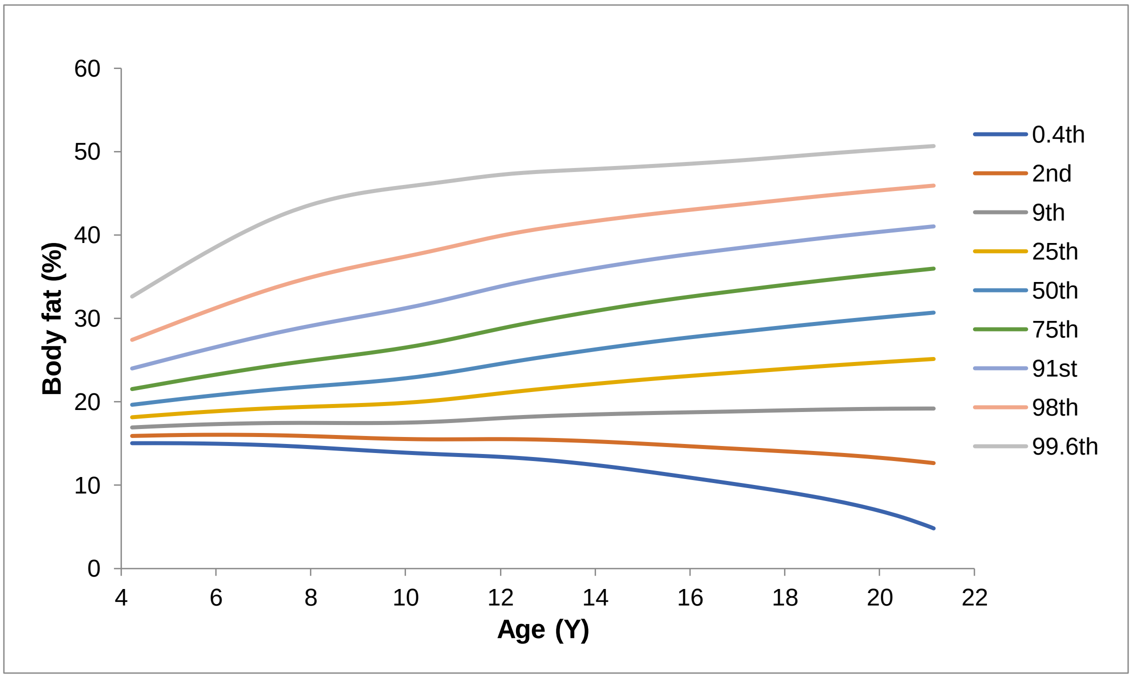


Figure 6.6: Body fat (%) centiles of females at 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles – merged data

6.4.2 Fat mass (kg)

Table 6.7 shows the descriptive statistics of fat mass (kg) with age and gender distribution in studied population (16-21yrs South Asians). Higher fat mass was observed in females (in all age groups) compared to males (in all age groups). Highest mean fat mass (20.1 kg) was observed in females of 20y age group followed by 18.7 kg (in 21y age group), 17.6 Kg (in 19y age group), 16.7 kg (in 18y age group), respectively. Among males, highest fat mass (14.2 kg) was observed in 17y age group while lowest fat mass (10.9 Kg) was observed in 20y age group.

As there is no reference data (UK 1990) available for fat mass, Z score could not be calculated.

Table 6.7: Descriptive statistics of fat mass (kg) with age and gender distribution

Descriptive statistics of fat mass (kg) with age and gender distribution												
	16 years		17 years		18 years		19 years		20 years		21 years	
	M (n=114)	F (n=71)	M (n=52)	F (n=37)	M (n=35)	F (n=26)	M (n=24)	F (n=25)	M (n=25)	F (n=20)	M (n=50)	F (n=66)
Mean	12.4	16.5	14.2	16.3	12.8	16.7	14.1	17.6	10.9	20.1	10.9	18.7
Std Dev	5.96	6.96	7.34	6.72	5.85	7.97	8.88	6.76	5.98	7.99	6.52	7.62
Minimum	4.1	4.0	5.01	3.8	5.0	7.1	3.7	8.8	1.5	9.9	1.3	3.8
Maximum	30.7	37.8	40.4	32.4	33.5	44.4	42.7	38.2	22.7	38.2	26.9	44.4

6.4.2.1 Scatter plots

The scatterplots for fat mass (plotted against age) for both genders (Fig 6.7 & 6.8) suggest that there is no particular data trend was seen. In the scatter plot for male participants, most observations fell in the closed range with one or two values (42.7 Kg and 40.4 Kg) at higher side and few observations (such as 1.4 Kg, 1.9 Kg) fell at lower side. Likewise, the observations of FM for females were evenly dispersed within the acceptable range at all age groups with the exception of few values on the slightly higher side but no outliers as such. There is no age dependent trend seen in the FM in both genders.

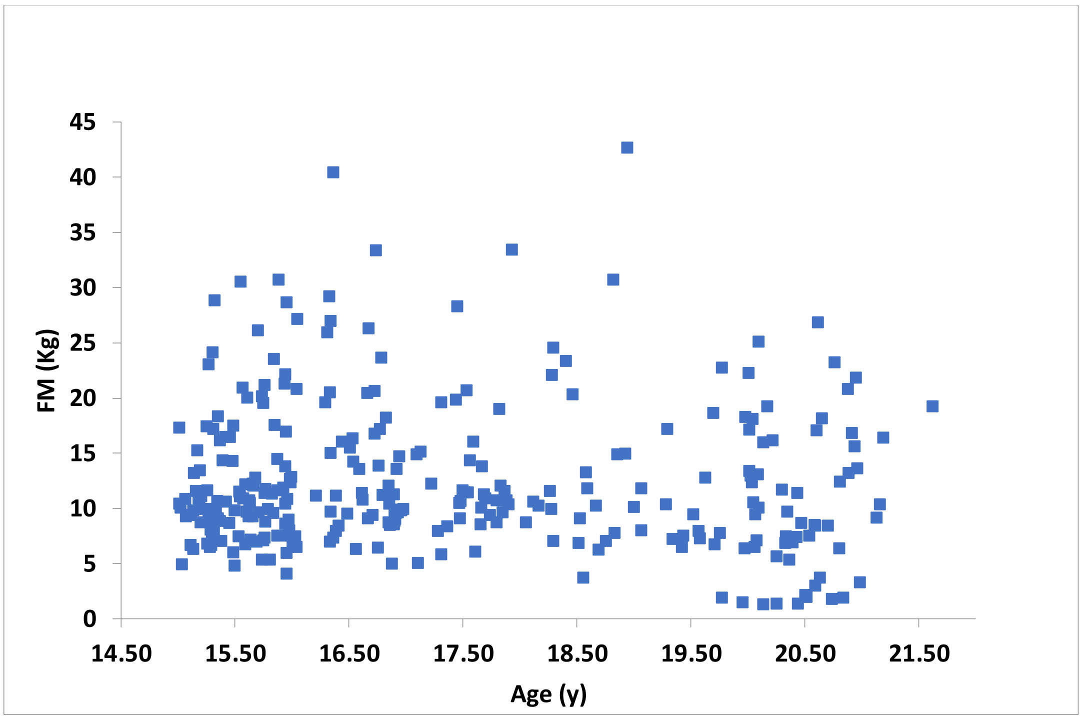


Figure 6.7: Scatterplot showing the distribution of the male body fat (kg) against age

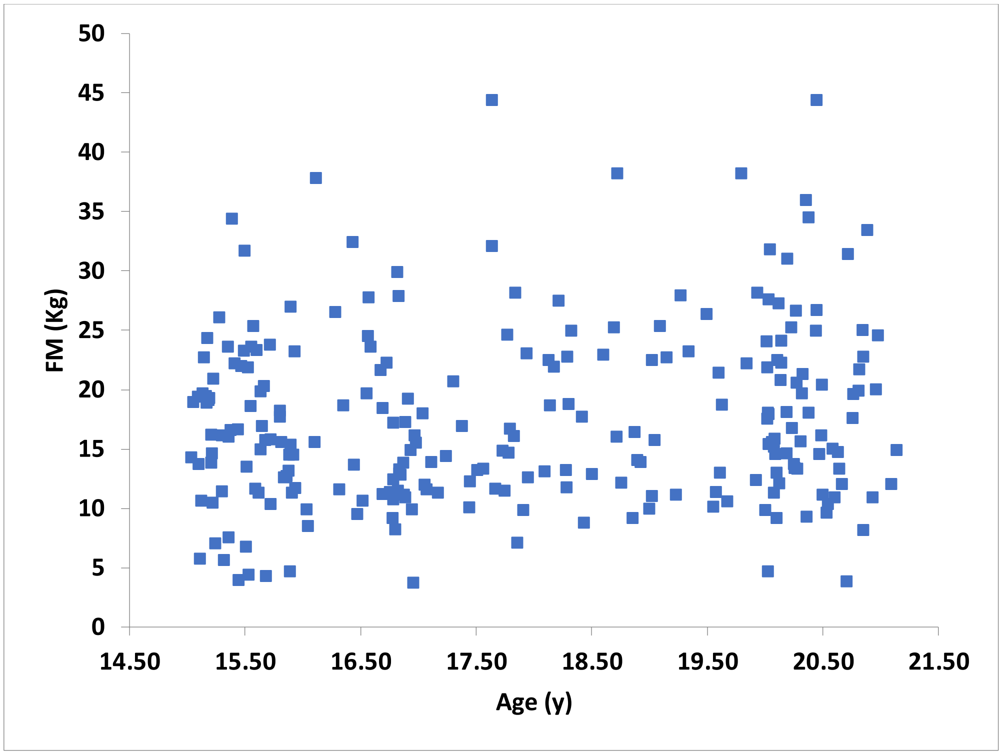


Figure 6.8: Scatterplot showing the distribution of the female body fat (kg) against age

6.4.2.3 Centile charts

Figure 6.9 shows the data analysed at different centile points for male participants for fat mass. As seen in the centile charts for body fat percentage, the fat mass did not seen to be dependent on age as no age-related increase in fat mass was seen consistently throughout the studied age group at all centile, though a minimal increase in the fat mass was seen from 15y to 17y but then the fat mass was found to be decreasing in subsequent age groups.

At 50th centile (Table 6.8) minimum mean fat mass of 9.9 kg was noted in 20y age group and maximum mean fat mass of 11.9 kg was seen in 16 and 17 yrs age group, reflecting that fat mass is independent of age in the studied age group.

Table 6.8: Centiles of FM by age and sex (male)

	2nd	9th	25th	50th	75th	91st	98th
Year	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0
15.0	5.1	6.3	7.9	**10.1**	13.4	18.3	26.1
15.5	5.3	6.6	8.3	**10.9**	14.5	20.1	29.2
16.0	5.4	6.8	8.7	**11.5**	15.5	21.8	31.9
16.5	5.5	7.0	9.0	**11.9**	16.2	22.8	33.5
17.0	5.4	6.9	8.9	**11.9**	16.3	22.9	33.6
17.5	5.1	6.7	8.8	**11.8**	16.3	23.0	33.5
18.0	4.8	6.4	8.6	**11.7**	16.2	23.0	33.3
18.5	4.2	5.9	8.1	**11.4**	16.0	22.8	32.6
19.0	3.5	5.2	7.6	**10.9**	15.6	22.1	31.1
19.5	2.7	4.4	6.9	**10.4**	15.0	21.2	29.1
20.0	1.8	3.7	6.4	**10.0**	14.7	20.5	27.5
20.5	0.9	3.0	6.0	**9.9**	14.7	20.3	26.7

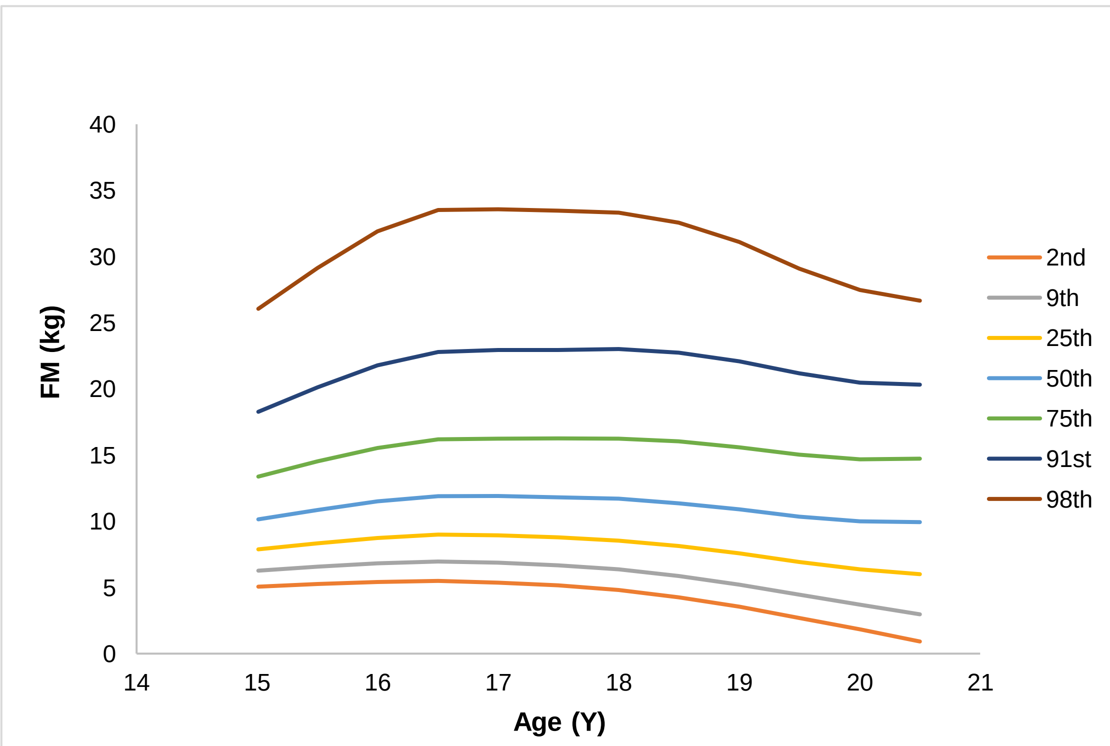


Figure 6.9: Fat mass (kg) centiles of males at 2nd, 9th, 25th, 50th, 75th, 91st, and 98th centiles

Figure 6.10 shows the centile curves constructed for different centile points for female population for fat mass. At 50th centile a moderate age-related increase in fat mass was seen in female between 18 to 21y. (Table 6.9) though there was a small wavering seen in FM at different age groups with maximum fat mass of 17.8 kg seen at 20.5y age group. At 95th and 98th centiles, maximum fat mass was seen at 19y age group followed by slight downward trend showing gradual decease in FM in subsequent age groups.

Table 6.9: Centiles of FM (kg) by age and sex (female)

	0.4th	**2nd**	**9th**	**25th**	**50th**	**75th**	**91st**	**98th**	**99.6th**
Age	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
15.0	0.4	3.6	7.5	11.7	**16.1**	20.8	25.7	30.7	35.8
15.5	2.0	4.6	7.9	11.8	**16.1**	20.9	26.0	31.6	37.5
16.0	3.2	5.4	8.2	11.7	**15.8**	20.6	26.1	32.2	39.0
16.5	4.0	5.9	8.4	11.6	**15.5**	20.2	25.8	32.5	40.3
17.0	4.5	6.2	8.5	11.4	**15.1**	19.7	25.5	32.6	41.3
17.5	5.0	6.7	8.9	11.8	**15.5**	20.2	26.3	34.1	43.9
18.0	5.4	7.2	9.4	12.4	**16.2**	21.2	27.6	36.0	46.8
18.5	5.6	7.4	9.8	12.8	**16.8**	21.9	28.6	37.2	48.3
19.0	5.6	7.5	9.9	13.1	**17.2**	22.4	29.1	37.7	48.6
19.5	5.3	7.3	9.9	13.3	**17.5**	22.9	29.6	38.0	48.3
20.0	4.9	7.0	9.8	13.3	**17.8**	23.3	29.9	38.0	47.6
20.5	4.3	6.5	9.5	13.2	**17.8**	23.3	29.8	37.5	46.3
21.0	3.5	5.9	9.0	12.9	**17.6**	23.0	29.3	36.4	44.4

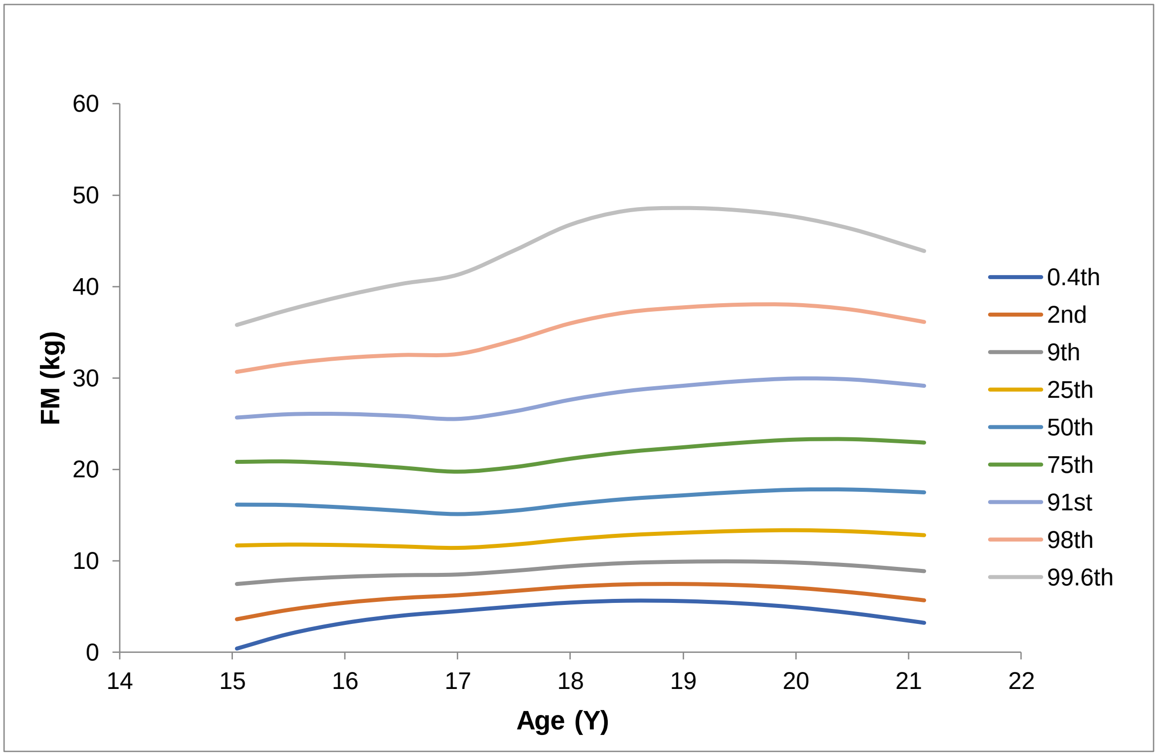


Figure 6.10: represents the fat mass (kg) centiles of girls at 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles

6.4.2.4 Merged centile curve

Merged centile curves were constructed for fat mass for both genders after combining the data collected from this study with the data collected by previous researcher for South Asian ethnic group to generate the full set of growth charts for the age range from 4 to 21 yrs. The centile charts for fat mass (kg) for male (Fig 6.11) showed an age-related increase in absolute fat mass from 4y onward until the age of 18.5y. when the maximum fat mass was achieved after which not much change in fat mass was seen at all centile cut offs and this was typically seen at 50th centile (Table 6.10). At 50th centile, minimum fat mass of 2.9 kg was seen at 4y age group and maximum mean fat mass of 11.6 kg was seen at 18.5y age group with no further increase in fat mass in subsequent age groups.

Table 6.10: Merged Centiles of FM (kg) by age and sex (male)

	2nd	**9th**	**25th**	**50th**	**75th**	**91st**	**98th**
Year	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0
4.5	1.9	2.2	2.5	**2.9**	3.5	4.4	5.7
5.0	2.0	2.3	2.7	**3.1**	3.8	4.8	6.5
5.5	2.1	2.4	2.8	**3.3**	4.1	5.3	7.4
6.0	2.1	2.5	2.9	**3.6**	4.4	5.9	8.3
6.5	2.2	2.6	3.1	**3.8**	4.8	6.5	9.5
7.0	2.3	2.7	3.3	**4.0**	5.2	7.1	10.8
7.5	2.4	2.8	3.5	**4.3**	5.7	7.9	12.3
8.0	2.5	3.0	3.7	**4.6**	6.2	8.8	13.9
8.5	2.6	3.2	3.9	**5.0**	6.7	9.7	15.7
9.0	2.8	3.3	4.2	**5.4**	7.3	10.7	17.7
9.5	2.9	3.5	4.4	**5.8**	7.9	11.7	19.7
10.0	3.0	3.7	4.7	**6.2**	8.6	12.8	21.6
10.5	3.2	3.9	5.0	**6.6**	9.2	13.8	23.5
11.0	3.3	4.1	5.3	**7.1**	9.9	14.9	25.2
11.5	3.5	4.4	5.6	**7.5**	10.5	15.9	26.8
12.0	3.6	4.6	5.9	**7.9**	11.2	16.9	28.2
12.5	3.8	4.8	6.2	**8.4**	11.8	17.8	29.4
13.0	3.9	5.0	6.5	**8.8**	12.5	18.7	30.4
13.5	4.0	5.1	6.8	**9.2**	13.1	19.5	31.3
14.0	4.1	5.3	7.1	**9.6**	13.6	20.2	31.9
14.5	4.2	5.5	7.3	**10.0**	14.2	20.9	32.4
15.0	4.2	5.6	7.5	**10.4**	14.7	21.5	32.7
15.5	4.3	5.7	7.7	**10.7**	15.1	21.9	32.8
16.0	4.2	5.7	7.9	**11.0**	15.5	22.3	32.7
16.5	4.2	5.7	8.0	**11.2**	15.8	22.5	32.5
17.0	4.1	5.7	8.0	**11.3**	16.0	22.7	32.2
17.5	3.9	5.6	8.1	**11.5**	16.2	22.7	31.7
18.0	3.7	5.5	8.0	**11.5**	16.3	22.7	31.1
18.5	3.4	5.3	8.0	**11.6**	16.4	22.6	30.5
19.0	3.1	5.1	7.9	**11.6**	16.4	22.4	29.9
19.5	2.8	4.9	7.8	**11.6**	16.4	22.3	29.3
20.0	2.4	4.7	7.7	**11.6**	16.4	22.1	28.6
20.5	2.0	4.4	7.6	**11.6**	16.4	21.9	28.0
21.0	1.5	4.1	7.5	**11.6**	16.4	21.7	27.5
21.5	0.9	3.7	7.4	**11.6**	16.3	21.5	27.0

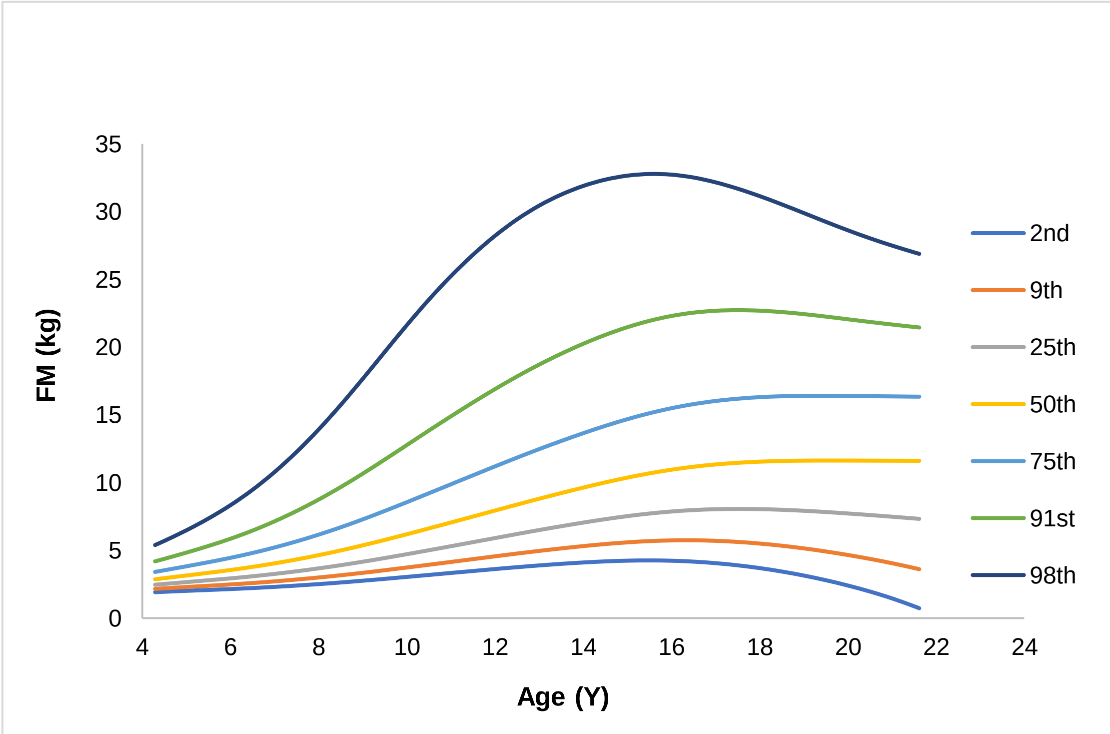


Figure 6.11: Fat mass (kg) centiles of male at 2nd, 9th, 25th, 50th, 75th, 91st and 98th centiles – merged data

The combined data (this study and data collected by previous researcher on the 4-15 yrs age group on the same ethnic group) was analysed for fat mass at the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centile points for female (Fig 6.12). The age-related increase in fat mass was evidently seen from the age of 5 to 21 yrs in all centiles in female. At 50th centile minimum mean fat mass of 2.7 kg was seen at 4y age group and maximum fat mass of 18.8 kg was seen at 21y age group (Table 6.11).

Table 6.11: Merged Centiles of FM (kg) by age and sex (female)

	0.4th	2nd	9th	25th	50th	75th	91st	98th	99.6th
Age	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
4.2	1.6	1.8	2.0	2.3	**2.7**	3.3	4.1	5.6	8.4
4.5	1.7	1.9	2.1	2.5	**2.9**	3.5	4.5	6.1	9.3
5.0	1.8	2.1	2.4	2.7	**3.3**	4.0	5.1	7.1	11.1
5.5	2.0	2.2	2.6	3.0	**3.6**	4.5	5.8	8.1	13.0
6.0	2.1	2.4	2.8	3.3	**4.0**	5.0	6.5	9.2	14.8
6.5	2.2	2.5	2.9	3.5	**4.3**	5.4	7.2	10.4	16.8
7.0	2.3	2.7	3.1	3.8	**4.7**	6.0	8.0	11.5	18.7
7.5	2.4	2.8	3.3	4.0	**5.0**	6.5	8.8	12.7	20.5
8.0	2.5	2.9	3.5	4.3	**5.4**	7.0	9.6	13.9	22.3
8.5	2.5	3.0	3.7	4.6	**5.8**	7.6	10.5	15.2	24.0
9.0	2.6	3.2	3.9	4.9	**6.3**	8.3	11.4	16.5	25.7
9.5	2.7	3.3	4.1	5.2	**6.8**	9.0	12.4	17.9	27.5
10.0	2.8	3.5	4.4	5.6	**7.3**	9.8	13.5	19.4	29.2
10.5	3.0	3.7	4.7	6.0	**7.9**	10.6	14.7	21.0	31.1
11.0	3.1	3.9	5.0	6.5	**8.6**	11.6	16.0	22.6	32.9
11.5	3.2	4.1	5.3	7.0	**9.3**	12.6	17.3	24.3	34.8
12.0	3.3	4.3	5.7	7.5	**10.0**	13.6	18.6	25.9	36.5
12.5	3.4	4.5	6.0	8.0	**10.7**	14.5	19.8	27.3	37.9
13.0	3.5	4.7	6.3	8.5	**11.4**	15.4	21.0	28.6	39.1
13.5	3.6	4.8	6.6	8.9	**12.1**	16.3	22.0	29.8	40.2
14.0	3.6	5.0	6.8	9.3	**12.7**	17.1	23.0	30.8	41.1
14.5	3.6	5.1	7.1	9.7	**13.2**	17.9	23.9	31.8	41.9
15.0	3.7	5.2	7.3	10.1	**13.8**	18.6	24.7	32.6	42.6
15.5	3.7	5.3	7.6	10.5	**14.3**	19.2	25.5	33.4	43.2
16.0	3.7	5.4	7.8	10.8	**14.8**	19.9	26.2	34.1	43.7
16.5	3.7	5.5	8.0	11.2	**15.3**	20.4	26.8	34.7	44.2
17.0	3.7	5.6	8.2	11.5	**15.7**	21.0	27.4	35.2	44.6
17.5	3.7	5.7	8.4	11.8	**16.1**	21.5	28.0	35.8	45.0
18.0	3.8	5.8	8.6	12.1	**16.5**	22.0	28.5	36.2	45.3
18.5	3.8	5.9	8.8	12.4	**16.9**	22.4	29.0	36.7	45.7
19.0	3.8	6.0	9.0	12.7	**17.3**	22.9	29.4	37.1	45.9
19.5	3.8	6.1	9.1	13.0	**17.7**	23.3	29.9	37.5	46.2
20.0	3.7	6.2	9.3	13.3	**18.1**	23.7	30.3	37.9	46.5
20.5	3.7	6.2	9.5	13.6	**18.4**	24.1	30.8	38.3	46.7
21.0	3.7	6.3	9.7	13.8	**18.8**	24.6	31.2	38.6	47.0

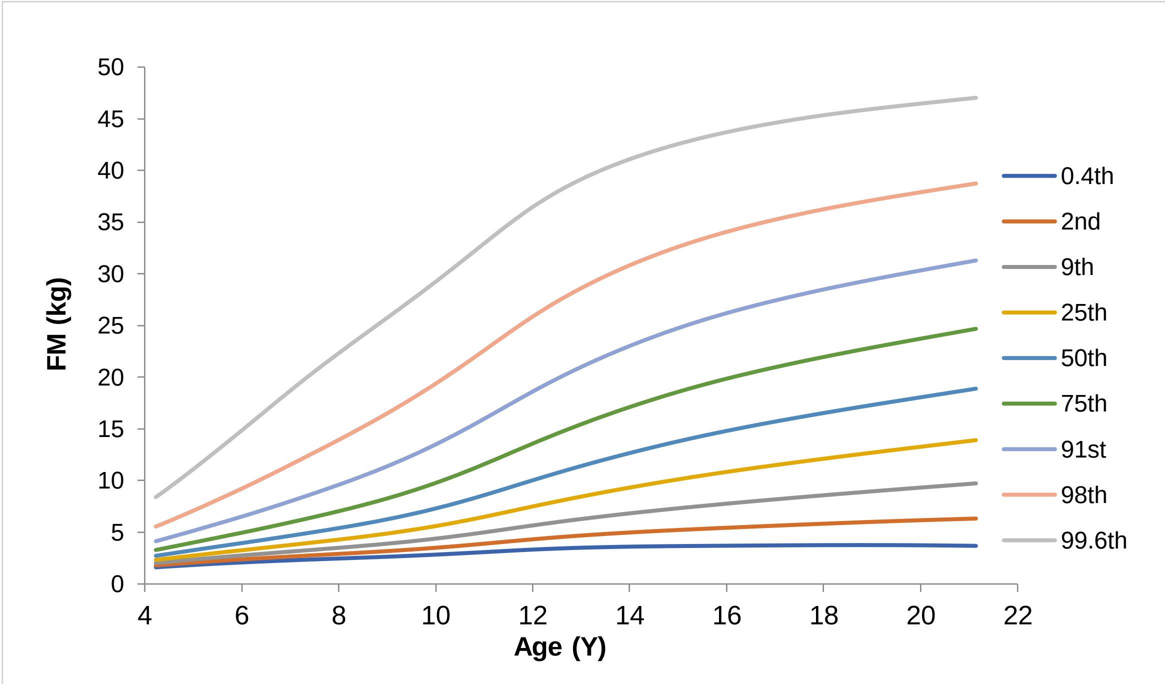


Figure 6.12: Fat mass (kg) centiles of female at 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles – merged data

6.5 Discussion

The centile charts for BF% and FM (kg) have been developed for different ethnic populations and regions, for example, Germany, Sri Lanka, Turkish, Asian Indian (Kurtoglu et al. 2010, Plachta-Danielzik et al. 2012, Ranasinghe et al. 2013, Chiplonkar et al. 2017). Even though there has always been a need to produce reference Centiles for children, adolescents and young adults for the South Asian ethnic group, to date the development of reference centiles at meaningful sample size hasn't been successful and no study has reported the reference data for South Asian in UK. To the best of our knowledge, this is the first study to develop a set of centile curves for the SA population in the age range of 4y to 21y living in UK and described the BF% and FM (kg) at each age.

One of the main advantages of body fat charts over BMI charts is the reduction in the risk of misclassification of children who can otherwise be categorized as healthy by the BMI despite having excess body fat or the other way around. Though ethnic-specific adjustments are usually performed in BMI to increase the precision of BF assessment to some extent in a particular population, still BMI underestimates BF% in South Asians. Those children who have high FM and low SMM but a BMI within the healthy range could potentially signal the early origins of sarcopenic obesity and metabolic disease (McCarthy et al. 2014, Hudda et al. 2018). BF% centile curves presented by McCarthy et al. (2006) is used as an alternative or addition to using BMI curves. The main advantage of these new curves is to assess excess adipose tissue, which is associated with comorbidities (Fortuño et al. 2003).

As the body fat is expected to rise until puberty in healthy individuals, trailing an early decrease in body fat during infancy, not seen in these data since they start only at age of 4.5 years, is very important as it helps detecting the health status, malnutrition and other issues. Our study with the combined age range of 4-21 years reflected the steady increase in the BF% in both genders and this finding is supported by many studies in the past. McCarthy et al. (2006) observed an increase of BF% in boys similar to what is seen in our study. Our study also showed that BF% in girls increases steadily from 4 to 18 years of age, which is in accordance with the study conducted in German and Chinese children and adolescents (Sung et al. 2001, Schwandt et al. 2012). Furthermore, the absolute differences in BF% in Caucasian boys and girls observed in our study, has been reported in many studies on the SA population. This sex-specific difference is due to changes in sex hormones which affect body composition during adolescence. In puberty, due to sex hormones boys gained proportionately more muscle and lean mass than fat mass, while in contrast girls have an increase of body fat mass (Demerath et al. 2006, McCarthy et al. 2006).

The estimation of %BF in the BIA system is based on regression equations (undisclosed by manufacturers) that include height, body weight, gender, age and the whole-body impedance. Montagnese et al. (2013) concluded that a single equation is not valid to determine FFM across the whole child and adolescent age range 4-24 years as at different pubertal stages the rise and diversion of the regression between Ht^2/Z and FFM changes (Montagnese et al. 2013). Shah (2015) confirmed that the registered inbuilt equation underestimates %FM for the SA population. Viner et al. (2010) has been recommended that due to the differences in body composition between SA and WE children, it is important to ensure that ethnic-specific equations or charts are used due to the potential metabolic risks associated with these body composition differences (Viner et al. 2010).

The centile curves for BF% and FM (kg) for lower centiles (0.4th and 2nd centiles) showed downward trend at the upper extreme age groups in our study i.e. 20- and 21-years age group. This most likely is due to the reduced numbers of participant in these age group, particularly in 20 yr age group where the participants were less in both genders. As this trend was more prominently seen in males, it can be due to the fact at that age group, males may become more conscious about their health and body weight and try to adopt a healthier lifestyle by either eating healthy or increasing their physical activity or both. As our study recruited more Sikh (sub-ethnic group within Indian region), they generally tend to have taller and high muscle mass (lean mass) compared to South Indians / Pakistanis (NOO, 2011).

6.6 Limitations

The data collection focused in the areas around London where the population generally tends to be higher Socioeconomic status, so this could have introduced bias in our data.

As with the other parameter, the BF% and FM (kg) charts would not be appropriate for use with other Asian populations such as Chinese.

It has been shown in many studies on SA populations that compared to DXA, BIA underestimates BF% by a mean of 2.23% and 2.93% in boys and girls respectively (Haroun et al. 2010, Sluyter et al. 2010), hence those studies while using BIA, used the in-built patented equations to make an adjustment in BF%. A previous student in this group constructed a predictive equation for the SA population for the age range of 9-14 years. However, applying this equation to the studied population generated unsuitable results so that we did not use that equation in our study. This could be due to the fact that the equation required further age specific adjustments, but this was beyond the scope of this thesis.

CHAPTER 7. Fat free mass and Skeletal muscle mass

7.1 Introduction

Various methods of body composition measurement have been developed over time (Keys et al. 1972). Several aspects of body composition, predominantly the distribution and total amount of body fat and the composition and amount of lean mass, are now believed to be important health parameters in infants and children (Heymsfield et al. 2016). A number of findings (Müller and Geisler 2017, Bhaskaran et al. 2018) have estimated relationships between body composition parameters and age in healthy subjects.

Though BIA is less accurate in measuring the FM and FFM than more sophisticated laboratory techniques such as DXA and ADP, it has advantages for being convenient in use, rapid, non-invasive and cost-effective with a good degree of precision (Ogden 2002, Luttikhuis et al. 2009). The lower but acceptable level of accuracy is balanced by the other qualities of this method. One important limitation however is the lack of ethnic-specific predictive equations in several BIA systems. This is seen as a drawback due to known variations in the hydration of the fat-free mass between ethnicities. Nightingale et al. (2013) conducted a study designed to assess the body composition with a purpose to determine whether equations for FFM need to be ethnic and gender specific for use in South Asian children. This study revealed the impact of ethnic and gender specific equations on the estimation of FFM. Previous studies have shown that there are several factors including age, physical activity, pubertal status, gender and ethnicity which are responsible for variations in FM and FFM composition (Deurenberg et al. 2002, Heyward and Wagner 2004, Saxena et al. 2004, Ehtisham et al. 2005, Irwin et al. 2005, Helba and Binkovitz 2009, Dulloo et al. 2010). Specifically, as indicated above, the hydration of the FFM is critically dependent on the above variables and since BIA relies on the prediction of the water content of the FFM to determine body composition, it is essential that predictive equations take this variable into account.

In relation to health status, a key component of the FFM is skeletal muscle, which in itself is an important marker of metabolic health. There is a strong relationship between a low SMM and high FM and metabolic risks. SMM is related to insulin sensitivity in both children and adults and is therefore a major tissue for glucose homeostasis. Moreover, sarcopenia and sarcopenic obesity are strongly linked to an increased risk for the metabolic syndrome (Stenholm et al. 2008, McCarthy et al. 2014). In addition, studies in young adults have revealed that the size of thigh circumference (most likely reflecting thigh muscle cross-sectional area and hence mass) has a strong association with the development of cardiovascular morbidity and early mortality (Heitmann and Frederiksen 2009). However, normative data which characterises the status of SMM across the age spectrum is not available in the South Asian population thus ultimately causing constraints in SMM measurement in surveillance (Pietrobelli et al. 2003). To date, SMM assessment does not yet have a prominent role in clinical settings or for longitudinal and cross-sectional surveillance of populations. At present, the evaluation of whole-body SMM is determined by MRI, dual energy X-ray absorptiometry (DXA), K_+ counting or biochemical assessment of 24 h creatinine excretion (Shen et al. 2004, Kim et al. 2006, Wang et al. 2007). All these methods are expensive, invasive, time consuming and complex to perform. Moreover, as FFM and SMM increase during growth across childhood and adolescence, (McCarthy et al. 2006). This demands the use of age and gender-related centile charts with different cut-off values for boys and girls at different ages to define low FFM or SMM. Bioelectrical impedance (BIA) has the potential to differentiate between fat mass (FM) and FFM based on their differential electrical conductance and impedance characteristics (Khalil et al. 2014, Mialich et al. 2014). Segmental analysers determine the measurement of FM and FFM separately for the trunk and limbs. The FFM in the limbs is further differentiated into bone and SMM, the latter described as appendicular skeletal muscle mass (SMM) (McCarthy et al. 2014). McCarthy et al. (2014) have developed a range of reference centile curves for both FFM and SMM from BIA for Caucasian children aged 4-18 years in the

UK. The findings of the study showed that these centile curves may have an application to assess children's SMM in clinical and epidemiological settings and can also identify the individuals with low SMM and hence at potential risk for sarcopenia and metabolic disease in later life.

7.2 Aim

Given the lack of equivalent charts for the South Asian child population, the aim of this study was to fulfil the demand of centile curves of SMM and FFM with different cut-off values for young adults from South Asian background living in UK.

7.3 Methodology

The FFM and SMM were also measured by Tanita using BIA method and described in the chapter 2 section 2.7 in detail.

7.4 Results

7.4.1 FFM

Table 7.1 presents the descriptive statistics of FFM. Females generally had lower FFM compared to males at equivalent ages across the age range. A steady and modest rise in FFM was seen in males with increasing age; the minimum mean FFM (50.4 kg) was seen in the 16y age group while the maximum mean FFM (58.9 kg) was seen in 21 yrs age group. A consistent increase in FFM with increasing age was not observed in the females - a minimum mean FFM of 39.0 kg was seen at age 19y, with a maximum mean of 41.5 kg at age 21y.

Table 7.1 Descriptive statistics (mean ± SD) of FFM (kg) for SA groups by age range and gender distribution

Descriptive statistics of FFM (kg) with age and gender distribution												
	16 years		17 years		18 years		19 years		20 years		21 years	
	M (n=114)	F (n=71)	M (n=52)	F (n=37)	M (n=35)	F (n=26)	M (n=24)	F (n=25)	M (n=25)	F (n=20)	M (n=50)	F (n=66)
Mean	50.4	39.7	54.7	40.1	54.1	39.9	56.6	39.1	58.8	41.0	58.9	41.5
Std Dev	6.74	4.06	8.24	4.15	7.24	4.52	7.06	3.67	5.14	4.05	7.62	4.30
Minimum	32.3	30.8	40.0	29.2	39.9	33.3	44.5	32.4	48.4	35.4	44.9	31.6
Maximum	66.8	48.5	82.9	50.9	73.8	55.2	73.5	49.6	68.6	46.8	77.7	53.9

7.4.1.1 Scatter plots

The scatterplots (Fig 7.1 & 7.2) for FFM vs age in both genders suggest that there is no obvious trend with respective to age, suggesting that most of FFM was already achieved by 16 years of age. As the number of participants in both genders were higher in the 16and 21 years age groups, the observations are more clustered around these age groups, however, no clear outliers were seen in observations of FFM among both genders.

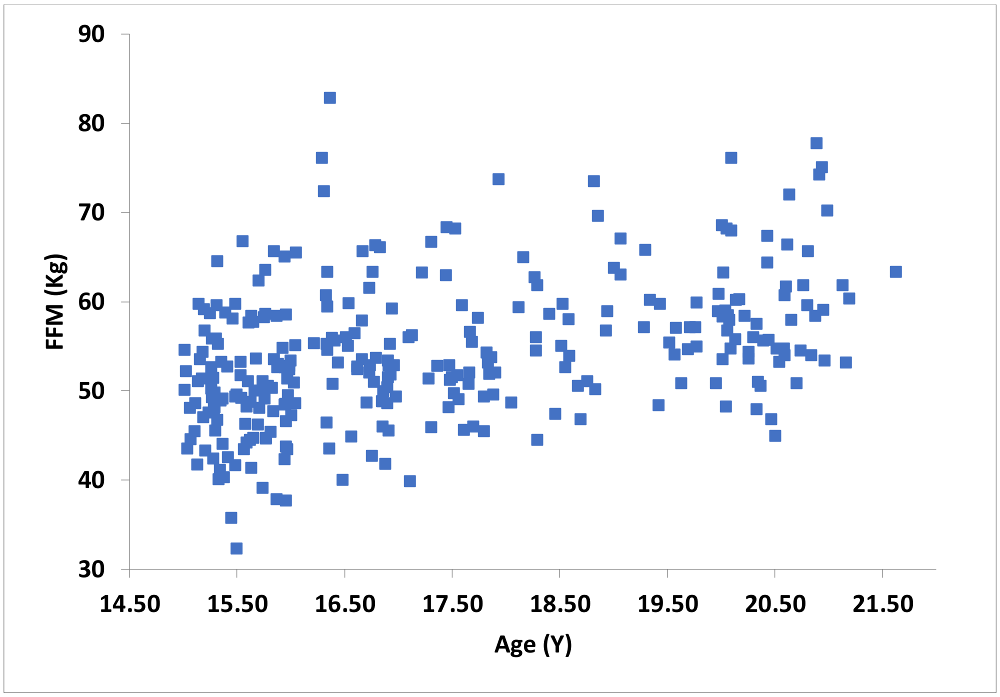


Figure 7.1: Scatterplot showing the distribution of FFM mass against age of male study participants

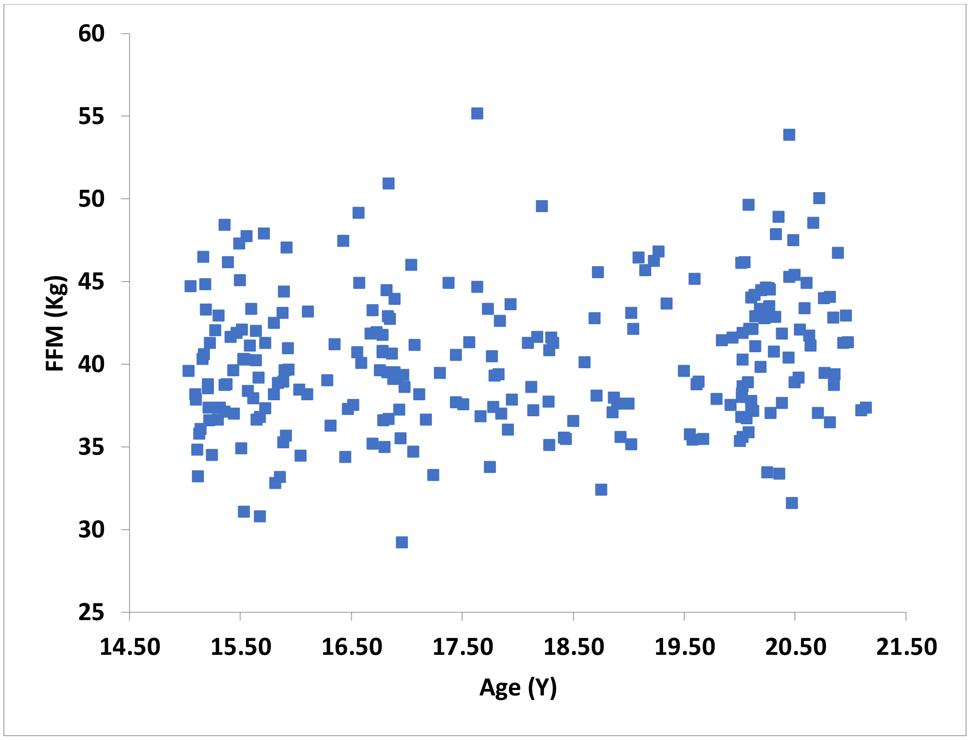


Figure 7.2: Scatterplot showing the distribution of FFM against age of female study participants

7.4.1.2 Centile Curve

The data for FFM was used to construct 9 centile points (0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles) for male participants across all age groups (Fig. 7.3). The resulting centiles showed a continuous and steady increase fat free mass in males from 15 years onwards. Table 7.2 shows that at 50th centile, the minimum fat free mass (49 kg) was observed in 15.0 years and maximum FFM (61.1 kg) was observed at the age of 21.5 years.

Table 7.2: Centiles of FFM (kg) by age and sex (male)

Age	0.4th	2nd	9th	25th	50th	75th	91st	98th	99.6th
	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
15.0	31.3	35.6	40.1	44.5	**49.0**	53.6	58.2	62.8	67.5
15.5	33.7	37.5	41.5	45.7	**50.2**	55.0	60.0	65.3	70.9
16.0	36.1	39.4	43.0	47.1	**51.6**	56.5	62.0	68.1	74.9
16.5	38.0	41.0	44.4	48.2	**52.6**	57.7	63.6	70.4	78.5
17.0	39.2	42.0	45.2	48.8	**53.1**	58.2	64.2	71.4	80.4
17.5	40.2	42.9	45.9	49.5	**53.6**	58.6	64.6	72.0	81.5
18.0	41.3	43.9	46.9	50.3	**54.4**	59.3	65.2	72.7	82.2
18.5	42.4	45.0	47.9	51.4	**55.4**	60.2	66.0	73.3	82.7
19.0	43.4	45.9	48.9	52.3	**56.3**	61.1	66.8	74.0	83.0
19.5	44.0	46.6	49.5	52.9	**56.9**	61.6	67.3	74.2	83.0
20.0	44.4	47.0	50.0	53.4	**57.4**	62.1	67.8	74.6	83.2
20.5	44.9	47.6	50.7	54.1	**58.2**	63.0	68.6	75.5	84.1
21.0	46.0	48.7	51.8	55.4	**59.6**	64.5	70.3	77.3	86.1
21.5	47.1	49.9	53.2	56.8	**61.1**	66.1	72.1	79.3	88.2

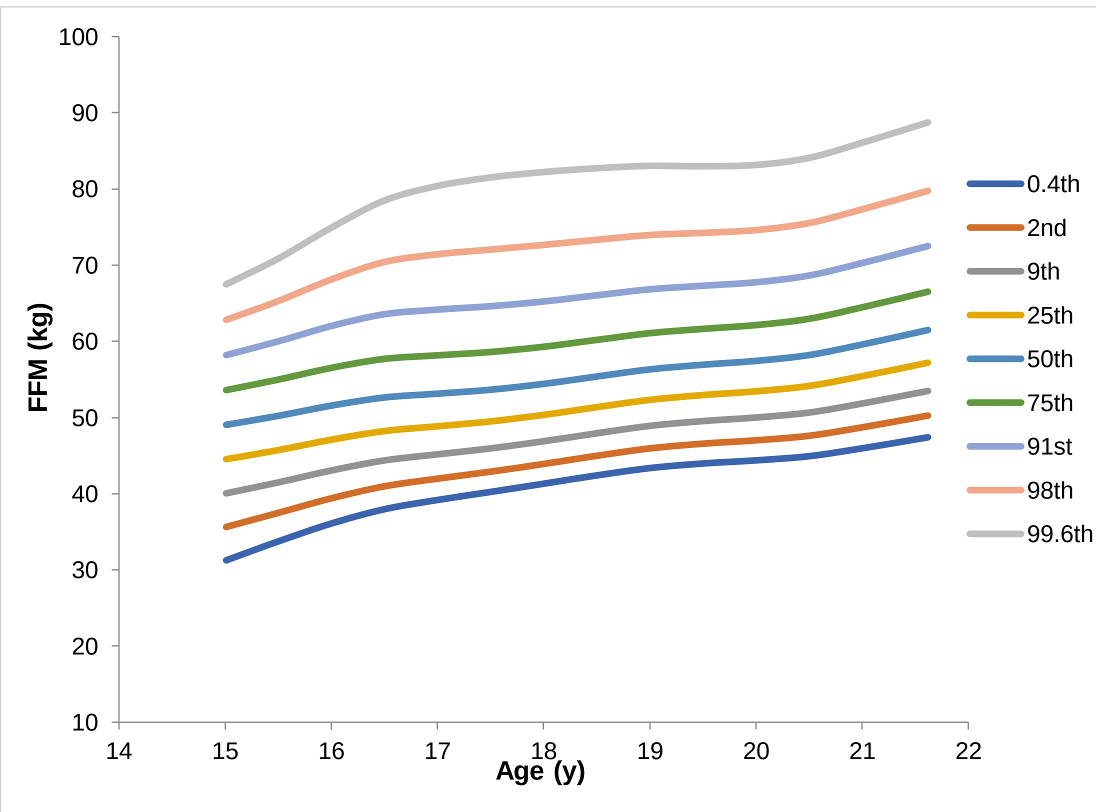


Figure 7.3: Smoothed computed FFM percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for male

The equivalent centiles for female participants of all age groups are shown in figure 7.4. All centiles showed a modest increase with increasing age, although this increase was not as distinct as seen in male participants. Table 7.3 shows that amongst the female participants at the 50th centile, the minimum fat free mass (39.5 kg) was observed in 15.0 years and maximum fat free mass (41.8 kg) was observed at the age of 21years.

Table 7.3: Centiles of FFM (kg) by age and sex (female)

Age	0.4th	2nd	9th	25th	50th	75th	91st	98th	99.6th
	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
15.0	29.8	32.0	34.4	36.9	**39.5**	42.2	45.0	48.0	51.1
15.5	30.0	32.2	34.5	37.0	**39.6**	42.4	45.3	48.4	51.6
16.0	30.2	32.3	34.6	37.0	**39.6**	42.4	45.4	48.7	52.1
16.5	30.4	32.5	34.7	37.1	**39.7**	42.5	45.6	49.0	52.7
17.0	30.6	32.5	34.7	37.0	**39.6**	42.5	45.6	49.2	53.1
17.5	30.8	32.6	34.7	37.0	**39.5**	42.4	45.7	49.3	53.5
18.0	30.9	32.7	34.7	36.9	**39.5**	42.3	45.6	49.4	53.7
18.5	30.9	32.7	34.7	36.9	**39.4**	42.3	45.6	49.3	53.7
19.0	31.0	32.8	34.9	37.1	**39.7**	42.5	45.7	49.4	53.7
19.5	31.1	33.0	35.1	37.5	**40.0**	42.9	46.1	49.7	53.8
20.0	31.4	33.4	35.6	38.0	**40.6**	43.5	46.7	50.2	54.0
20.5	31.6	33.8	36.1	38.6	**41.3**	44.2	47.4	50.8	54.5
21.0	31.8	34.0	36.5	39.0	**41.8**	44.7	47.8	51.1	54.6

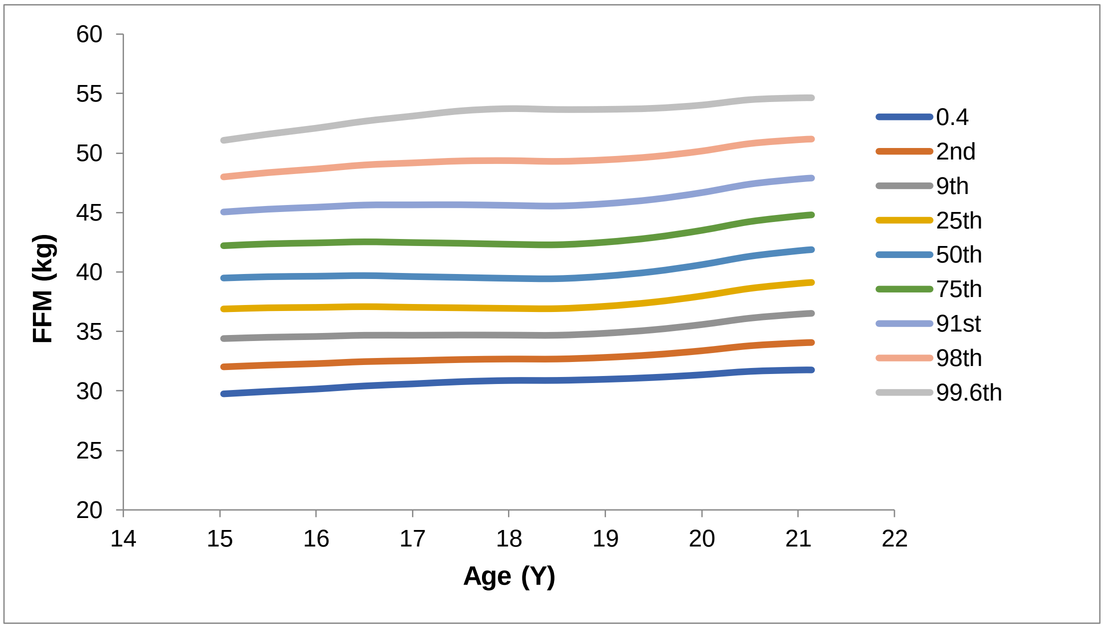


Figure 7.4: Smoothed computed FFM percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for female

7.4.1.3 Merged Centile curve

Merged centile curves were constructed after combing current data with the data collected by previous researcher on the same ethnic population are shown in figure 7.5. It was observed that FFM was increasing with age however, trend either plateaued or showed only a slight increase at the upper end of the age range i.e. from 18 years onwards. At the 50th centile (Table 7.4) below showing that, a minimum FFM (13.1 kg) was seen in youngest age group (4.5 yrs) while maximum FFM (61.7 kg) was seen in highest age group (21.5 yrs).

Table 7.4: Merged centiles of FFM (kg) by age and sex (male)

Age	0.4th	2nd	9th	25th	50th	75th	91st	98th	99.6th
	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
4.3	9.5	10.3	11.1	12.0	**13.1**	14.2	15.6	17.1	18.8
4.5	9.8	10.5	11.4	12.3	**13.4**	14.6	16.0	17.6	19.4
5.0	10.3	11.1	12.0	13.1	**14.2**	15.6	17.1	18.9	20.9
5.5	10.8	11.7	12.7	13.8	**15.1**	16.6	18.2	20.2	22.5
6.0	11.3	12.3	13.4	14.6	**16.0**	17.6	19.4	21.6	24.1
6.5	11.9	12.9	14.1	15.4	**16.9**	18.7	20.7	23.1	25.9
7.0	12.5	13.6	14.9	16.3	**18.0**	19.9	22.1	24.7	27.8
7.5	13.2	14.4	15.7	17.3	**19.1**	21.1	23.6	26.5	29.9
8.0	13.9	15.2	16.6	18.3	**20.2**	22.5	25.2	28.3	32.2
8.5	14.6	16.0	17.6	19.4	**21.5**	23.9	26.9	30.3	34.5
9.0	15.5	16.9	18.6	20.6	**22.8**	25.5	28.7	32.4	37.0
9.5	16.4	18.0	19.8	21.8	**24.3**	27.2	30.6	34.7	39.7
10.0	17.4	19.1	21.0	23.2	**25.8**	28.9	32.6	37.1	42.5
10.5	18.5	20.3	22.3	24.7	**27.5**	30.8	34.8	39.6	45.4
11.0	19.6	21.6	23.8	26.3	**29.3**	32.9	37.1	42.2	48.5
11.5	20.9	22.9	25.3	28.0	**31.2**	35.0	39.5	44.9	51.6
12.0	22.3	24.4	26.9	29.8	**33.2**	37.2	42.0	47.7	54.7
12.5	23.7	26.0	28.7	31.7	**35.3**	39.6	44.6	50.6	58.0
13.0	25.2	27.6	30.5	33.7	**37.5**	41.9	47.2	53.5	61.2
13.5	26.8	29.3	32.3	35.7	**39.7**	44.3	49.8	56.4	64.3
14.0	28.4	31.0	34.1	37.7	**41.8**	46.7	52.4	59.2	67.3
14.5	30.0	32.8	36.0	39.7	**43.9**	48.9	54.8	61.8	70.2
15.0	31.5	34.4	37.7	41.5	**45.9**	51.1	57.1	64.2	72.8
15.5	33.1	36.0	39.4	43.3	**47.8**	53.1	59.2	66.4	75.1
16.0	34.5	37.6	41.0	45.0	**49.5**	54.9	61.1	68.4	77.1
16.5	35.9	39.0	42.5	46.5	**51.1**	56.5	62.7	70.1	78.8
17.0	37.2	40.3	43.9	47.9	**52.5**	57.9	64.1	71.5	80.2
17.5	38.4	41.6	45.1	49.2	**53.8**	59.2	65.4	72.7	81.3
18.0	39.6	42.8	46.3	50.4	**55.0**	60.3	66.5	73.7	82.2
18.5	40.7	43.9	47.4	51.5	**56.1**	61.3	67.5	74.6	83.0
19.0	41.8	44.9	48.5	52.5	**57.1**	62.3	68.3	75.4	83.6
19.5	42.8	46.0	49.5	53.5	**58.0**	63.2	69.2	76.0	84.1
20.0	43.9	47.0	50.5	54.5	**59.0**	64.1	69.9	76.7	84.5
20.5	44.9	48.0	51.5	55.5	**59.9**	64.9	70.7	77.3	85.0
21.0	46.0	49.1	52.5	56.4	**60.8**	65.8	71.4	77.9	85.4
21.5	47.0	50.1	53.6	57.4	**61.7**	66.6	72.1	78.5	85.8

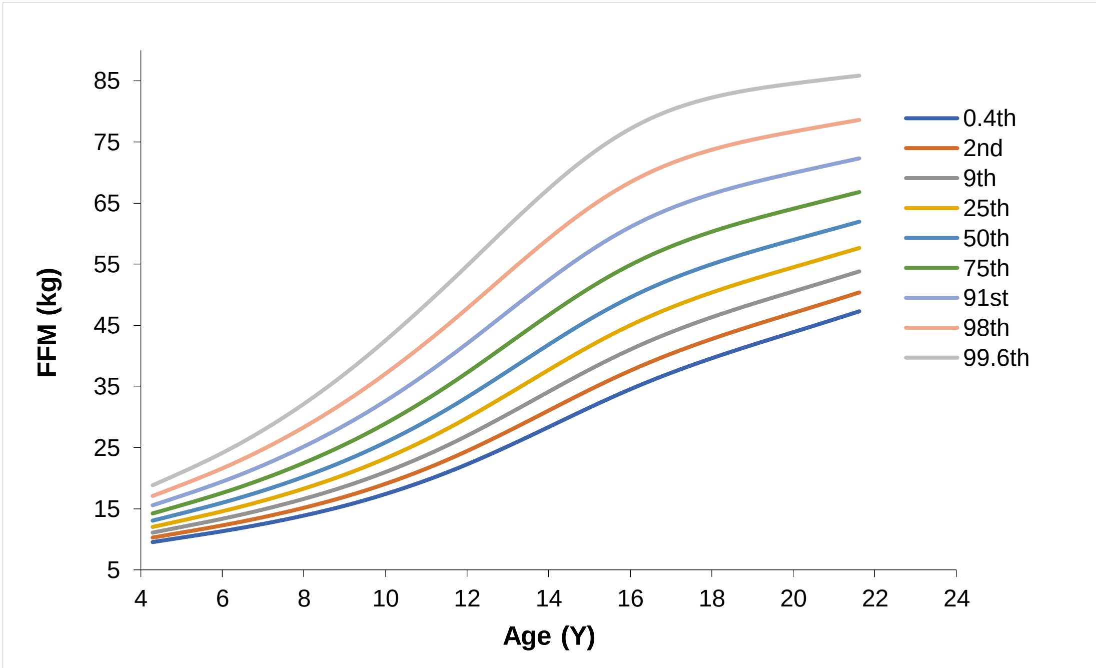


Figure 7.5: Smoothed computed FFM percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 95th and 98th centiles for male

The centile charts were also constructed for female participants from a combined data (Fig 7.6). As with male participants, a similar trend of increasing FFM was seen in female participants at all age groups. This increase was more noticeable up to the age of 14y after which the increase in FFM was increasing moderately in subsequent age groups. At the 50th centile (Table 7.5) the minimum FFM (11.9kg) was seen in youngest age group in the dataset (4.5) years and maximum FFM (41.7) was seen in highest age group in the dataset (21.0 years)

Table 7.5: Merged centiles of FFM (kg) by age and sex (female)

Age	0.4th	2nd	9th	25th	50th	75th	91st	98th	99.6th
	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
4.5	8.3	9.0	9.8	10.8	**11.9**	13.3	14.9	17.0	19.7
5.0	9.0	9.7	10.6	11.7	**12.9**	14.4	16.2	18.5	21.3
5.5	9.6	10.4	11.4	12.6	**14.0**	15.6	17.5	19.9	22.9
6.0	10.2	11.2	12.3	13.5	**15.0**	16.8	18.8	21.4	24.4
6.5	10.8	11.9	13.1	14.5	**16.1**	18.0	20.2	22.8	26.0
7.0	11.4	12.6	13.9	15.4	**17.2**	19.2	21.6	24.4	27.6
7.5	12.1	13.3	14.8	16.4	**18.3**	20.5	23.0	25.9	29.3
8.0	12.7	14.1	15.7	17.5	**19.5**	21.8	24.5	27.5	31.0
8.5	13.4	14.9	16.6	18.6	**20.8**	23.2	26.0	29.2	32.7
9.0	14.1	15.8	17.7	19.7	**22.1**	24.7	27.6	30.9	34.5
9.5	14.8	16.7	18.7	21.0	**23.5**	26.3	29.3	32.7	36.4
10.0	15.6	17.6	19.8	22.3	**25.0**	27.9	31.1	34.6	38.4
10.5	16.5	18.7	21.0	23.6	**26.5**	29.6	32.9	36.5	40.4
11.0	17.4	19.7	22.3	25.0	**28.0**	31.3	34.8	38.5	42.5
11.5	18.3	20.8	23.5	26.4	**29.6**	33.0	36.5	40.4	44.4
12.0	19.2	21.9	24.7	27.8	**31.1**	34.6	38.2	42.1	46.2
12.5	20.1	22.9	25.9	29.1	**32.5**	36.0	39.8	43.7	47.8
13.0	20.9	23.9	27.0	30.3	**33.7**	37.3	41.1	45.0	49.1
13.5	21.8	24.8	28.0	31.4	**34.9**	38.5	42.3	46.2	50.2
14.0	22.6	25.7	29.0	32.4	**35.9**	39.6	43.3	47.2	51.2
14.5	23.4	26.6	29.9	33.3	**36.8**	40.5	44.2	48.0	51.9
15.0	24.2	27.4	30.7	34.1	**37.6**	41.2	44.9	48.7	52.5
15.5	25.0	28.2	31.5	34.8	**38.3**	41.9	45.5	49.2	53.0
16.0	25.7	28.9	32.1	35.5	**38.9**	42.4	46.0	49.6	53.3
16.5	26.4	29.5	32.7	36.0	**39.4**	42.8	46.3	49.9	53.5
17.0	27.1	30.2	33.3	36.5	**39.8**	43.1	46.5	50.0	53.6
17.5	27.8	30.7	33.8	36.9	**40.1**	43.4	46.7	50.1	53.6
18.0	28.4	31.3	34.2	37.3	**40.4**	43.6	46.8	50.1	53.5
18.5	29.0	31.8	34.7	37.6	**40.6**	43.7	46.9	50.1	53.4
19.0	29.6	32.3	35.1	37.9	**40.8**	43.9	46.9	50.1	53.3
19.5	30.2	32.8	35.5	38.2	**41.1**	44.0	47.0	50.0	53.2
20.0	30.7	33.3	35.9	38.5	**41.3**	44.1	47.0	50.0	53.1
20.5	31.3	33.7	36.2	38.8	**41.5**	44.2	47.1	49.9	52.9
21.0	31.9	34.2	36.6	39.1	**41.7**	44.4	47.1	49.9	52.7

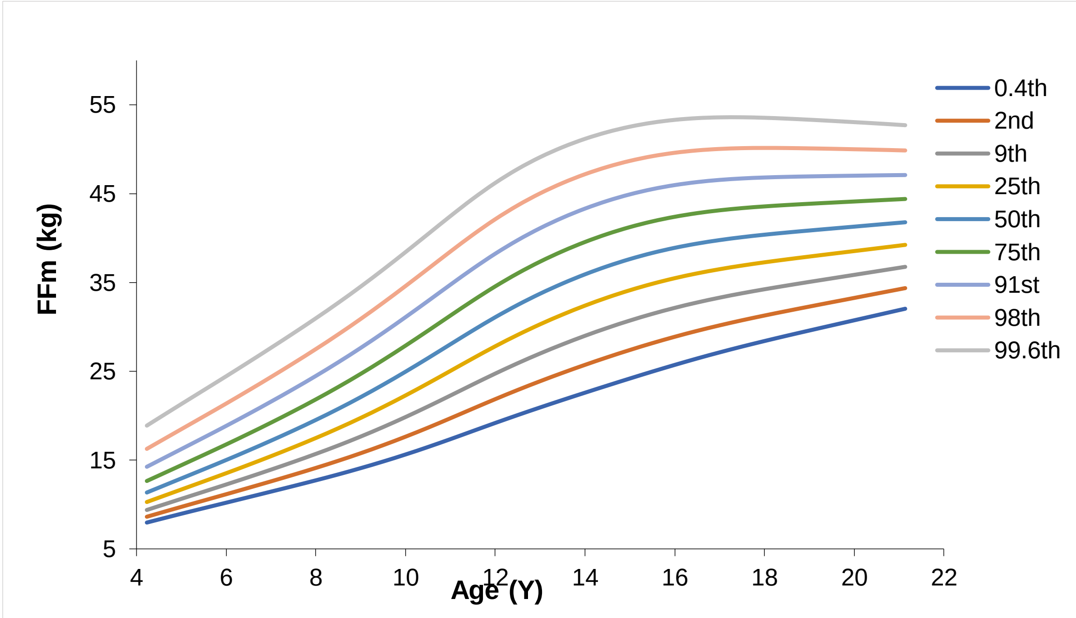


Figure 7.6: Smoothed computed FFM percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for female

7.4.2 SMM

Table 7.6 describe detail descriptive statistics of skeletal muscle mass (SMM) in both genders in the studied age groups. As like FFM, the SMM was higher in males compared to females in all age groups. In male SMM was subsequently increasing with age except at age 18y where there was a very small decrease in SMM was observed.

In female there is no pattern of increasing or decreasing in SMM, However, the lowest mean SMM of 16.4 kg was observed at age 16 y females while the highest mean SMM of 17.1 kg was seen in aged 21y.

Table 7.6: Descriptive statistics (mean ± SD) of SMM (kg) for SA groups by age range and gender distribution

Descriptive statistics of SMM (kg) with age and gender distribution												
	16 years		17 years		18 years		19 years		20 years		21 years	
	M (n=114)	F (n=71)	M (n=52)	F (n=37)	M (n=35)	F (n=26)	M (n=24)	F (n=25)	M (n=25)	F (n=20)	M (n=50)	F (n=66)
Mean	21	16.3	22.8	16.7	22.0	16.6	23.2	16.5	26.3	17.1	26.3	17.1
Std Dev	3.38	1.81	4.11	1.95	3.54	2.08	3.51	2.62	2.13	2.14	3.14	1.95
Minimum	11.9	12.3	13.8	12.0	15.4	13.5	17.3	13.1	22.1	13.9	20.6	13.5
Maximum	29.5	19.8	37	21.7	31.5	23.2	31.4	26.6	30.8	21.1	34.4	22.8

7.4.2.1 Scatter plot

The scatterplots (Fig 7.7) for SMM vs age in male participants suggest that there is a steady and modest increase in SMM with increasing age, however, the same scatterplot (Fig 7.8) in female participants shows a flat associate with age, suggesting that there was no increase in SMM seen with age. The observations were obviously more clustered around 16- and 21-years age groups among both genders due to of higher number of participants in these age groups.

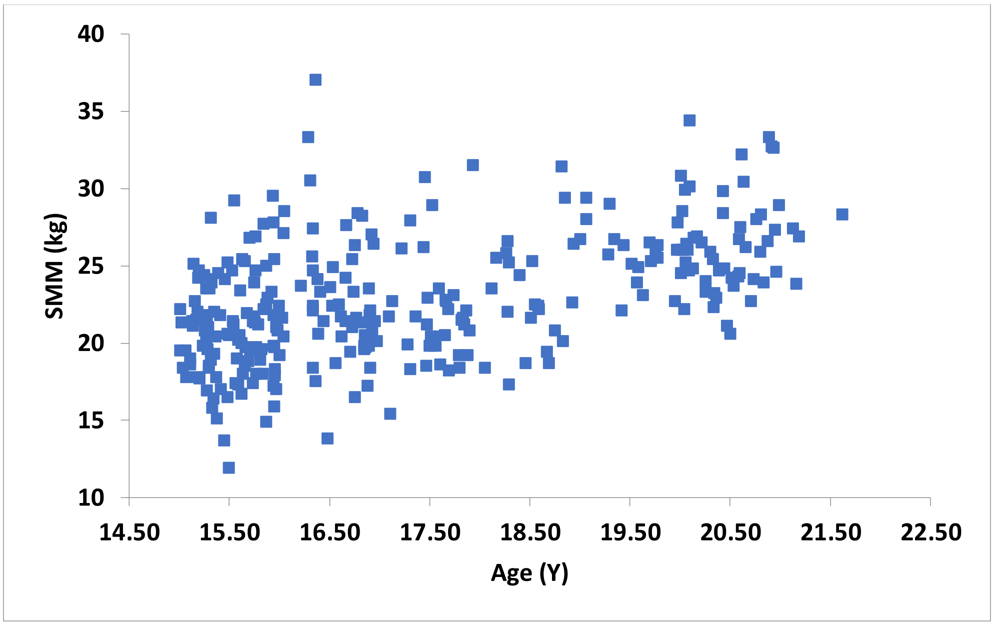


Figure 7.7: Scatterplot showing the distribution of the SMM of male study participants against age

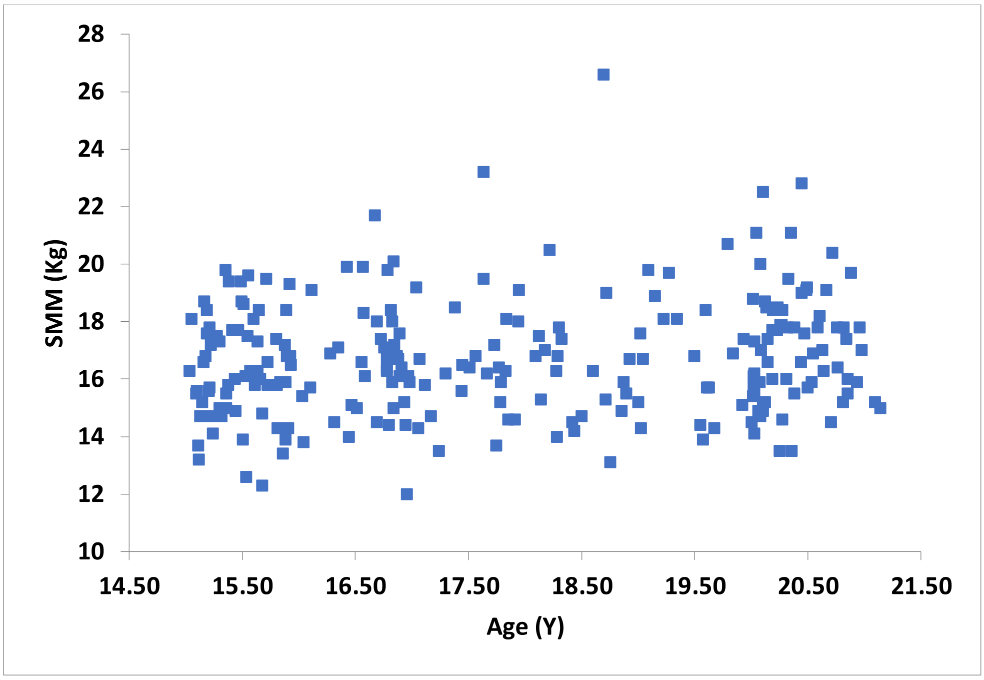


Figure 7.8: Scatterplot showing the distribution of the SMM of female study participants against age

7.4.2.2 centile curve

Figure 7.9 shows the data analysed at different centile points for male participants for SMM. An age-related increase in SMM was seen in males between 15 to 21 years of age and this trend was generally similar in all the 9 centiles. At 50th centile (Table 7.7), a small plateau was seen from 16 years to 17.5 years (21.4 kg SMMs to 21.9 kg SMM), though the general trend was still upwards from 16 to 21 years age groups with lowest value of 20.2 kg (of SMM) observed at 15.0 years and highest value of 27.5 kg (of SMM) observed at 21.5 years.

Table 7.7: Centiles of SMM by age and sex (male)

Age	0.4th	2nd	9th	25th	50th	75th	91st	98th	99.6th
	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
15.0	11.5	13.6	15.8	18.0	**20.2**	22.4	24.7	27.0	29.3
15.5	12.7	14.5	16.5	18.6	**20.8**	23.2	25.7	28.3	31.1
16.0	13.7	15.4	17.2	19.2	**21.4**	23.9	26.7	29.7	33.1
16.5	14.5	16.0	17.7	19.6	**21.8**	24.3	27.2	30.6	34.5
17.0	14.9	16.3	17.9	19.7	**21.8**	24.3	27.3	30.8	35.1
17.5	15.4	16.7	18.1	19.9	**21.9**	24.3	27.2	30.8	35.2
18.0	15.9	17.2	18.6	20.3	**22.3**	24.6	27.5	31.0	35.4
18.5	16.8	18.0	19.4	21.1	**23.0**	25.3	28.1	31.5	35.7
19.0	17.8	19.1	20.5	22.1	**24.0**	26.2	28.9	32.2	36.3
19.5	18.8	20.0	21.4	23.0	**24.9**	27.1	29.6	32.8	36.6
20.0	19.6	20.8	22.2	23.8	**25.5**	27.6	30.1	33.1	36.7
20.5	20.3	21.5	22.8	24.3	**26.1**	28.1	30.5	33.3	36.7
21.0	21.2	22.4	23.6	25.1	**26.8**	28.7	31.0	33.7	37.0
21.5	22.1	23.3	24.5	25.9	**27.5**	29.4	31.6	34.1	37.2

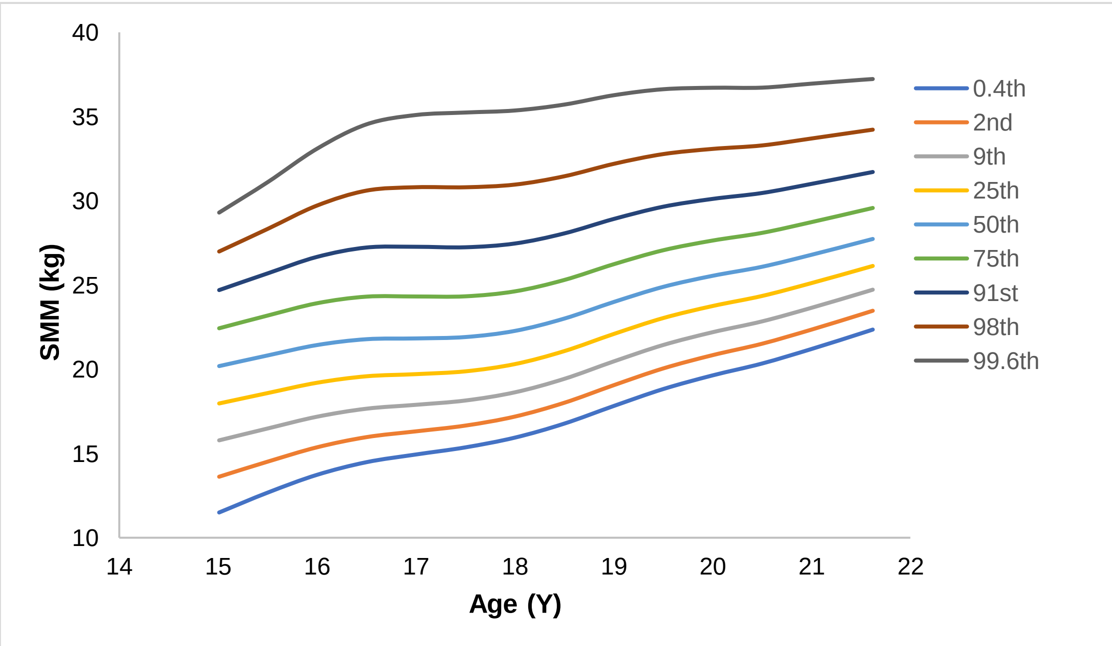


Figure 7.9: Smoothed computed SMM percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for male

Figure 7.10 shows the data set plotted at 9 centile cut offs for female participants for SMM. Though an age-related increase could be seen in females between 15 to 20 years of age and this trend was more or less consistent in all the 9 centiles, however, this upward trend was not as obvious and clear as it was seen in the male participants, At the 50th centile (Table

7.8), there was a modest increase in SMM from 16 years onwards until 20 years followed by a plateauing in subsequent age groups, reflecting that maximum SMM was achieved in females by 20 years of age.

Table 7.8 Centiles of SMM by age and sex (female)

Age	0.4th	2nd	9th	25th	50th	75th	91st	98th	99.6th
	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
15.0	11.4	12.7	13.9	15.1	**16.3**	17.4	18.5	19.6	20.7
15.5	11.7	12.8	14.0	15.2	**16.4**	17.6	18.8	20.0	21.3
16.0	11.9	13.0	14.1	15.2	**16.4**	17.7	19.0	20.4	21.9
16.5	12.1	13.1	14.1	15.2	**16.5**	17.8	19.2	20.8	22.5
17.0	12.3	13.2	14.1	15.2	**16.4**	17.8	19.4	21.2	23.2
17.5	12.4	13.2	14.2	15.2	**16.4**	17.8	19.5	21.5	24.0
18.0	12.5	13.3	14.2	15.2	**16.4**	17.8	19.6	21.9	24.9
18.5	12.6	13.3	14.1	15.1	**16.3**	17.8	19.7	22.1	25.5
19.0	12.7	13.4	14.2	15.2	**16.4**	17.9	19.7	22.2	25.8
19.5	12.8	13.5	14.3	15.3	**16.5**	17.9	19.8	22.2	25.6
20.0	13.0	13.7	14.5	15.5	**16.7**	18.1	19.9	22.1	25.2
20.5	13.2	13.9	14.8	15.7	**16.9**	18.3	19.9	22.0	24.7
21.0	13.3	14.0	14.9	15.8	**16.9**	18.2	19.8	21.7	24.1
21.1	13.3	14.1	14.9	15.8	**16.9**	18.2	19.8	21.6	23.9

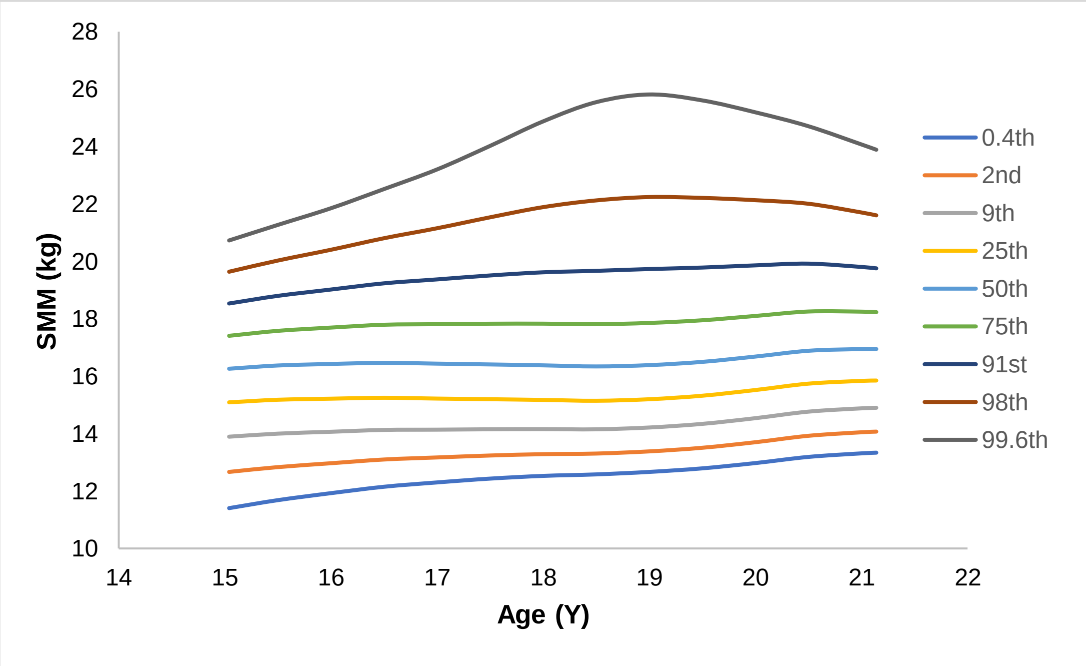


Figure 7.10: Smoothed computed SMM percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for female

7.4.2.3 Merged Centile curve

The data for SMM collected for this study was combined with data collected by previous researcher for earlier age groups to generate the centile charts for male and female. It was noticed (Fig 7.11) that skeletal muscle mass (kg) increased continually from 4 years to 22 years of age and this trend was consistently noticed in all centile charts. It was generally observed in all centiles that increase in SMM was more rapid and prominent following the age of 14 years, as the SMM increased from 16.7 kg at 14y to 28 kg at 22y (Table 7.9).

Table 7.9: Merged centiles of SMM by age and sex (male)

Age	0.4th	2nd	9th	25th	50th	75th	91st	98th	99.6th
year	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
4.29	1.6	1.9	2.2	2.7	**3.2**	3.8	4.4	5.2	6.2
5	1.9	2.2	2.7	3.2	**3.8**	4.5	5.3	6.3	7.4
6	2.4	2.8	3.3	4.0	**4.7**	5.5	6.6	7.7	9.2
7	2.9	3.4	4.0	4.8	**5.7**	6.7	7.9	9.4	11.1
8	3.5	4.1	4.8	5.7	**6.7**	7.9	9.4	11.1	13.2
9	4.2	4.9	5.7	6.7	**7.9**	9.3	11.0	13.1	15.5
10	5.0	5.8	6.8	7.9	**9.3**	10.9	12.8	15.2	18.1
11	6.0	6.9	8.0	9.3	**10.9**	12.7	14.9	17.6	20.9
12	7.1	8.2	9.5	10.9	**12.7**	14.8	17.2	20.2	23.8
13	8.5	9.7	11.1	12.7	**14.7**	17.0	19.7	23.0	26.9
14	9.9	11.3	12.8	14.6	**16.7**	19.2	22.1	25.6	29.6
15	11.4	12.9	14.5	16.5	**18.7**	21.3	24.3	27.8	32.0
16	12.9	14.4	16.2	18.2	**20.4**	23.1	26.1	29.6	33.7
17	14.3	15.9	17.6	19.6	**21.9**	24.5	27.5	30.8	34.7
18	15.8	17.3	19.1	21.0	**23.2**	25.7	28.5	31.7	35.4
19	17.2	18.8	20.5	22.4	**24.5**	26.8	29.5	32.4	35.7
20	18.8	20.3	21.9	23.7	**25.7**	27.9	30.3	33.0	36.0
21	20.4	21.8	23.3	25.0	**26.8**	28.8	31.0	33.5	36.1
22	22.1	23.4	24.8	26.3	**28.0**	29.8	31.7	33.9	36.1

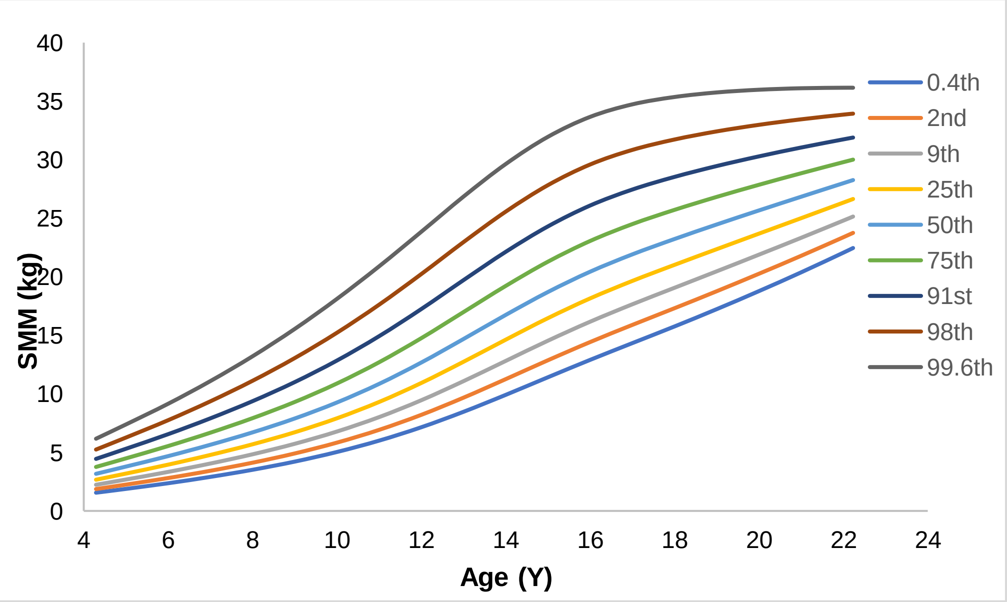


Figure 7.11: Smoothed computed SMM percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for male

Likewise, smoothed centile curves were constructed for SMM for female (Fig 7.12) merging the data collected from this study with data collected by previous researcher for earlier age. It was noticed that skeletal muscle mass (kg) increased continually from 4 years to 22 years of age and this trend was consistently noticed in all centile cut off charts, however, the mean SMM at each group was lower for female than for male (Table 7.10). Additionally, there was no considerable increase in the SMM after 14 years of age as it was seen in case of male. For example, compared to male, mean SMM for female of 14 years age group was 13.9 kg while the mean SMM at 22 years of age was 17.3, meaning there is not much increase in SMM at later years of adolescents in female.

Table 7.10: Merged centiles of SMM by age and sex (female)

Age	0.4th	2nd	9th	25th	50th	75th	91st	98th	99.6th
Year	-2.7	-2.0	-1.3	-0.7	**0.0**	0.7	1.3	2.0	2.7
4	1.7	2.0	2.3	2.7	**3.1**	3.7	4.3	5.0	5.9
5	2.0	2.4	2.8	3.2	**3.8**	4.4	5.1	6.0	7.0
6	2.5	2.9	3.4	3.9	**4.6**	5.3	6.2	7.2	8.4
7	3.0	3.5	4.0	4.7	**5.5**	6.4	7.4	8.5	9.9
8	3.5	4.1	4.8	5.6	**6.4**	7.5	8.6	9.9	11.4
9	4.1	4.8	5.6	6.5	**7.5**	8.7	10.0	11.4	13.0
10	4.7	5.6	6.5	7.6	**8.7**	10.0	11.4	13.0	14.7
11	5.5	6.5	7.6	8.7	**10.1**	11.5	13.0	14.7	16.6
12	6.4	7.5	8.7	10.0	**11.4**	13.0	14.6	16.4	18.3
13	7.3	8.5	9.8	11.2	**12.7**	14.3	16.1	17.9	19.9
14	8.2	9.5	10.8	12.3	**13.9**	15.6	17.3	19.2	21.2
15	9.1	10.4	11.8	13.3	**14.9**	16.6	18.3	20.2	22.2
16	10.0	11.3	12.7	14.1	**15.7**	17.3	19.1	21.0	22.9
17	10.8	12.0	13.4	14.8	**16.3**	17.9	19.6	21.4	23.3
18	11.5	12.7	13.9	15.2	**16.6**	18.2	19.8	21.6	23.5
19	12.1	13.2	14.3	15.5	**16.9**	18.3	19.9	21.6	23.4
20	12.7	13.6	14.7	15.8	**17.0**	18.4	19.9	21.5	23.2
21	13.2	14.1	15.0	16.1	**17.2**	18.4	19.8	21.3	23.0
22	13.7	14.5	15.4	16.3	**17.3**	18.5	19.7	21.1	22.6

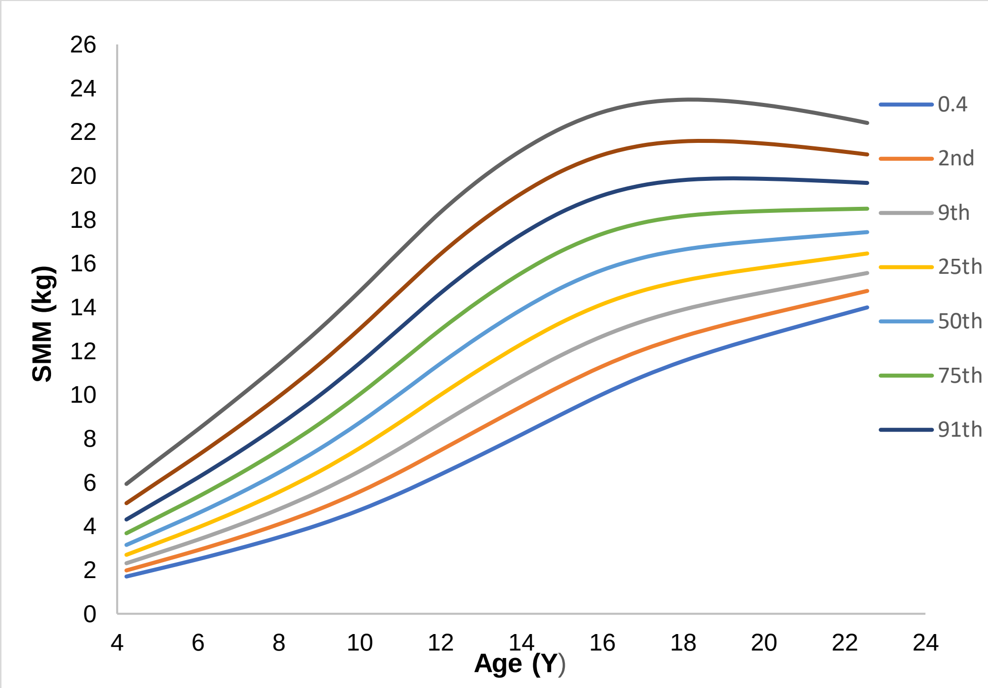


Figure 7.12: Smoothed computed SMM percentile curves for the 0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th and 99.6th centiles for female

7.5 Discussion

In this study, centile charts for FFM and SMM have been constructed for the South Asian UK populations between ages 4 and 21 years. These are the first such set of centile charts to be produced. Even though, there has always been an ambition to have reference data for children, adolescents and young adults for specific ethnic groups, their development has been challenging due, in part, to the difficulty of obtaining the specific and precise body composition measurements. With techniques such as DXA being an expensive, invasive and time-consuming, the extensive use of this approach to develop reference charts has been the limiting factors. Indeed to date, several body references have been developed using much simpler technology such as height, weight, skinfold thickness and WC (Chumlea et al. 2002, Nakao and Komiya 2003, Moreno et al. 2007, Addo and Himes 2010, Alwis et al. 2010, Kurtoglu et al. 2010). Yet, Atherton et al. (2013) have been able to develop reference charts and SDSs using the accurate 4C model and several simpler techniques across the age range from 5 to 20y. However, to our knowledge, no study has previously reported reference data for South Asians in UK, but the advancement in BIA technology has allowed such references to be developed. In the current study, we have attempted to resolve this problem by developing centile charts for FFM and SMM in South Asians range from ages 16 to 21y and to supplement the equivalent charts for the younger age range.

The charts developed in the present study clearly demonstrate the changes and distinctions in the proportions of the body compartments across growth and development. These charts can facilitate users to assess the body composition in South Asian population group and to identify individuals at extremes of body composition who may present with increased risk for metabolic disease. One critical observation has been how the age-related changes in body composition varies between South Asians and Caucasians (Stanfield et al. 2012). This is a clear indication why ethnic-specific centile charts should be used as using charts specifically designed for Caucasians could lead to the misclassification of South Asians with respect to overweight, obesity, abdominal fatness and SMM. In this study, the centile charts determined the gender specific changes, which are mainly associated with the growth of the studied population. Firstly, a very small increase in FFM (kg) has been observed in girls which most likely reflects the normal ontogenic increase in the proportion of body fat (Freedman et al. 2002). However, the relatively stable FFM (kg) in the older adolescents and young adults could be the reflection of the testosterone driven increase in muscle and bone, meaning that maximum effect having already been achieved.

Moreover, the small increase in SMM (kg) with age observed in males which is absent or less obvious in the females where an opposite trend was noticed with SMM remaining stable as a proportion of whole-body mass up to age 21 years. The stability with SMM is again most likely the result of their higher absolute and proportional body fatness. However, one critical aspect not included in this study in the potential impact of physical activity. Culturally, South Asian females tend to engage less in exercise and physical activity compared with males, especially in the teenage years. This impact cannot be assessed in this study. The charts also determine the differences in age and gender-related variations in measurements. To date, these are the first BIA-derived centile charts produced which determine the gender and age-related variations in FFM and SMM in South Asian young adults living in UK, so comparison with previous studies cannot be made. The mean SMM in the current study represented 21 – 27.7 kg in boys and 16.4 – 16.9 kg in girls which is a slightly lower than reported by Wells et al. (2012). Similar centile charts have been developed using the same BIA system for populations e.g. Turkish children (Kurtoglu et al. 2010).

In order to find the difference between SA and WE body composition, in current study we compare the SMM of SA male and female with WE SMM centile developed by McCarthy et al., 2013 at 50Th centile (Fig 7.13, Fig 7.14). Both male and female have less SMM as compared to WE population. Pomeroy et al. (2019) indicated that low lean mass is a characteristics of SA population due to neutral variation that cannot be change in short period of time.

In conclusion, these charts can provide reference data for FFM and SMM for South Asian young adults between 16 to 21 years living in UK and can achieve the demand of clinicians for tracking anthropometry and body composition in this population.

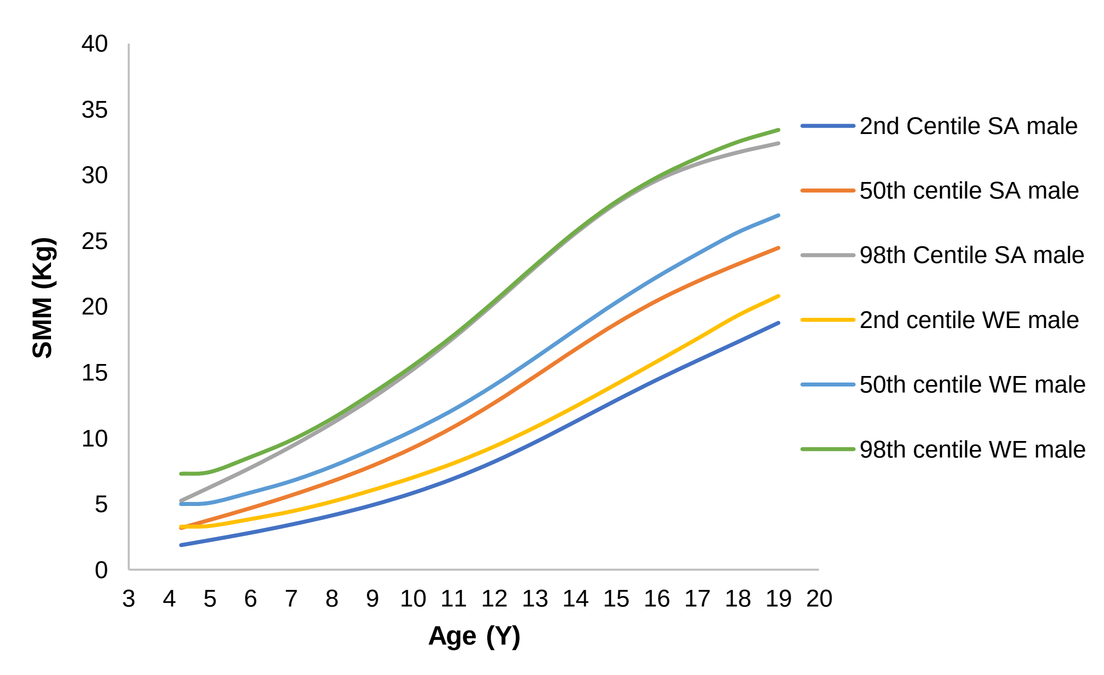


Figure 7.13: centile comparisons between WE and SA male at the 2nd, 50th, & 98th Centiles

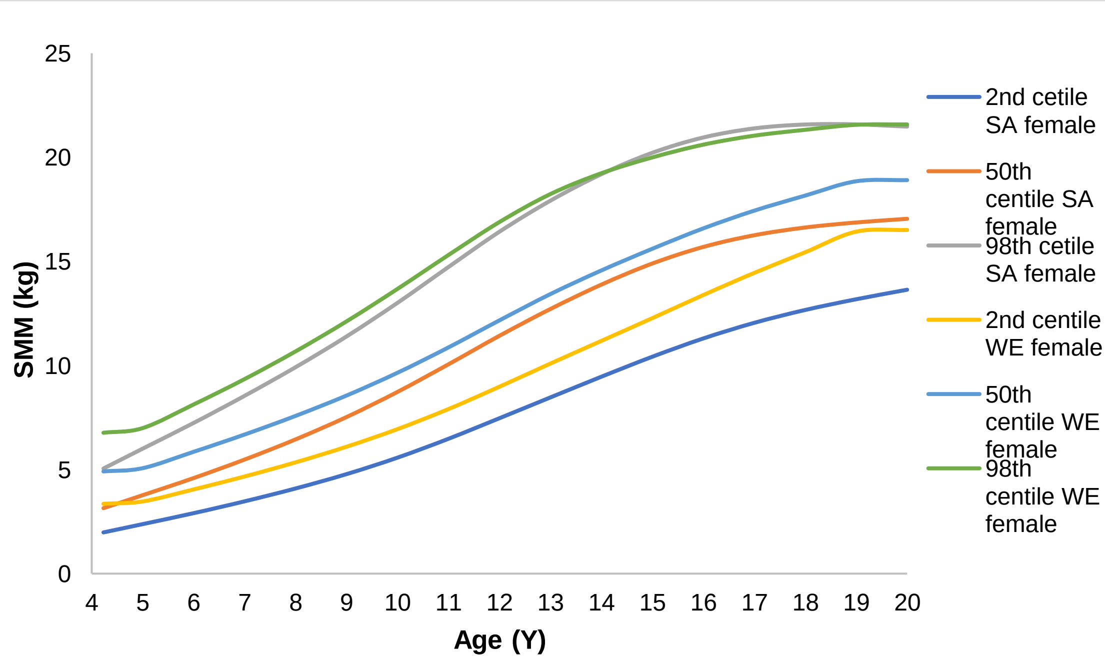


Figure 7.14: centile comparisons between WE and SA female at the 2nd, 50th, & 98th centiles

7.6 Limitations

As mentioned in the previous chapter that BIA underestimates the BF% compared to DXA, a conversion equation is ideally needed to make an adjustment for all age groups. However, no single BIA equation is likely to be valid throughout childhood and adolescence, given that the hydration of FFM is not constant during this period (Lohman 1989, Wells et al. 2010), as has been demonstrated by (Montagnese et al. 2013). As mention in previous chapter.

Also as highlighted in other anthropometric and body composition measurements, the data collection focused in the areas around London and not from all across the United Kingdom, this could have an impact on FFM and SMM because people from different parts of the UK may have different socio-economic status which in turn has an impact on body composition.

CHAPTER 8 – General discussion, Conclusion and Limitation

8.1 General discussion

Obesity and overweight have become a growing threat over the last two decades in developing countries because its rising trend in children has led to negative impacts on health, healthcare and economies. This worrying situation has instigated a need of extensive research work in this subject a new era of monitoring childhood obesity has started globally. Several national and international studies have described that the occurrence of overweight and obesity in children and teenagers varies in different ethnic groups due to various reasons (Ng et al. 2014). Obesity trends, risk factors and tools for monitoring obesity has been extensively studies for Caucasians living in the UK, however, there is little or no established reference data for monitoring growth in other ethnic groups including African-Caribbean and South Asians populations. The latter group has distinctive characteristics in terms of their body composition, dietary habits and genetic background. Our study focussed on the anthropometric measurements including weight, height and sitting height and body composition analyses obtained from the selected population (South Asian) in the UK to develop the reference charts, that demonstrate differences in respective measurements with UK reference population.

Historically, height has been considered as key element in the monitoring of growth and prediction of risks. Numerous studies have demonstrated that children with greater adiposity tend to be taller for their age than children who are of a healthier weight. This concept has increased its importance as a contributor or risk factor towards overweight/obesity (He and Karlberg 2001, Dangour et al. 2002, Freedman et al. 2002, Paajanen et al. 2010, Stovitz et al. 2010, Navti et al. 2013). However, even though South Asians tend to be shorter compared with white Europeans, the height for age issue remains (McCarthy et al. unpublished observations). The findings in chapter 4 indicated the need to create specific centile growth curves for height, weight, sitting height and leg length of children, adolescents and young adults in the South Asian population living in UK. This was the first attempt to develop the growth curves in this population group. Nightingale et al. (2011) already demonstrated that young adolescents in the UK SA population were shorter in overall height compared with the UK 1990 reference data. Their findings align with those in the current study in which the mean height and z-height was lower compared with the with UK 1990 reference population. The findings in the current study compares favourably with those found by the Indian Association of Paediatrics, where the median (50th centile) height of Indian boys and girls overlaid those of this sample (Khadilkar et al. 2015). Even though, both environmental and genetic factors are considered to have strong associations with height, the total and definite factors involved in height variations are still unclear. Both nutrition and parental height are well known variables associated with height of the offspring (Perkins et al. 2016). The findings of this chapter also showed that the body weight of the studied age group was lower compared with the UK 1990 which aligns with the results of CHASE study (Nightingale et al. 2011). We found no strong evidence of gender differences – both were lower compared with UK1990. Differences found in body weight can also be due to differences in genetics, environment, socioeconomics conditions, diet or lifestyle but still need to be further studied (Albuquerque et al. 2017).

In children with unusually short or tall stature, measurement of body proportions can provide important clues in the identification of growth disorders. It is a general concept that taller children tend to have relatively long legs, and shorter children have relatively shorter legs. However, it is also known that proportionality (i.e. leg length for overall height) is linked to obesity risk and morbidity. However, due to a lack of references of norms for sitting height and leg length measurements in the South Asian population, the study also aimed to develop the centile curves for sitting height and leg length for the young adolescents from SA population living in UK. The results revealed an increase in sitting height with increasing age – a phenomenon also demonstrated by Bundak et al. (2014). However, in comparison with the findings of (Fredriks et al. 2005), they found that SA have smaller trunk length as compared to Dutch girls and boys. It has been reported that better environmental circumstance has a positive impact on leg length which grows proportionately more in the years up to puberty (Fredriks et al. 2000). While In compare to British reference sub-ischial leg length (Dangour et al. 2002) there is no increase in growth after age 14 years. In current study we collect data from age 16y to 21y and concluded that there was no increase in leg length between these ages.

There is a growing body of evidence to suggest that decrease in relative leg length increases the risk of insulin resistance and CHD (Smith 2001, Gunnell et al. 2003, Langenberg et al. 2003, Ferrie et al. 2006). As it has been found in many studies that people living in UK from SA have a higher risk of CHD compared with the indigenous population (Jalal et al. 2019), it is possible that body proportionality may be one contributory factor.

Due to the increasing trend of paediatric obesity and its related morbidities particularly in SA, it was important to develop a simple anthropometric tool which can be easily used for the assessment of children who may be at risk. Recognising the fact that there is a lack of studies for the development of growth centile curves in the SA population living in UK (perhaps due to difficulties and challenges in body measurements), we collected data on BMI and waist circumference (WC) to develop centile curves for simple anthropometric measurements in South Asian boys and girls aged 16 to 21 years. These results, discussed in detail in chapter 5, showed that children from the SA ethnic group differed from the Caucasian population in terms of BMI and WC. In the studied age group, the results provided the initial evidence which would help further investigations to develop ethnic-specific references for South Asian population living in UK. In the studied age group, a consistently higher BMI was observed from 4 to 21 years in boys and girls and mean BMI for this population group was the same as the UK 1990 reference population. As it has been shown that South Asians have a higher risk of metabolic disease at the same BMI for a white European, this is the reason why a revised cut off for the SA population was defined (Misra et al. 2016, Hudda et al. 2018).

McCarthy et al. (2001) developed WC reference centiles for white European children aged between 4.5 to 15 years. Even though the data used for the construction of these WC centile curves in boys and girls is quite old, the curves can still be used to make comparisons between the SA and UK populations. This comparison was undertaken by Shah et al. (2019) who first developed the reference centile charts for the UK SA population for age range 4y to 14 y. They found similar observations to the indigenous Pakistani and urban Indian children (Kuriyan et al. 2011) whereby UK South Asian children had a higher WC than the WE children. The result of the current study aligns with those of Shah et al. 2019 and revealed that SA have higher WC as compared to their WE counterparts. However, it is important to note that comparing with the UK 1990 reference data UK South Asian children on average, had similar BMI but higher waist circumference and the overall levels of fatness were higher as judged by higher trunk skinfold thickness (Nightingale et al. 2011). The findings of chapter 5 will facilitate researchers and practitioners in the early detection of obesity related health problems and to promote early preventive action after tracking changes in abdominal adiposity.

In Chapter 6, it was discussed that even though ethnic-specific adjustments in BMI measurement are believed to increase the accuracy of assessment of excess fatness, to some extent in a particular population, it still underestimates fatness in certain ethnic groups. This essentially means that a better evaluation and characterisation of obesity requires stronger parameters such as BF% and FM beyond BMI and WC in fully predicting the health-related risks in the SA population. BIA has made the assessment of FM and FFM not only possible, but this has been adopted as readily accessible tool. Though data for all age groups for BF% exist as a reference chart for white European children (McCarthy et al. 2006), the equivalent reference chart for UK resident SA population has not been available despite the widely accepted fact that differences exist in body composition across different ethnic groups. In the current field-based study, BIA was used to assess body composition (BF% and FM) in the SA population between the ages of 16 and 21 years (inclusive). This was then combined with the set of data for BF% and FM for ages 4-15 years of SA children to construct the full range of reference chart for 4 to 21 years. The centile curves generated for BF% and FM for both males and females showed that there was the same gender-related difference in the pattern of BF% over time that matches with the finding of McCarthy et al. (2006). The overall pattern for absolute FM, however, was different in both genders. An age-related increase in FM in males was observed from 4 years onward until the age of 15 years with not much change in the later age groups. A constant and smooth age-related increase in FM was clearly seen from the age of 5 to 21 years in females, which did not appear to plateau. In contrast, (Kyle et al. 2001) conducted the study in18 to 94 years old and found that FM increased from 18 years until the age of 75 years. Their findings would suggest that the increase in FM is a continuous phenomenon from childhood until very late in life. Whilst this is to an extent consistent with our findings where we have also seen a continuous increase in FM from 13 years onward, any gain in FM in adulthood and in the later years simply reflects excess weight gain and positive energy balance rather than age-related growth. Acknowledging that this is the first study to develop a set of centile curves for the UK SA population in this age range, there is no direct population reference to compare with, despite countries such as India generating equivalent references in children and adolescents (Chiplonkar et al. 2017).

In Chapter 7, it was discussed that in addition to fat body content, the FFM and SMM are equally important measures in children (Heymsfield et al. 2016). The accurate assessment of FFM (and SMM) is highly impacted by the degree of hydration when using BIA as it relies on the prediction of the water content of the FFM. While recognising that hydration of the FFM varies between individuals from different ethnic groups, the prediction of FFM via BIA critically depends on specific equation for each population group. Hence either specific predictive equations for the estimation of FFM in other ethnic groups is needed or alternatively, reference curves for specific populations based upon existing equations could be generated. In this thesis, this requirement has been partially achieved, since FFM and SMM references have been generated using existing equations. This was not by choice, but by necessity since previously generated equations for the UK SA child and youth population based upon DXA as the criterion method, which had been intended to be used in this study were found to be not transferable to this population (Shah 2015).

Although not reported in the chapter, attempts were made to fit these equations in this population, without success, hence reverting to the use of existing equations. Future research could repeat such validation studies for this age range. In addition, SMM is a major component of FFM. Furthermore, there is a strong relationship between a low SMM and high FM as an important indicator of metabolic risk. As both FFM and SMM increase during growth across childhood and adolescence (Forbes 1978) and also varies between different ethnic groups, this emphasises the use of age and gender-specific centile charts with different cut-off values for boys and girls at different ages to be used as reference for the SA population. The current study used BIA for the estimation of SMM, whereas other methods of evaluation (DXA, 24 h creatinine monitoring) although perhaps have greater accuracy but expensive, invasive, time consuming and overly complex.

The FFM and SMM charts obtained from this study demonstrates some gender specific differences in the proportion of both body compartments. There was an increase in absolute FFM in both genders with age, however, males have higher amount of FFM as compared to female participants at each age. In addition, the centile charts for SMM show that this increases with age in both genders but there was a noticeable increase in SMM in males at around the pubertal age range which was not obvious in females. In this study we compared the centile charts for SMM in SA children, adolescents and young adults for the first time with the UK SMM reference data (McCarthy 2014). Compared to these centile charts for British WE children and adolescents, SA children and young adults in this study at the 50th centiles had lower SMM for all age groups in both genders. Even though these differences may be due to differences in hydration status not accounted for by the BIA equations, nevertheless the findings in our study that South Asians have low SMM relative to height provides one possible explanation why they may be more prone to develop T2DM, particularly since they also have a greater FM (Pomeroy et al. 2019). It is interesting to note that McCarthy (2014) proposed a new index of muscle-to-fat ratio (MFR) as a potentially better marker of risk for metabolic disease than BMI. Although not explored in this thesis, this new index could equally be applied to other ethnic groups and may not require any different cut-offs, similar to the waist-to-height ratio (WHtR) which is becoming more accepted in the health community, practitioners and indeed life insurers (Ashwell and Gibson 2014, Yoo 2016).

8.2 Limitations of the study

Even though all attempt were made to design, conduct, analyse and interpret the study in the best possible way, nevertheless there remained several limitations in our study. These limitations have been addressed in all of the experimental chapters. However, it is worth reiterating the issue of sample size. The sample size for this study was not derived or based on the statistical power or testing a null hypothesis. The sample size was chosen as 500 participants which was close to the recommended 50 case per yearly age group and gender and exceed the sample size used in similar studies (Peter et al. 2005, Biau et al. 2008).

The selection of the sample was not based on any stratification factors such as age group or country of origin. The selection of participants was opportunistic i.e. those who fulfilled the criteria and consented to participate in the study. This led to a slight imbalance in the distribution of participants from different part of South Asia. It is not known if this numerical imbalance has any statistical influence. Of interest the HSE 2004 revealed that small differences in phenotype and body composition within SA groups.

Occasionally overweight and obese individuals may not feel comfortable being weighed in public due to social stigma or embarrassment. This means that potentially some overweight/obese participants may have chosen not to take part in the study hence it may have caused a potential selection bias in the study. This is difficult to avoid and is a common feature of any study requiring weighing, such as the National Child Measurement Programme. This can lead to an under estimation of obesity prevalence.

Even though the age group was defined for the study participants (16 to 21 years age), the study relied on self-reported age. Despite the fact that the participants were asked for their date of birth, rather than age, this does not rule out the possibility of recruiting participants outside the defined age group.

As the study needed the anthropometric measurements to be taken from the study participants, these measurements were taken once and not duplicated. Duplicate measurements (followed by mean of the two measurements) are believed to increase accuracy, but this was not done in our study as this would have taken long time from the participants and would have made the recruitment challenging.

It is understood that the study was conducted to target the South Asians living in UK, which ideally should have recruited South Asians from across the entire UK. However, our study participants were selected from the Southern part of England, focussing on the London area. This might also have impacted the distribution of participants with reference of socio-economic status. However, similar geographic-specific recruitment has also been used to develop national references (McCarthy et al. 2006, McCarthy 2014).

Lastly, as the goal of the study was to include South Asians in UK, the information was not collected on how long they have lived in UK. Some study participants might have been born in the UK while some participants might have lived a part of their lives in other countries with differing environmental factors before coming to UK. Typically, these can be referred to as first and second generation migrants. This could have impacted upon their anthropometric measurements and body composition. However due to constraints upon data collection, this information was not obtained. Nevertheless, if could be argued that the sample population reflected the typical pattern seen in the community.

8.3 Conclusions

Centile charts allow health professionals to measure and monitor child growth, allowing for comparisons with a reference population of the same gender and age. They are also used to predict how tall or heavy healthy children are expected to be at any age.

This was the first study to develop the growth charts for SA population living in UK. The study provided the reference data for anthropometric measures in SA population between 4 to 21 years which will enable researchers and health practitioners to measure young people across the age spectrum with growth and obesity related issues.

It is clear that body composition plays a vital role in the assessment of health risks associated with obesity, however, the contribution of body size and proportionality in the overall obesity related risk should not be underestimated. In Particular the stature and relative leg length are of importance in children as they are indicators of growth and can predict obesity in later ages. Height has historically been considered an indicator of linear growth, general health and nutritional status.

The trends in centile charts related to stature in the South Asians population was consistent with typical growth patterns generally seen in other population of same age group. At the 50th centile of the growth curves which reflect the median value of the study population, the increase in body size (standing height, sitting height and leg length) was observed in all age groups (from 16-21 yrs), however, the increase was more pronounced up to the age of 18 years and modest increase afterwards. The relationship between standing height, sitting height and leg length was more or less consistent and found to be moving in one direction as expected, although this trend was clearer in some components of body stature than others. This implies that the proportionality of appendicular growth (leg length) and truncal growth (sitting height) is usually maintained and these two components cumulatively dictate the total height.

It was also observed for almost all the anthropometric measurements that increase in the centile curves with the increasing age is not consistent at extremes of the centile curves i.e. at 0.4th centile and 99.6th centile. This reflects that extreme (upper and lower) end of the population either lag in growth (lower centiles) or exceeds in growth (upper centiles).

Comparison of the data collected in this study from the UK population (as reference) gave some very useful information. The SA children generally had shorter height, sitting height and leg length and a lower body weight compared to UK reference population. However, they had higher BMI, WC, BF% compared to the UK reference population. Even though the BF% extended only up to 18 year for reference population, but for the age group where BF% for reference population was available, it clearly indicated that SA children had higher BF%, contributing to their overall obesity and increase in waist circumference. It reflects the ethnic differences in the overall population in SA and Caucasians living in UK.

The development of ethnic specific BF% and SMM centile curves offer the potential of identifying those children and adolescents that may be at increased risk of developing T2DM, who would otherwise be considered 'healthy' based on the current BMI centile cut-offs. This is because the balance between body fat and muscle appear to be critical predictor of metabolic disease.

8.4 Further Research

The work conducted in this thesis has generated a whole new set of anthropometric and body composition assessment tools specific for the UK SA population. They provide a launching pad for further application and testing of these charts in clinical, public health and research settings. Immediate research should test these charts in an independent population group and to demonstrate how they might better capture metabolic risk compared with the current UK1990 references. Furthermore, defined cut-offs have not been set but there is no reason to suggest that these should differ from the conventional cut offs 2nd, 91st and 98th centiles as they are population specific.

An acknowledged limitation of this study is the fact that the BIA data was not transformed or corrected for ethnicity. The reasons for this have been explained but further research should prioritise the production of body compartment correction factors using DXA as the criterion method. In the meantime, however, these charts should be used untransformed.

No blood or physiological measurements were collected in this study. It is always best to demonstrate adverse changes in parameters such as blood pressure, HbA1c and blood lipids in relation to cut-offs for WC, BMI, %BF and SMM (kg). Therefore, it is recommended that such studies should be conducted which could then add further credibility to these SA-specific assessment tools in relation to metabolic risk.

It has been acknowledged that all participants in this study came from a range of South Asian heritages. Whether these charts are equally applicable across the difference groups should be evaluated. In addition, due to little international comparison data being available, more studies should be undertaken in India, Pakistan and Bangladesh to explore how body composition and anthropometry varies between indigenous and migrant groups. Such studies might also allow for examination for socio-economic influences – an important factor that could not be evaluated in this study.

The literature still questions the accuracy of BIA as a means of predicting body composition. However, the technology has improved over the recent years and there is no doubt that reliability is excellent. Given the non-invasive nature of the technology, its portability, ease and speed of use, a small compromise in accuracy is deemed acceptable. However, further research into producing more accurate predictive equations, especially taking into account the variation in the hydration of the FFM should be recommended.

In relation to this study the sample should be expanded to include participants nationwide to try to achieve a truer representation of the SA population living in UK including those from different socioeconomic status. Due to growing interest in use of centile charts in adult population it is feasible to construct centile charts for additional parameters such as blood pressure and thigh circumference for SA adults. The latter variable could be used as a quick screening tool to assess risk for sarcopenia – a key factor in deciding whether an elderly individual should be considered to be moved to a care home With a growing elderly and relatively inactive population, this has been seen as the next major public health issue to affect the UK and beyond.

In addition, as both environmental and genetic factors are considered to have a strong association with adult stature the specific factors involved in height variations are still unclear. This could be important in this population group so there is a need for further research to explore the impact in relation to obesity-related morbidity.

Despite all the research being undertaken to relate body composition to metabolic risk, particularly in SAs, nevertheless in no country worldwide has there been evidence of a successful public health intervention to reduce overweight and obesity and consequence metabolic disease. This must the most pressing area of further research. Failure to achieve this goal will only continue to add burden to decreasing healthcare resources and quality of life for a large section of the global population.

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APPENDICES

Appendix 1 – Participant Information Sheet

LONDON METROPOLITAN UNIVERSITY

PARTICIPANT INFORMATION SHEET

Full title of Project: Improved characterisation of measures of health and metabolic risks in older adolescence and young adults in south Asian population in the UK

You are being invited to take part in a study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

What is the purpose of the study?

The study is being conducted to collect information on measures of growth including height, weight, waist circumference, and leg length in the UK south Asian population aged between 16 and 21 years. People living in UK from South Asian background have greater risk of developing heart disease and type 2 diabetes compared to other UK residents and it is thought that this is due, in part, to differences in the composition of the body. For example, it is known that there are important differences between south Asians and Europeans in how much skeletal muscle is gained during growth and how fat is distributed around the body. Collection of these body measurements will help us to better understand why the south Asian population are at higher risk of these health conditions. The measurements collected from South Asian population will be used to make growth reference charts, similar to those that are used to measure the growth of a baby. We have already obtained these measurements for South Asians children and youths aged between 5 and 15 years, but we don’t have this information for 16 to 21 years old adolescents and young adults. This study will help to fill this information gap for this particular age group. This will result in the full set of references for age range 5 to 21 years.

Why have I been invited to participate?

You have been approached because you meet the age range and live in the area of London where we are conducting the study. We are looking to recruit a total of 500 participants who belong to the south Asian community.

Do I have to take part?

Your participation is entirely voluntary, and it is up to you to decide whether or not to take part in this study. Refusal to take part will not have any implication on you at all. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a consent form agreeing to take part. If you decide to take part, you are still free to withdraw from the study at any time and without giving a reason.

What will happen to me if I take part?

We will take you in a private area where we will take measurements of your height, weight and around your waist. The measuring time will not take more than 10 minutes. Some of the time you would be standing barefoot on a special set of scales. These scales are completely safe, will then send a tiny electrical signal through the body to measure the amount of fat and muscle in the body. All these measurements will be taken by a female trained measurer.

What are the possible disadvantages and risks of taking part?

There are no risks involved if you decide to take part in the study. Body measurements will be taken on one occasion only during your study participation.

What are the possible benefits of taking part?

There are no direct benefits expected to you if you chose to participate in the study except that you can receive a record of your own body composition measurement.
The measurements collected from you and the other participants will, however, be used to construct the growth charts for specific for south Asian populations.

Will my information be kept confidential?

All information collected about you will be kept strictly confidential (subject to legal limitations). Access to the data will only be by researchers working on this study. Computer files will be password protected and all data, codes and identifying information will be anonymised and kept in locked filing cabinets. The findings generated in the course of the research will be kept securely for a period of ten years after the completion of a research project.

What should I do if I want to take part?

If you would like to take part in this study, you can do so by contacting the researchers at the mail address or email address given at the end of this information sheet.

What will happen to the results of the research study?

The results of this research will be published in a scientific journal. Your identity will not be recognisable from this. If you would like a copy of the published research, you can contact the researchers at the mail address or email address given below following completion of the study.

Who has reviewed the study?

This research proposal has been reviewed and approved by the Research Ethics Committee at London Metropolitan University.

Contact for Further Information:

Prof. H David McCarthy
School of Human Sciences
London Metropolitan University
Holloway Road
London
N7 8DB
Email: d.mccarthy@londonmet.ac.uk

Erum Moqueem
Researcher
School of Human Sciences
London Metropolitan University
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Appendix 2 – Consent Form

LONDON METROPOLITAN UNIVERSITY

Project Title: Improved characterisation of measures of health and metabolic risks in older adolescents and young adults in the South Asian population in the UK

FULL CONSENT FORM

Name of the Participant (capitals)

____

Name of participant's parents (capitals)

____

(Either mother or father)

Please initial each statement to show your agreement

1. I confirm I have read the participant information sheet on the above project and have been given a copy to keep. I have had the opportunity to ask questions about the project and I am satisfied with the information that I have been given. ☐

2. I understand that my child's participation is voluntary and that I am free to withdraw at any time, without giving any reason, without legal rights being affected. ☐

3. I consent for my child to take part in the study and know how to contact the research team if I need to. ☐

Parent's signature ____________________ Date _____________

I confirm that I have fully explained the nature of this study to the above-named volunteer and his/her parents

Co-ordinator's signature __________________

Date_____________

Appendix 3 – Letter to Parents

Re: Improved characterisation of measures of health and metabolic risks in older adolescents and young adults in the South Asian population in the UK

Dear Parent,

We are writing to seek your permission for your son/daughter to take part in a study involving measurement of their height, weight, around the middle of the body and measurement of muscles and fat present in the body. Your son/daughter is being selected to take part in the above titled study because he/she meets the age range. The study is being conducted to collect the information to develop growth charts (BMI centile charts, WC centile charts, and body fat mass centile charts and skeletal muscle mass centile charts) for south Asian population aged between 16 and 21 years.

These measurements will not take more than 10 minutes of your son/daughter's time. Some of the time your child would be standing barefoot on a special set of scales to weigh them. These scales, which are completely safe, will then send a tiny electrical signal to the body to measure their body weight and how much fat and muscle is present in the body.

All measurement will be taken and recorded in strict confidence. Access to the information will only be by researchers working on this study. If you wish, a copy of result can also be sent to you.

We hope you will agree to give your son/daughter an opportunity to help the school in such an important project.

Sincerely,

Erum Moqueem
Researcher
School of Human Sciences
London Metropolitan University
Holloway Road
London, N7 8DB
Email: erm0181@my.londonmet.ac.uk

Contact for Further Information:

Prof. H David McCarthy
School of Human Sciences
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Appendix 4 – Letter to Schools, Colleges and Mosques

LONDON METROPOLITAN UNIVERSITY

Re: Improved characterisation of measures of health and metabolic risks in older adolescents and young adults in the South Asian population in the UK

We are health researchers in London Metropolitan University with a particular interest in the health of people from a south Asian background living in the UK. We are carrying out a study on measures of growth and body composition in this population group aged between 16 and 21 years. The measurements will be used to develop growth charts specific for the south Asian community.

You may be aware that being from a south Asian heritage carries a greater risk of developing type 2 diabetes and heart disease. This risk is due, in part, to specific characteristics of body composition, particularly the amount and distribution of body fat and the amount of muscle. At the same time, these risks begin in childhood and develop across adolescence as individuals grow and mature into adulthood

We hope that the results of the study will help us developing the growth charts that can be used to identify the individuals who are at high risk for type 2 diabetes and heart disease in the south Asian population. These growth charts would also help health authorities with their strategies for addressing high-risk groups in this population.

We are writing to enquire whether you would give us permission to recruit participants for this study from among the students currently enrolled at your school/college /mosque. We have focussed on your institution due to the large number of students from a south Asian background. We have already collected identical measurements in children aged 5-15 years, but we need to extend this to cover the age range 16-21 years.

Our previous experience informs us that students aged 16 years and above are able to consent for themselves to take part in studies, however we have also prepared a letter to send to parents in order to, where requested, obtain parental permission. We would also need permission to complete these measurements during school hours. These measurements will not take more than 10 minutes per individual and a female trained measurer in private will take all measurements.

If you have any comments or questions about this study please feel free to contact us via email.

Sincerely,

Erum Moqueem BSc, MSc

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Appendix 5. Ethical Approval letter

LONDON METROPOLITAN UNIVERSITY

26.10.2016

Mrs. Erum Moqeem
Research student
School of Human Sciences
London Metropolitan University
London
N7 8DB

Dear Mrs Moqeem,

Research project title: Improved characterisation of measures of health and metabolic risks in older adolescence and young adults in south Asian population in the UK

Thank you for submitting your project for ethical approval together with associated documents. I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the research ethics form, project protocol and supporting documentation.

Approved documents

The final list of documents reviewed and approved is as follows:

Document	**Date/version no.**
Ethics application form	05/10/2016
Participant information sheet	04/10/2016, v2
Participant consent form	04/10/2016, v2
Letter to parents	04/10/2016, v2
Letter to schools	04/10/2016, v2
Letter to mosques	04/10/2106, v2

Where a variation or substantial amendment to any aspect of the above documentation is required, the updated version(s) with new version number must be submitted to the ethics panel for approval. This approval covers the duration of your MPhil/PhD registrations.

Wishing you every success with this project.

Yours sincerely,

H. David McCarthy

(Prof). H. David McCarthy PhD RNutr
Chair SHS ethics panel

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