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The growth of Bradford infants

By

William Johnson

A Doctoral Thesis

Submitted in partial fulfilment of the requirements for the award of

Doctor of Philosophy of Loughborough University

8th January 2010

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Abstract

Background
Infant growth is a key indicator of health and a relevant component of paediatric surveillance. Certain growth characteristics are also associated with greater risk for diseases such as obesity and cardiovascular disease. South Asian populations are known to demonstrate poor infant growth and suffer from a high prevalence of non-communicable disease. Relatively little is known about the growth of Pakistani infants, especially following migration. In the United Kingdom (UK), infant growth is routinely monitored to detect poor health, and this process produces a repository of largely unutilised data. In 2009, new growth charts, which include a component of the World Health Organisation (WHO) growth standards, were introduced to routine practice. The adoption of prescriptive standards, which are based on breastfed infants living in an unconstrained environment, will have implications for the assessment of growth.

Aims
To develop and assess the quality of routine growth monitoring data collected in Bradford, UK, so that it can be used to describe the differences in growth between White British and Pakistani infants in the same city. To investigate the factors that influence this growth. To assess the implications of adopting growth standards for practice.

Methods
The frequency of routine growth monitoring data that are collected at prescribed age periods was assessed. Test-retest growth data were collected from 192 practitioners, and technical error of measurements were calculated. Data on 2464 (boys 51%, White British 45%) infants were submitted to multilevel modelling analysis to produce sex and ethnic specific weight-for-age, abdominal circumference-for-age, head circumference-for-age, and length-for-age growth curves between birth and nine months. Multivariable linear regression models were used to investigate factors that influence size at birth and at nine months. Growth curves were plotted
against the WHO standards and the UK 1990 references, Z-scores were calculated, and the relative risks (RR) of underweight, obesity, and poor infant weight gain using the standards compared to the references were assessed.

**Results**
During each prescribed age period for routine growth monitoring generally only 30% to 35% of measurements were recorded. None of the technical error of measurements were excessively large, and coefficients of reliability ranged from 0.96 to 1.00. Multilevel models explained that Pakistani infants were smaller than White British infants, in the first nine months of life, for weight (-210.3g to -321.7g), abdominal circumference (-1.15cm to -0.39cm), head circumference (-0.59cm), and length (-0.32cm). Compared to the WHO standards, infants demonstrated dissimilar weight growth, but similar head circumference and length growth. The common weight growth pattern was slow growth between birth and two months, followed by rapid growth. Using the standards, infants were significantly less likely to be classified as underweight (RR at birth 0.496; 95% Confidence Interval 0.363 to 0.678) and demonstrating poor weight gain from birth to nine months (0.783; 0.644 to 0.952).

**Conclusions**
Growth monitoring data are not collected at prescribed age periods, but following initial training of practitioners are reliable. Integrating research with practice has developed routine data to research calibre and has established protocols to make data more accessible. Pakistani infants were consistently smaller than White British infants, and, despite efforts, the determinants of this phenomenon have not yet been fully elucidated. Growth in weight of infants in Bradford differs significantly from that represented by the WHO standards, and without adequate training of practitioners infant growth may be incorrectly interpreted.

Key Words: infant growth, Pakistani, growth monitoring, routine data, growth standards, developmental origins of adult disease
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I would finally like to thank the Child Growth Foundation for providing me with part of my studentship, and the Born in Bradford babies, without which this research would not have been possible.
The Tiger

William Blake 1757-1827

Tiger! Tiger! burning bright
In the forests of the night,
What immortal hand or eye
Could frame thy fearful symmetry?

In what distant deeps or skies
Burned the fire of thine eyes?
On what wings dare he aspire?
What the hand dare seize the fire?

And what shoulder, and what art,
Could twist the sinews of thy heart?
And when thy heart began to beat,
What dread hand? And what dread feet?

What the hammer? What the chain?
In what furnace was thy brain?
What the anvil? What dread grasp
Dare its deadly terrors clasp?

When the stars threw down their spears,
And watered heaven with their tears,
Did he smile his work to see?
Did he who made the lamb make thee?

Tiger! Tiger! burning bright
In the forests of the night,
What immortal hand or eye
Dare frame thy fearful symmetry?
Publications

Papers


Prepared manuscripts
Cameron, N., Johnson, W., Leon, D., Wright, J. “The growth of Pakistani and White British infants, living in Bradford UK, in comparison to the WHO standards”, *British Medical Journal*.

Conferences contributions

The 77th annual meeting of the American Association of Physical Anthropologists (AAPA)- Columbus, Ohio 9th to 12th April 2008.

The 87th scientific meeting of the Society for the Study of Human Biology (SSHB) 50th Anniversary Meeting – Oxford University 1st to 3rd April 2008.

Johnson, W., Cameron, N. 2009, (paper) “The growth of Pakistani and Caucasian infants, living in Bradford UK, in comparison to the WHO Standards”.
The 88th scientific meeting of the Society for the Study of Human Biology (SSHB) – Rome 18th to 20th June 2009.

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<tbody>
<tr>
<td>ACFA</td>
<td>Abdominal Circumference-for-Age</td>
</tr>
<tr>
<td>AGA</td>
<td>Appropriate for Gestational Age</td>
</tr>
<tr>
<td>ALSPAC</td>
<td>Avon Longitudinal Study of Parents and Children</td>
</tr>
<tr>
<td>BiB</td>
<td>Born in Bradford</td>
</tr>
<tr>
<td>BIHR</td>
<td>Bradford Institute for Health Research</td>
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<tr>
<td>BLUP</td>
<td>Best Linear Unbiased Prediction</td>
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<tr>
<td>BMI</td>
<td>Body Mass Index</td>
</tr>
<tr>
<td>BMIFA</td>
<td>Body Mass Index-for-Age</td>
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<tr>
<td>BRI</td>
<td>Bradford Royal Infirmary</td>
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<tr>
<td>CGF</td>
<td>Child Growth Foundation</td>
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<tr>
<td>CHD</td>
<td>Coronary Heart Disease</td>
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<tr>
<td>CI</td>
<td>Confidence Interval</td>
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<tr>
<td>CPT</td>
<td>Community Practice Teacher</td>
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<tr>
<td>CVD</td>
<td>Cardiovascular Disease</td>
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<tr>
<td>DoH</td>
<td>Department of Health</td>
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<tr>
<td>GDM</td>
<td>Gestational Diabetes Mellitus</td>
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<td>GMBS</td>
<td>Gateshead Millennium Baby Study</td>
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<tr>
<td>GTT</td>
<td>Glucose Tolerance Test</td>
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<tr>
<td>HBCS</td>
<td>Helsinki Birth Cohort Study</td>
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<tr>
<td>HCFA</td>
<td>Head Circumference-for-Age</td>
</tr>
<tr>
<td>HDL-C</td>
<td>High Density Lipoprotein-Cholesterol</td>
</tr>
<tr>
<td>HPG</td>
<td>Hypothalamic-Pituitary-Gonadal</td>
</tr>
<tr>
<td>HSE</td>
<td>Health Survey for England</td>
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<tr>
<td>IDF</td>
<td>International Diabetes Federation</td>
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<tr>
<td>IFS</td>
<td>Infant Feeding Survey 2005</td>
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<td>IMD</td>
<td>Index of Multiple Deprivation</td>
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<tr>
<td>IMR</td>
<td>Infant Mortality Rate</td>
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<tr>
<td>LBW</td>
<td>Low Birth Weight</td>
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<tr>
<td>LFA</td>
<td>Length-for-Age</td>
</tr>
<tr>
<td>LGA</td>
<td>Large for Gestational Age</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>LMS</td>
<td>Least Mean Squares</td>
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<td>LSOA</td>
<td>Lower layer Super Output Areas</td>
</tr>
<tr>
<td>MetS</td>
<td>Metabolic Syndrome</td>
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<tr>
<td>MCS</td>
<td>Millennium Cohort Study</td>
</tr>
<tr>
<td>MGRS</td>
<td>Multicentre Growth Reference Study</td>
</tr>
<tr>
<td>MLM</td>
<td>Multilevel Model</td>
</tr>
<tr>
<td>NIDDM</td>
<td>Non-Insulin Dependent Diabetes Mellitus</td>
</tr>
<tr>
<td>NCD</td>
<td>Non-Communicable Disease</td>
</tr>
<tr>
<td>NCHS</td>
<td>National Center for Health Statistics</td>
</tr>
<tr>
<td>NCMP</td>
<td>National Child Measurement Program</td>
</tr>
<tr>
<td>NHS</td>
<td>National Health Service</td>
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<tr>
<td>NMC</td>
<td>Nursing and Midwifery Council</td>
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<tr>
<td>NSPD</td>
<td>National Statistics Postcode Directory</td>
</tr>
<tr>
<td>OR</td>
<td>Odds Ratio</td>
</tr>
<tr>
<td>P2PG</td>
<td>Phase 2-Postnatal Growth</td>
</tr>
<tr>
<td>PAR</td>
<td>Predictive Adaptive Response</td>
</tr>
<tr>
<td>PCHR</td>
<td>Personal Child Health Record</td>
</tr>
<tr>
<td>PCT</td>
<td>Primary Care Trust</td>
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<tr>
<td>PMNS</td>
<td>Pune Maternal Nutrition Study</td>
</tr>
<tr>
<td>RCPCH</td>
<td>Royal College of Paediatrics and Child Health</td>
</tr>
<tr>
<td>REM</td>
<td>Random-Effects Model</td>
</tr>
<tr>
<td>RR</td>
<td>Relative Risk</td>
</tr>
<tr>
<td>SACN</td>
<td>Scientific Advisory Committee on Nutrition</td>
</tr>
<tr>
<td>SD</td>
<td>Standard Deviation</td>
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<tr>
<td>SE</td>
<td>Standard Error of the Estimate</td>
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<tr>
<td>SES</td>
<td>Socio-Economic Status</td>
</tr>
<tr>
<td>SGA</td>
<td>Small for Gestational Age</td>
</tr>
<tr>
<td>TEM</td>
<td>Technical Error of Measurement</td>
</tr>
<tr>
<td>TFR</td>
<td>Total Fertility Rate</td>
</tr>
<tr>
<td>tPCT</td>
<td>teaching Primary Care Trust</td>
</tr>
<tr>
<td>UK90</td>
<td>United Kingdom 1990 (growth references)</td>
</tr>
<tr>
<td>USA</td>
<td>United States of America</td>
</tr>
<tr>
<td>VIF</td>
<td>Variance Inflation Factor</td>
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<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<td>---------------------------</td>
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<tr>
<td>WFA</td>
<td>Weight-for-Age</td>
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<tr>
<td>WHO</td>
<td>World Health Organisation</td>
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1 Introduction
1.1 Investigating infant growth in Bradford, United Kingdom

Infant growth is a key indicator of current health and nutritional status, and a relevant component of paediatric surveillance worldwide. Epidemiological research has established that infant growth is also a key indicator of future health. Small size at birth and rapid postnatal growth have been associated with increased risk various non-communicable diseases (NCDs) during adulthood (Eriksson et al. 2001; Frankel et al. 1996; Hales et al. 1991; Ong & Dunger 2004; Osmond et al. 2007). All of the biological mechanisms responsible for these associations have not yet been fully elucidated, although numerous hypotheses have been proposed to explain the developmental origins of adult disease.

The growth of South Asian populations is an important research topic because of known health inequalities. South Asian infants are among the smallest in the world (Yajnik 2004a), and South Asian adults have higher prevalence rates of cardiovascular disease (CVD) and non-insulin dependent diabetes mellitus (NIDDM) than western populations (Misra et al 2007). The majority of research reporting growth inequalities during infancy has been conducted among native populations in India (Krishnaveni et al. 2005; Yajnik et al. 2003). There are fewer published data on infant growth in populations from other countries that comprise South Asia, including Bangladesh and Pakistan, and among South Asian populations in western countries, such as the United Kingdom (UK) (Cheung, Yip & Karlberg 2001; Fikree, Rahbar & Berendes 1999, 2000; Janjua et al. 2009; Karlberg et al. 1993; Nahar, Mascie-Taylor & Begum 2007).

With the building of the Mangla Dam in the 1960’s, there was a large scale population displacement of individuals from the Mirpur region of Pakistan, and a subsequent increase in the number of Pakistanis residing in the UK. The city of Bradford was a popular destination choice for Pakistani migrants, and it is now estimated that half of the annual births at Bradford Royal Infirmary (BRI) are to parents of South Asian origin (Born in Bradford Collaborative Group 2006). Knowledge of the growth of Pakistanis following
migration to the UK, and the socio-economic, cultural, and nutritional factors common to that ethnic group that are responsible for their growth, helps elucidate the biological mechanisms responsible for increased disease risk and informs potential interventions. However, of the publications that have investigated the growth of Pakistanis in the UK, most have focused solely on birthweight as a surrogate measure of foetal growth (Harding, Rosato & Cruickshank 2004; Kelly et al. 2009). Only two studies have investigated infant growth of Pakistanis in the UK, in which data were collected at few and infrequent ages (Bansal et al. 2008; Tate et al. 2006).

In the UK, health care practitioners assess infant growth using growth charts, which depict the range of sizes, of a source sample, in the form of a centile distribution. There are no published growth curves for Pakistani infants in the UK, and without this information it is unknown whether the charts are representative of this population. This is a particularly relevant topic, because of the recent launch of new growth charts for use in the UK, which combine the World Health Organisation (WHO) standards (WHO Multicentre Growth Reference Study Group 2006a, 2007) with the previously used UK 1990 references (UK90) (Cole, Freeman & Preece 1995, 1998; Freeman et al. 1995). The difference in design between growth references, which describe how infants are growing, and growth standards, which describe how infants ought to be growing, means that the new UK-WHO charts will have implications for the interpretation of the growth of both White British and Pakistani infants in the UK. Only one study has addressed these implications, in which cross-sectional data were compared to the longitudinal WHO standards, potentially limiting the accuracy of the results (Wright et al. 2008).

The National Health Service (NHS) in the UK routinely collect infant growth data for the purposes of growth monitoring. These data are largely unutilised, even though they have potentially important uses for research into different aspects of infant growth and health, and for public health surveillance. When entered into an electronic system, as is usual practice (Patterson et al. 2006), these data also provide the NHS with easily
accessible data to assess and improve the quality of growth monitoring. The collaboration of researchers with the NHS to standardise the measurement technique of practitioners responsible for data collection, and improve other aspects of data collection, entry, and extraction will allow growth monitoring data to be developed to research calibre and be utilised to its full extent.

1.2 Aims

The development of routine growth monitoring data
- To assess whether routine growth monitoring data are collected at prescribed age periods.
- To determine whether routine growth monitoring data are reliable.

The growth of White British and Pakistani infants
- To describe the differences in growth between White British and Pakistani infants between birth and nine months of age.
- To describe the differences in size between White British and Pakistani infants at birth and nine months of age, after adjusting for other factors known to influence growth.
- To compare the growth of White British and Pakistani infants to the UK90 references and WHO standards in order to assess the implications of adopting the new UK-WHO growth charts.
2 Background
2.1 Human growth

Growth is defined as a quantitative increase in size or mass of a body dimension (Bogin 1999). It is a distinct biological process that should not be confused with maturity or development, which are an increase in functional ability. The endpoint of growth occurs when adult size is attained, whereas the endpoint of maturation occurs when we are able to reproduce (Cameron 2002). Fundamentally, growth occurs at the cellular level, as the result of hypertrophy and hyperplasia, and interstitial secretion (Thompson 1971).

This thesis will, however, focus on growth at the organismic level, that is at the level of the whole individual.

2.1.1 Representation of growth

The distance curve is a way of visualising how far an individual has progressed towards adult size (Cameron 2002). The first distance curve was produced by an American anatomist, R. E. Scammon, who translated length measurements of the son of a French Encyclopaedist, De Montbeillard, from the French units of measurement at the time (pieds, pouces, and lignes) to centimetres. Scammon (1930) joined together the six monthly data points to produce a height distance curve between birth and 18 years of age. Distance curves are now more commonly referred to as size-for-age curves.

The length-for-age curve of De Montbeillard’s son described growth as a reasonably smooth and continuous, non-linear process. Since then, it has been established that growth is not, as once thought, continuous. The pattern of growth that is represented in size-for-age curves is function of the frequency of data acquisition. By using daily, biweekly, and weekly measurements Lampl et al (1992) demonstrated that growth is a process of incremental bursts (saltations) that punctuate longer periods of no growth (stasis).

A natural extension of the size-for-age curve is the velocity curve. By visualising velocity it is possible to identify the pattern of changing rates of growth (Cameron 2002). Using the length velocity curve of De Montbeillard’s son (see Figure 2.1) it is possible to identify five periods of varying
velocities, or phases of growth, which are best explained in terms of developmentally functional stages within the life cycle.

**Figure 2.1. The length velocity curve of De Montbeillard’s son between birth and 18 years of age (redrawn from Tanner JM. Growth at Adolescence, 2nd Ed. Oxford: Blackwell Scientific Publications, 1962)**

![Graph showing height velocity curve](image)

### 2.1.2 Stages in the life cycle

Postnatal growth occurs during four developmentally functional stages: infancy, birth to two years; childhood, second to seventh year; juvenile, seventh to tenth for girls and seventh to twelfth for boys; and adolescence, occurs at the end of the previous stage and ends at approximately 18 years of age (n.b. this stage comprises two phases of growth). Infancy marks the critical transition between life in utero, where the uterine environment provides support for the developing foetus, and postnatal life. It is a high velocity, rapidly decelerating phase of growth, and encompasses many developmental milestones in physiology, behaviour, and cognition. The onset of childhood marks the cessation of bottle feeding or less commonly breastfeeding, and is a stage characterised by a more moderate and constant growth velocity. During childhood, individuals start to learn survival skills but are still dependent on others for food and protection (Bogin 1999).
At the end of childhood there is a small increase in growth velocity, referred to as the mid-growth spurt (Tanner 1947). Juveniles are distinguishable from children in that they demonstrate a slower growth velocity and are not dependent on others for survival (Pereira & Altman 1985). Adolescence is characterised by a dramatic increase in growth velocity, referred to as the adolescent growth spurt, due to the reactivation of the hypothalamic-pituitary-gonadal (HPG) axis and an increase in the secretion of sex steroids (Plant 2008). Puberty is often used synonymously with adolescence, although refers more to the reactivation of the HPG axis and the development of secondary sexual characteristics than somatic and psychosocial change, and shall be used as such. Maximum growth velocity in height is reached at approximately three and a half years after the onset of the adolescent growth spurt, after which velocity decelerates until the attainment of adult stature at approximately 20 years of age (Cameron 2002). This thesis will refer to stages in the life cycle as defined above, but will primarily focus on growth during infancy.

2.1.3 Growth during infancy
Infants grow very fast, with a height velocity of approximately 18cm/yr, and during the first year of life velocity is even faster, at approximately 25cm/yr (Cole, Freeman & Preece 1998). This is more than double the velocity observed in childhood of 7cm/yr. There are also small sex differences present from birth of 0.8cm and 151g, in favour of boys, that reach about 1.0cm and 500g by two years of age (Cole, Freeman & Preece 1998).

It has long been recognised that growth is dependent on both genetics and the environment, and growth during infancy can not be solely explained in terms of individual genotype (Lejarraga 2002). Tanner (1964) reported that size at birth is poorly correlated (coefficient of 0.2) with adult stature. However, by two years of age the correlation between current height and adult height has increased (coefficient of 0.8). Thus, during infancy, the genes that regulate growth become more influential. Bogin (1999) states that the environment has a larger effect on growth during infancy compared to any other postnatal stage in the lifecycle.
One factor proven to be very important in the modulation of foetal growth, and therefore size at birth and arguably infant growth, is maternal size. Walton and Hammond (1938) were the first to propose that small mothers tend to have small babies, and large mothers tend to have large babies, independent of genotype. This research group crossed a Shire horse sire with a Shetland pony mare, and a Shetland pony sire with a Shire horse mare. The offspring of the Shire horse mare had a greater birthweight compared to that of the Shetland pony mare, even though both foals shared the same proportion of genes from each parent. It is the size of the mother, and more specifically the mother’s uterus, that determines maximal intrauterine size. In evolutionary terms this is an adaptive mechanism that allows for a genetically large foetus (i.e. with large parent(s)) to be born to a mother with a small uterus.

It is likely that we have a genetically determined potential for adult stature, and in an unconstrained environment the process of growth takes us inexorably toward that target (Cameron 2002). Waddington (1957) proposed that individuals grow within some imaginary canal that is parallel to any given centile on a growth reference chart (see section 2.1.6). He called this phenomenon homeorhesis, although it is know more commonly known as canalisation. With birth, the uterine environment no longer limits growth, and infants can seek their genetically determined growth canal. Genetically large infants who are born small demonstrate catch-up growth (upward shifting through centiles), and genetically small infants who are born large demonstrate catch down-growth (downward shifting through centiles) (Tanner 1986). In the first 13 months of life, as many as two thirds of infants shift centiles to achieve a new growth canal (Smith et al. 1976).

To summarise, infancy is a high velocity phase of growth characterised by adjustment to environmental changes and increasing genetic regulation (Johnston 1986). These characteristics mean that growth during infancy is a relevant indicator of health and instrument for paediatric surveillance.
2.1.4 Growth and health
The growth rate of an infant or child is perhaps a better indicator of general health and nutritional status than any other single measure (Cameron 2007). Some diseases or conditions can be recognised because the first clinical sign is poor growth, commonly referred to as failure to thrive. Infants and children suffering from malnutrition, acquired hypothyroidism, and celiac disease all demonstrate slow growth velocities (Tanner & Whitehouse 1980). Conversely, a fast growth velocity may indicate increased risk for overweight and obesity. This phenomenon will be discussed in more detail in section 2.2.

The limits of normal growth and, therefore, the ability to identify abnormal growth is fundamental for any paediatric surveillance programme (Himes 2004). How then is normal growth defined, and at what point does an infant or child start to demonstrate abnormal growth? The layman may judge an individual’s size as normal based on exposure to people within their native population (Cameron 2002). In practice, healthcare practitioners do exactly the same, they consult growth charts that provide comparative anthropometric data from a reference population. Before discussing the intricacies of growth charts, the anthropometric measures that have clinical importance for health during infancy will be summarised.

2.1.5 Measures of clinical importance
It is generally agreed that the three most important anthropometric measures for paediatric surveillance during infancy and childhood are weight, length, and head circumference.

2.1.5.1 Weight
Weight is a three-dimensional measurement, which in the study of human growth is typically measured at the level of the whole individual. As such, weight does not help us understand the relative proportions of different body compartments. A change in body weight may indicate dehydration or overhydration due to a change in body water, muscle hypertrophy or atrophy due to a change in muscle mass, wasting due to a change in lean body
mass, obesity or malnutrition due to change in body fat, and so on (Lejarraga 2002). It is, however, a very sensitive measure that can vary from day to day due to small alterations in body composition. For this reason, weight is an important tool for the early detection of disease, and is ubiquitously used to assess infant and child health.

2.1.5.2 Length/height
Length and height are unidimensional measurements that indicate the length of the long bones of the lower limb and the irregular bones of the vertebral column. Supine length is usually measured until two years of age, after which standing height is recorded (Cameron 1984). Poor length growth, referred to as stunting, is a primary manifestation of malnutrition and is often associated with poor economic and social conditions during childhood (Bogin & Loucky 1997). When length is combined with weight, body mass index (BMI, kg/m²) can be calculated and used to identify overweight, obesity, and wasting.

2.1.5.3 Head circumference
Head circumference and brain volume at birth are strongly correlated, with an R-squared value of 0.46 ($p<0.001$) (Cheong et al. 2008). Head circumference can, therefore, be used to assess the normal growth of the brain. It is a particularly important measure during infancy because at this age brain growth is rapid.

2.1.6 Growth charts
Growth charts provide comparative anthropometric data from a reference population of healthy infants and children, and are used universally in paediatric care (de Onis, Wijnhoven & Onyango 2004). The growth chart shown in Figure 2.2 depicts the normal range of weights of a reference population. Most charts are expressed in centiles lines, as opposed to Z-scores, but the exact centiles used vary. The illustrated centiles approximately equate to 0.67 Z-scores from the median. The lowest and highest centiles on the current growth charts used in the UK are the 0.4th and 99.6th, respectively. These centiles are commonly used as the limits of
normal growth (Cameron 2002). It is, however, important to note that, by design, 0.8% of normal infants and children will have weights below the 0.4\textsuperscript{th} or above the 99.6\textsuperscript{th} centile. As such, growth charts provide reasonable limits of normal size that can be used to identify infants and children with potentially abnormal weights.

*Figure 2.2. Growth chart for boys from birth to one year of age (© Child Growth Foundation 1990)*

In addition, growth charts provide guidelines for how we expect normal growth to proceed (Cameron 2002). Ong et al (2000), for example, proposed that an infant or child who exhibits movement of more than 0.67 Z-scores between measurement occasions is demonstrating either clinically significant catch-up or catch-down growth, depending on whether he/she crosses upwards or downwards through centile bands. The movement of an infant’s weight either upward or downwards through centile bands (for example, 9\textsuperscript{th} to 25\textsuperscript{th}), can be viewed by practitioners as more than simply a chance occurrence (Cameron 2002). Evidence of marked centile crossing
over time is, therefore, an indicator of a potential growth abnormality (Cole 2002).

**2.1.6.1 References Vs. standards**

There are two types of growth charts: growth references and growth standards. Growth references are descriptive of prevailing growth patterns for a reference population or source sample of normal individuals. Whereas, growth standards are prescriptive ‘standards’ that define optimum growth, and are constructed using anthropometry from individuals who live in an unconstrained environment. Growth references describe how children are growing, whereas growth standards describe how children ought to be growing (Cameron & Hawley 2009). Growth references are usually based on cross-sectional data and serve to provide a comparison of the growth of samples of infants or children. Alternatively, growth standards are based on longitudinal data and should be used specifically for individuals as opposed to samples. The choice of which type of growth chart to use depends on the question being asked. Growth references are used to respond to the question ‘is this child’s growth normal compared to the reference population?’, and growth standards are used to respond to the question ‘is this child’s growth optimal compared to infants living in an unconstrained environment?’ (Cameron & Hawley 2009).

**2.1.6.2 Which charts are being used in the United Kingdom?**

In 1999, the Royal College of Paediatrics and Child Health (RCPCH) convened an expert working group to provide guidance on the validity of different growth reference charts that were being used in the UK (Wright et al. 2002). The most widely used charts at the time were the UK90 growth references. At a similar time, the WHO were conducting a project to produce a single international growth standard that represents the best physiological growth for all children. In 2006, the WHO Standards were published. Subsequently, the RCPCH and the Scientific Advisory Committee on Nutrition (SACN) recommended that a modified version of the WHO standards should be adopted for use in the UK (Scientific Advisory Committee on Nutrition & Royal College of Paediatrics and Child Health
Despite these recommendations, on May 11th 2009 the Department of Health (DoH) launched new growth charts in the UK, which combined the UK90 data with the WHO data. The combined UK-WHO growth charts are recommended for practice throughout the UK, although it is likely that most practitioners still use the UK90 references (Fry 2009). Hereafter follows a more detailed description of the UK90 references, the WHO standards, and the UK-WHO charts.

### 2.1.6.3 United Kingdom 1990 growth references

The UK90 weight-for-age, height-for-age, and BMI-for-age growth reference curves were published in 1995 (Cole, Freeman & Preece 1995; Freeman et al. 1995) and revised in 1996. The reference for head circumference was added in 1998 (Cole, Freeman & Preece 1998). They were designed to replace the previous references that were first published in 1966 by Tanner et al (1966a, 1966b). The UK90 references combine anthropometric data collected on 37,000 individuals from 17 distinct cross-sectional surveys representative of England, Scotland, and Wales occurring between 1984 and 1992. Cole et al (1998) provide a detailed description of the surveys. Data were analysed by maximum penalised likelihood using the Least Mean Squares (LMS) method (Cole & Green 1992), which estimates the centiles in terms of three age and sex specific cubic spline curves.

The final references consisted of sex specific centile and Z-score curves between 23 weeks of gestation (33 weeks for height and BMI) and 23 years of age (17 or 18 years for head circumference, depending on sex). The nine centile format (0.4th, 2nd, 9th, 25th, 50th, 75th, 91st, 98th, 99.6th) was used to reduce the type one (false positive) error rate associated with screening based on the 3rd or 5th centiles (Cole 1994). The references allow measurements to be converted to Z-scores that are normally distributed, which means the calculation and use of velocity and conditional measures is greatly simplified (Cole, Freeman & Preece 1998). The source sample excluded individuals from ethnic minorities because of known differences in growth and final attained size between ethnic groups (Freeman et al. 1995). The UK90 references are, therefore, specific to white individuals in the UK.
2.1.6.4 World Health Organisation child growth standards

The development of the WHO standards began early in the 1990s. In preparation for a consultation of the WHO Expert Committee on the use and interpretation of anthropometry, the WHO formed seven working groups to review issues specifically relevant to health throughout the lifecourse. The mission statement of the working group on infant growth was to develop recommendations for the appropriate use and interpretation of anthropometry in infants and young children (Garza & de Onis 2004). Among other things, the group assembled anthropometric data on healthy breastfed infants, and compared their growth to the US National Center for Health Statistics (NCHS)/WHO International Growth Reference (Hamill et al. 1977). The most salient finding was that the growth of infants who were exclusively or predominately breastfed for four months did not track parallel to the 50th centile of the references, instead infants were born large and then demonstrated slow growth (WHO Working Group on Infant Growth 1994). Also, the variability of growth in the breastfed infants was significantly smaller than that of the references. Narrowing the distance between the outer centiles and the 50th centile significantly influences the prevalence of infants with measurements outside the commonly used statistical cut-off points (±2 standard deviations (SD)) used to identify inadequate or excessive growth (Garza & de Onis 2004). The working group concluded that new growth standards, that establish the breastfed infant as the normative feeding model, were needed. These recommendations were subsequently endorsed by the WHO Expert Committee (World Health Organisation 1995) and the World Health Assembly (2004).

In 1997, the WHO initiated the Multicentre Growth Reference Study (MGRS) to collect anthropometric data for the production of new international growth standards. The MGRS collected anthropometric data from birth to 71 months of age on a source sample of 8,500 infants from widely different ethnic and cultural settings in Brazil, Ghana, India, Norway, Oman, and the United States of America (USA) (de Onis et al. 2004). Inclusion criteria for mother-infant dyads were: no health, environmental, or economic constraints on growth (screening criteria included parental education and
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income levels); singleton term birth (37 to 41 weeks gestational age); absence of significant morbidity; non-smoking mother (before and after delivery); and mother willing to follow feeding recommendations (exclusively or predominately breastfed for a minimum of four months, introduction of complimentary foods by six months, and partially breastfed to be continued for a minimum of 12 months) (de Onis et al. 2004). Data were analysed using a restricted application of the LMS method, which avoids making assumptions about the distribution of the data beyond the limits of the observed values (WHO Multicentre Growth Reference Study Group 2006a).

The WHO standards were published in 2006, and consisted of length/height-for-age, weight-for-age, weight-for-length, weight-for-height, and BMI-for-age sex specific centile and Z-score curves between birth and five years of age (WHO Multicentre Growth Reference Study Group 2006a). Standards for head circumference-for-age, arm circumference-for-age, triceps skinfold-for-age, and subscapular skinfold-for-age were added in 2007 (WHO Multicentre Growth Reference Study Group 2007). The standards are representative of the best physiological growth for all children from birth to five years of age, and by identifying the breastfed infant as the normative feeding model help align research with practice (Garza & de Onis 2004). Given the short time since publication, it is not surprising that few publications have used the standards to assess the growth of a study population. Published comparisons are only available from studies in four countries, consisting of the UK (Wright et al. 2008), Belgium (Roelants, Hauspie & Hoppenbrouwers 2009), South Africa (Norris et al. 2009), and India (Prinja, Thakur & Bhatia 2009). Of these countries, only the UK has adopted the standards, or more specifically a component of the standards, for paediatric surveillance at a national level.

2.1.6.5 United Kingdom-World Health Organisation growth charts

The UK-WHO charts (available at http://www.rcpch.ac.uk) combine the preterm element of the UK90 references with the WHO standards from two weeks to four years. There are no centile lines between birth and two weeks of age because of known differences in weight loss and gain immediately
after birth (Royal College of Paediatrics and Child Health 2009). Instead, the charts emphasise that weight gain relative to birth weight is more important than centile position in the first two weeks of life. The UK90 references are recommended from four years onwards to allow all anthropometry at school entry to be plotted on the same charts (Royal College of Paediatrics and Child Health 2009). In their 2007 report the RCPCH and the SACN recommended that the WHO standards should only be used until two years because “there is already a disjunction at this age when measurement changes from supine length to standing height” thus avoiding two disjunctions (Scientific Advisory Committee on Nutrition & Royal College of Paediatrics and Child Health 2007, pp.16). The report also stated that switching from standards to references at two years would not “create difficulties for national school entry surveillance programs” (Scientific Advisory Committee on Nutrition & Royal College of Paediatrics and Child Health 2007, pp.16). It is, therefore, unknown why the UK-WHO charts include the WHO standards until four years, not two. The UK-WHO charts were launched on the 11th May 2009, and as such it is likely that most practitioners still use the UK90 references to assess child growth and health (Fry 2009).

2.2 Growth and adult health

The growth of individual is not only an indicator of current health but has also been established as an indicator of health during adulthood. Various NCDs, that often proceed a number of metabolic abnormalities, are more prevalent in adults who demonstrated specific growth patterns in infancy and childhood. Researching the accuracy and feasibility of using growth rates to identify and intervene in those most at risk of NCD may be beneficial for informing national health surveillance programmes.

2.2.1 The metabolic syndrome

The metabolic syndrome (MetS) is the clustering within an individual of metabolic abnormalities or symptoms that increase risk for various NCDs, in particular CVD and NIDDM (Reaven 1988). This clustering of symptoms has
been documented in prospective studies by cluster analysis and cannot be explained by chance occurrence alone (Hanley et al. 2002). However, there has been debate whether the MetS actually exists and if it should be incorporated into clinical practice. Grundy (2006, pp.1689) states that, “if the metabolic syndrome is defined as multiple risk factors that are metabolically interrelated, then the syndrome certainly exits”. The debate really pertains to whether the risk associated with the MetS is more than the sum of its parts. Published data on this topic are inconclusive (Alexander et al. 2003; Sundstrom et al. 2006; Yarnell et al. 1998) and the term syndrome continues to be commonly used. Also, despite efforts, there is no consensus on the symptoms that best define the MetS, although most diagnostic criteria include measures of abdominal adiposity, elevated blood pressure, and elevated blood glucose (Grundy 2007).

The prevalence of the MetS is increasing to epidemic proportions in both developed and developing nations, and represents a global health problem (Cornier et al. 2008). In 2005, CVD accounted for 30% of all global deaths (World Health Organisation 2009a), making it the number one cause of death. Whereas, the global mortality attributable to diabetes in 2000 was estimated to be 2.9 million deaths, which is equivalent to 5.2% of all deaths (Roglic et al. 2005). Wild et al (2004) have estimated that the total number of people with diabetes will increase from 171 million in 2000 to 366 million in 2030. This represents an increase in the global prevalence of diabetes from 2.8% to 4.4%. Heart disease and stroke account for approximately 65% of deaths among people with diabetes (Geiss, Herman & Smith 1995). An increase in NIDDM will inevitably lead to an increase in deaths attributable to both CVD and NIDDM.

The high prevalence rates of CVD and NIDDM are, in part, a result of the overweight and obesity epidemic. The WHO estimated that, in 2005, 1.6 billion adults were overweight and at least 400 million were obese (World Health Organisation 2009b). Furthermore, the WHO projects that by 2015 these figures will have increased to 2.3 billion and 700 million, respectively. Individuals are developing excess adipose tissue at increasingly earlier
ages, and an increasing prevalence of overweight and obesity has been reported among British children aged three to four years (Bundred, Kitchiner & Buchan 2001), Canadian children aged seven to 13 years (Tremblay & Willms 2000), and Belgian individuals aged six to 18 years (Hulens et al. 2001). The early onset of overweight and obesity means that there is an increasing prevalence of children with components of the MetS, and increased risk for adult obesity, CVD, and NIDDM (Burke et al. 2005; Ford, Giles & Dietz 2002; Weiss & Caprio 2005).

2.2.2 Associations between growth and non-communicable diseases

In the early 1900’s, Kermack et al (1934) reported that better childhood living conditions were responsible, in part, for the declining mortality rates observed in the UK and Sweden between 1751 and 1930. Almost half a century later, Forsdahl (1977) demonstrated a significant positive correlation between mortality from arteriosclerotic heart disease, in people aged between 40 and 69 years of age, and infant mortality 70 years earlier. Forsdhal (1977) postulated that poverty and food insecurity in childhood and adolescence were risk factors for CVD in adulthood. In the early 1980’s, Barker and colleagues from Southampton University conducted a detailed analysis of one million CVD related deaths between 1968 and 1978 in the UK (Barker & Osmond 1986). The geographical distribution of CVD closely mapped the distribution of infant mortality 50 years prior to the study, when the population being studied were born. Barker et al (1989a) subsequently proposed that environmental conditions, which impair growth and development early in life, result in an increased risk for CVD later in life.

Direct evidence that growth is negatively correlated with risk for CVD came from subsequent studies conducted by Barker and colleagues in the 1980’s and 1990’s. Among 15,726 people born in Hertfordshire, UK between 1911 and 1930 death rates from CVD fell progressively with increasing birth weights in both men and women (Barker et al. 1989b). In fact, the risk of death from CVD was double in individuals who were born low birth weight (LBW <2500g) compared to those born with a weight of more than 4000g.
(Osmond et al. 1993). Following this, a series of worldwide epidemiological studies sought to describe the growth characteristics in infancy and childhood that are risk factors for the NCDs common to persons with the MetS.

2.2.2.1 Small size at birth
A negative correlation between birthweight and risk for CVD in adulthood has been reported in numerous countries, including Finland (Eriksson et al. 2001), India (Stein et al. 1996), Sweden (Leon et al. 1998), the UK (Frankel et al. 1996), and the USA (Rich-Edwards et al. 1997). A consistent finding in these studies is that increased disease risk is not confined to infants with the lowest birthweights, but is rather a continuum that extends across the full range of birth weights in a graded manner. For example, the Hertfordshire study showed that men with above average birth weights had 24% lower standardised mortality ratios from coronary heart disease (CHD) compared to those with average birth weights (Barker et al. 1989b). Similar associations between birthweight and other NCDs, including NIDDM (Barker et al. 2002), stroke (Martyn, Barker & Osmond 1996), and hypertension (Barker et al. 1990) have been reported. However, the association between birthweight and risk for NIDDM appears to be U-shaped. Both smaller and larger birth weights were found to increase the risk for NIDDM among individuals born in Finland (Eriksson et al. 2003). It is likely that maternal diabetes promotes both larger birth size and confers increased risk for NIDDM in offspring (Dabelea et al. 2000).

Studies of historical birth cohorts have provided a wealth of data to investigate the birthweight-disease risk association. The Brompton Cohort Study of 2088 individuals born between 1975 and 1977 in the UK reported that systolic blood pressure at 22 years of age increased by 1.3mmHg (95% Confidence Interval (CI) 0.3 to 2.3) for every one Z-score decrease in birthweight (Law et al. 2002). Leon et al (1998) have used data on a cohort of 14,611 individuals born at Uppsala Academic Hospital, Sweden between 1915 and 1929, and found that among the men in the sample, a 1000g increase in birthweight was associated with a 23% reduction in the risk of
ischemic heart disease. The Helsinki Birth Cohort Study (HBCS) collated detailed birth and child welfare clinic records on 8760 individuals born at the Helsinki University Central Hospital between 1934 and 1944. These data have been used to demonstrate that low ponderal index and small head circumference at birth, as well as LBW, are associated with an increased risk for CHD later in life (Eriksson et al. 2001; Barker et al. 2005). The data have also been used to demonstrate an association between BMI at birth and risk for stroke (Osmond et al. 2007). A one Z-score increase in BMI at birth was associated with a 9% reduction in the risk of stroke. It appears that individuals who are generally small at birth, not just LBW, are at increased risk for NCD in adulthood.

2.2.2.2 Rapid Vs. slow growth during infancy

Risk for NCD is influenced by growth velocity during infancy. Rapid growth velocity during infancy has been shown to increase risk for obesity during childhood (Cameron et al. 2003; Dennison et al. 2006; Ong et al. 2000), whereas slow growth velocity increases risk for various NCDs during adulthood. Using the Hertfordshire data, for example, Barker et al (1989b) reported that low weight at one year added to the increased risk of CVD associated with LBW, and Hales et al (1991) demonstrated that weight at one year of age is negatively correlated with risk for impaired glucose tolerance at 64 years of age. Data from the HBCS have shown that small size (weight, length, and BMI) at one year of age predicts CHD, independently of size at birth (Eriksson et al. 2001). Using the same data, Osmond et al (2007) reported that the association between stroke and size (weight and BMI) was stronger at one year of age than at birth, and stronger still at two years of age. A one Z-score increase in weight at two years of age was associated with a 17% reduction in the risk of stroke. Similarly, a one Z-score increase in BMI at two years of age was associated with a 16% reduction in risk. The slow growth in infants with increased risk for NCD is a persisting response to the impaired development of certain somatic structures that also increases disease risk (see section 2.3). Whereas, the rapid growth in infants with increased risk for obesity is most likely the result
of a mother’s choice to bottle rather than breastfed (Bonuck, Kahn & Schechter 2004).

2.2.2.3 Rapid growth during childhood

After infancy, rapid growth has been shown to increase risk for the NCDs common to persons with the MetS. Before reviewing the literature, it is important to distinguish between rapid growth in childhood that increases risk for NCD and classic catch-up growth. The latter refers to a period of accelerated growth, following the alleviation of some growth constraining factor, that ultimately takes the child towards a genetically determined growth canal (Cameron 2007). Whereas, children who demonstrate rapid growth exhibit growth increments large enough to make their ascent through centiles on a growth reference chart extraordinarily large. Eventually, these children canalise at centiles greater than would be expected according to parental size. Rapid growth and catch-up growth are not synonymous terms, and will not be used interchangeably. In the context of this section, the term ‘rapid growth’ will be used to describe the growth of children who are most at risk of the MetS and all associated NCDs.

Eriksson et al (2001) reported that individuals with CHD were small at birth and during infancy, and demonstrated rapid weight and BMI growth thereafter. The effect of rapid growth in childhood on risk for CHD was greater among men with a low ponderal index at birth. Barker et al (2005) have demonstrated that change in BMI Z-score between two and 11 years of age significantly predicts risk for CVD in adulthood. The hazard ratio associated with a one Z-score increase in BMI was 1.28 (95% CI 1.15 to 1.42). Risks for insulin resistance (Ong & Dunger 2004), poor glucose tolerance (Crowther et al. 1998), and NIDDM (Barker et al. 2002) are also greater among individuals who demonstrate rapid growth during childhood. However, risk for stroke is not influenced by growth velocity in childhood (Osmond et al. 2007). Evidence for the effects of childhood growth on adult blood pressure are inconclusive. Law et al (2002) have reported that weight gain in childhood influences adult blood pressure and risk for hypertension. Systolic blood pressure at 22 years of age increased by 1.6mmHg (95% CI
0.6 to 2.7) for every one Z-score decrease in weight gain between one and five years of age (Law et al. 2002). Whereas, Adair et al (2009) have stated that weight gain in childhood does not pose a greater risk for adult blood pressure than weight gain at any other age.

2.3 Developmental origins of adult disease

The developmental origins of adult disease paradigm proposes that environmental factors, particularly those that impair growth, act early in life to determine the risk of adverse health outcomes (e.g. obesity, CVD, and NIDDM) in adult life (Solomons 2009), thus providing an explanation for the observed associations between growth and disease risk found in epidemiological studies. This section, firstly, explains the biological mechanisms that act early in life to impair growth and determine risk of adverse health outcomes later in life and, secondly, describes the various hypotheses that have been proposed to explain this phenomenon.

2.3.1 Biological mechanisms that determine disease risk

There have been a number of biological mechanisms proposed to explain the basis of the associations between impaired growth and increased risk for NCDs later in life. Some of these include altered tissue differentiation (Hoet, Ozanne & Reusens 2000), altered cell function (Jennings et al. 1999), endothelial dysfunction (Brawley, Poston & Hanson 2003), and altered hormone sensitivity (Vickers et al. 2000; Gluckman & Harding 1997). The permanent setting or programming of glucose and insulin metabolism is the most important determinant of impaired growth and increased disease risk, and will be the focus of this section. McMillen and Robinson (2005) provide a detailed review of all the biological mechanisms that program disease risk early in life.

Different environmental factors have specific effects on the development and functioning of specific somatic structures which can impair growth and increase disease risk. Undernutrition is arguably the most common environmental condition that affects growth and has long term
consequences for health and disease (McMillen et al. 2008). The foetus responds to reduced nutritional supply by reducing plasma concentrations of hormones, such as insulin and insulin-like growth factor, which in turn limits the transportation of glucose to the muscles and impairs lean tissue growth (Phillips 1996). This adaptation occurs so that glucose is readily available in the bloodstream to maintain growth of high priority organs, such as the brain (Gluckman 1995). The persistence of high blood glucose levels following birth increases risk for obesity, CVD, and NIDDM.

In animal models, undernutrition causes an increase in foetal glucocorticoids (Lesage et al. 2001), which in turn inhibits glucose uptake by cells, restricting the growth of lean tissue, and increases blood pressure and risk for CVD by increasing the sensitivity of the vasculature to adrenaline and noradrenaline. Benediktsson et al (1993) have reported that the offspring of rats who were fed a restricted diet during pregnancy had lower birth weights and higher adult blood pressure compared to a control group of rats who were fed a normal diet. Undernutrition, or a low protein diet, in pregnant rats also results in a decrease in the number of beta cells and insulin content in the foetal pancreatic islets as a consequence of a decrease in the proliferation and an increase in apoptosis of the islet cells (Snoeck et al. 1990; Petrik et al. 1999). Beta cell mass is not fully restored in adult life when rats are fed a normal diet after weaning (Garofano, Czernichow & Breant 1998), and subsequently there is a decreased insulin secretory response to glucose which increases risk for NIDDM (Houdijk et al. 2000; Rasschaert et al. 1995).

The programming of metabolic, endocrine, and immune parameters during development aids immediate survival but often has long term consequences for health and disease. For example, programmed insulin resistance would reduce basal metabolic requirements during a period of food insecurity, but would also increase future risk for obesity, CVD, and NIDDM (Gluckman & Hanson 2005). Even brief periods of undernutrition can cause permanent alterations in blood pressure, cholesterol metabolism, and insulin metabolism (Barker 1995). Importantly, the adaptations made in response to
undernutrition in foetal life are more harmful to long term health when nutrition during postnatal life is not compromised to a similar degree (Symonds et al. 2009). For example, a defect in insulin metabolism is likely to increase adiposity and weight gain in infancy and childhood, if the postnatal environment is not characterised by food insecurity. This is a key characteristic of all the developmental origins of adult disease hypotheses in the next section.

2.3.2 The developmental origins of adult disease hypotheses

Various hypotheses have been proposed to explain the association between environmental conditions early in life that impair growth and increased risk for NCD. Animal studies have now elucidated many of the biological mechanisms that programme risk for NCD (McMillen & Robinson 2005). However, the hypotheses that have evolved provide useful conceptual frameworks to understand the developmental origins of adult disease.

2.3.2.1 Thrifty genotype and phenotype hypotheses

Neel (1962) proposed that thrifty elements of individuals are hereditary, and the genes responsible have been selected over a long period of time during our ancestors’ hunter-gatherer existence. In periods of food insecurity thrifty genes result in a ‘fast-insulin trigger’ and an increased ability to store fat (Neel 1962). The evolutionary selection of thrifty genes provides a survival mechanism for individuals whose environment is characterised by intermittent periods of food insecurity. The thrifty genotype hypothesis postulates that modern populations, who have inherited thrifty genes, are at an advantage in a food insecure environment, but at an increased risk for NCDs in a food rich environment.

Thirty years later, Hales and Barker (1992) argued that the rapidly changing incidence of NCDs could not be explained by genetics alone. This led to the proposition of the thrifty phenotype hypothesis, which states that adaptations are made in utero, in response to adverse environmental conditions, which optimise the growth of high priority organs to the detriment of others leading to altered postnatal metabolism (Hales & Barker 1992).
Similarly to thrifty genes, a thrifty phenotype becomes detrimental when food availability in the postnatal environment surpasses that of the intrauterine environment.

### 2.3.2.2 Foetal and developmental origins hypotheses

The terminology underwent a second revision in 1995 when Barker (1995) proposed the foetal origins hypothesis. This hypothesis specified that foetal undernutrition in middle to late gestation, which leads to disproportionate foetal growth and LBW, programmes risk for CVD in adult life. The notion of a thrifty component was removed from the terminology and more emphasis was placed on the foetal environment, in particular foetal nutrition. Following Barker’s change in terminology much criticism was voiced, in part for its overt simplicity. Of particular concern was the fact that the foetal origins hypothesis failed to recognise environmental conditions in infancy and childhood that modify disease risk (Eriksson et al. 2002). Subsequently, the term, the ‘developmental origins hypothesis’ began to appear in publications (Barker 2004; Barker 2005) to account for the fact that some environmental factors during infancy and childhood are sufficiently severe to disrupt normal growth and development (Eriksson 2005).

### 2.3.2.3 Predictive adaptive responses

Gluckman and Hanson’s (2004) proposition of predictive adaptive responses (PARs) redefined the way in which people think about the developmental origins of adult disease. PARs occur in response to environmental factors during critical periods of development, and are made in the expectation of a future environment. They are distinguishable from homeostatic or homeorhetic responses that only confer an immediate advantage (Bateson et al. 2004). If a PAR is made during development based on a predicted future environment, and this prediction subsequently becomes accurate, the mature phenotype will provide a survival advantage (Gluckman, Hanson & Beedle 2007). However, if the predicted environment is not accurate, the programmed phenotype will not be advantageous and may have negative consequences for health.
When humans are undernourished in utero they predict a similar postnatal environment. Following birth, if there is a mismatch between the actual environment and the predicted environment, certain somatic structures will have been incorrectly programmed and risk for NCDs will be higher. For example, if a foetus predicts that he/she will be undernourished in the postnatal environment, insulin resistance will be programmed to reduce basal metabolic requirements (Gluckman & Hanson 2005). If the foetus is not undernourished in the postnatal environment, blood glucose levels will be permanently high and risk for obesity, CVD, and NIDDM will be increased.

Similarly to the previous hypotheses, PARs identify the postnatal, or some future, environment as the defining factor that determines disease risk. However, PARs are the programming of somatic structures that occur in the expectation of a particular postnatal environment, and in this way are novel. Although they are not without criticism (Rickard & Lummaa 2007; Wells 2007), PARs provide the most recent and arguably most robust conceptual framework to understand the developmental origins of adult disease and the emergence of obesity in transitional populations (Gluckman & Hanson 2008). Maybe more importantly, all developmental origins of adult disease hypotheses have greatly emphasised the importance of a lifecourse approach to epidemiological study, thus placing greater importance on measurement of growth during infancy.

2.4 Factors that influence growth

Research has identified certain factors that influence growth during foetal life, infancy, and childhood. In the study of human growth, these factors have confounding effects and should be controlled for during analysis of growth data. Some of these factors result in a pattern of growth common to persons most at risk for the MetS. Knowledge of them is, therefore, essential for targeted interventions and health policy programmes which aim to reduce the prevalence of the MetS and all associated NCDs.
2.4.1 Sexual dimorphism
There are known differences in size between sexes during foetal life, infancy, and childhood, with girls generally being smaller than boys for all linear body dimensions (Lejarraga 2002). All growth reference and standards charts are sex specific. On the 50th centile of the UK90 charts boys are about 1.0cm longer and 500g heavier than girls at the end of infancy (Cole, Freeman & Preece 1998). The difference between sexes in head circumference is also about 1.0cm, in favour of boys, at the end of infancy. Following childhood, the later onset of puberty in boys, allowing an additional two years of growth compared to girls, and the sex specific differences in adolescent growth increases the differences in size between males and females (Hauspie 2002). There is clearly a need to control for sex in the study of human growth.

2.4.2 Parity
It is well established that the firstborn infant is smaller than the second or third born (Hindmarsh et al. 2008). Prentice et al (1987) studied the growth of 412 rural Gambian infants and reported that firstborn infants were, on average, 250g lighter than infants of multiparous pregnancies. In this sample, supine length and head circumference at birth were not affected by parity. Using data collected on 1335 infants enrolled in the Avon Longitudinal Study of Parents and Children (ALSPAC), Ong et al (2002) reported a similar difference in birthweight between infants of primiparous pregnancies and infants of multiparous pregnancies. For this sample, infants of primiparous pregnancies were also significantly shorter, had smaller head circumferences, and were thinner at birth compared to infants of multiparous pregnancies. Following birth, infants of primiparous pregnancies demonstrated rapid weight and length growth, and by 12 months of age were significantly heavier and longer than infants of multiparous pregnancies (Ong et al. 2002). Observations that truncal obesity is more common in firstborn infants have also been made (Stettler et al. 2000; Morton 2002). It appears that infants of primiparous pregnancies are born small with relatively large amounts of truncal fat and demonstrate rapid growth during infancy.
2.4.3 Multiple births

Individuals of multiple births demonstrate different patterns of intrauterine and postnatal growth compared to singletons, to the extent that an argument has been made for specific growth references charts to assess their growth (van Dommelen et al. 2008). Twins are the most common order of multiple birth, and monozygotic twins account for approximately four in every 1000 births (Sunderam et al. 2009). Numerous studies have demonstrated that twins exhibit slower growth in comparison to singletons, from 26 weeks of gestation until birth (Bleker, Oosting & Hemrika 1988; Hennequin et al. 1999; Liu & Blair 2002). This slower growth results in a difference in birthweight between twins and singletons of nearly 1000g (Bleker, Oosting & Hemrika 1988). Following birth twins exhibit rapid growth compared to singletons (Wilson 1979). At 2.5 years of age the differences in size between twins and singletons has decreased but not disappeared, and twins remain significantly lighter and shorter than singletons (van Dommelen et al. 2008). After infancy, there is a paucity of data regarding the growth of twins and higher order multiple births.

2.4.4 Diabetes

Gestational diabetes mellitus (GDM) is defined as a glucose intolerance of any degree that is diagnosed or first recognised during pregnancy (Yogev & Visser 2009). In most cases, GDM develops at 24 to 26 weeks of gestation and normal carbohydrate metabolism is restored within a couple of weeks of delivery (Zawiejska et al. 2008). Women with GDM are distinguishable from pregnant women with pre-existing NIDDM, although both conditions potentially have the same effects on glucose metabolism. Impaired glucose tolerance during pregnancy results in maternal hyperglycemia, increased placental glucose transfer to the foetus, and rapid foetal growth (Yogev & Visser 2009). González-Quintero et al (2007) have reported that 30% of infants born to mothers with GDM had birth weights above the 90th centile on appropriate references charts. Similarly, Schaefer-Graf et al (2005) have reported that 30.9% of infants, born to mothers with GDM at Vivantes Medical Center in Berlin, had a BMI at birth above the 90th centile on an
appropriate reference chart. Mean BMI at one, two, and six years of age were also significantly larger than the mean values of a reference population of German infants (Kromeyer-Hausschild et al. 2001) whose mothers did not have GDM. It appears that individuals who are born to mothers with GDM or uncontrolled pre-existing NIDDM demonstrate rapid growth and are more likely to be classified as obese.

2.4.5 Socio-economic status
Socio-economic status (SES) is a composite measure of an individual’s, family’s, or area’s economic and social position relative to others (Sheppard et al. 2009). It is a good indicator of general health and is known to be associated with a variety of growth characteristics (Aber et al. 1997). Numerous publications have demonstrated that risk for LBW is greater for infants born to parents (Gortmaker 1979; Hirve & Ganatra 1994; Karim & Mascie-Taylor 1997) and in neighbourhoods (Brooks-Gunn & Duncan 1997; O’Campo et al. 1997) with low SES. Following birth, SES has been shown to have effects on height growth. Jones et al (2008) have reported that SES was a significant predictor of stunting, at one and two years of age, in a sample of Filipino infants. Bogin et al (2002) have demonstrated that Maya children aged five to 12 years, living in the USA, were on average 11.5cm taller and 6.8cm longer-legged than Maya children living in rural Guatemala, where there are more socioeconomic constraints on growth. Similar effects of SES on height during childhood have been reported among Papa New Guinean children (King & Mascie-Taylor 2002). In the UK, Teranishi et al (2001) have reported that the mean difference in heights between children who were born LBW and all other children were less notable in higher social classes. Griffiths et al (2008) have demonstrated that SES also has effects on body composition during childhood, and in the UK risk for obesity is greater among children whose mothers have low educational achievement (Matijasevich et al. 2009).

2.4.6 Nutrition
Undernutrition at different stages in the life cycle impairs growth (McCance 1962). Inadequate maternal nutrition at conception and during pregnancy
can result in poor foetal growth (Prada & Tsang 1998). Research in the UK has found associations between inadequate maternal nutrition and reduced birthweight (Doyle et al. 1982, 1990; Rees et al. 2005). In India, where the prevalence of LBW is high, weight and length are positively correlated with maternal intake of foods rich in micronutrients at 18 and 28 weeks of gestation (Rao et al. 2001). A recent review by Shah et al (2009) found a significant reduction in the risk of LBW among individuals born to women who received micronutrient supplementation during pregnancy, compared to offspring of women who received a placebo (Relative Risk (RR) 0.81, 95% CI 0.73 to 0.91). The effects of macronutrients on foetal growth are less clear, although recent studies in the developed world report associations between neonatal size and the balance of macronutrients (Kind, Moore & Davies 2006).

Following birth, the choice of whether to breastfeed influences infant growth. Slower growth has consistently been seen in exclusively breastfed infants (Kramer et al. 2002), probably because of the natural limitations of available energy supply (Heinig et al. 1993). A recent study of infants born in Denmark and Iceland found that infants who were exclusively breastfed for three to four months gained 348g (95% CI 69g to 626g) less weight, between two and six months of age, than infants who were exclusively breastfed for less than two months (Gunnarsdottir et al. 2009). Similar effects of breastfeeding on growth in the first six months of life have been found among infants in the UK (Hindmarsh et al. 2008). Ong et al (2002) demonstrated that the differences in weights and lengths between infants who were breastfed at three months of age and infants who were bottle-fed were still significant at 31 months of age. Breastfeeding appears to have a protective affect against rapid growth during infancy and even childhood, that reduces risk for obesity (Singhal 2007). Of course, regardless of breastfeeding status, undernutrition during infancy and childhood will impair growth and, in severe cases, result in wasting and stunting.
2.4.7 Ethnicity and migration

People in the same ethnic group typically share geographical residence, ancestral origins, cultural traditions, and languages (Bhopal 2004). Variation in growth not only occurs within ethnic groups, but also between them (Eveleth & Tanner 1990). As such, certain ethnic groups demonstrate particular patterns of growth to reach sizes that distinguish them from other ethnic groups. For example, the average pygmy adult living in Zaire or the Central African Republic is 27.5cm shorter than the average African American adult (Eveleth & Tanner 1990). Of course, these differences are not always so obvious. Some ethnic groups demonstrate specific patterns of growth that are distinguishable at birth and during infancy and childhood. For example, it is well established that South Asian infants are born small, but have relatively large amounts of central fat compared to White British infants (see section 2.5).

Following the migration of individuals within an ethnic group to another country or area, that has different geographical, nutritional, and socioeconomic characteristics, differences in growth may develop between the migrated group and the non-migrated group. The classic studies of Goldstein (1943) and Lasker (1952) on the growth of Mexicans in Mexico and the USA were among the first to confirm this phenomenon. The majority of migration among ethnic groups occurs from less to more economically developed countries and from rural areas to urban areas (Mascie-Taylor & Lasker 1988). As a result, the migrated group usually experience an increase in height, relative to the non-migrated group, due to better socioeconomic conditions and/or increased adiposity due to a change in diet from more traditional food to ‘western foods’ that are high in fat and low in fibre (Bogin 1999). Bogin and Loucky (1997), for example, have reported that Maya children aged four to 12 years, living in California, were on average 5.5cm taller and 4700g heavier than Maya children living in Guatemala. Others have reported a significant difference in adiposity between children, of a particular ethnicity, who live in their native country and children of the same ethnicity who live in another country or area as the result of migration (Reyes, Tan & Malina 2003; Smith et al. 2003). Smith et
al (2003) demonstrated that the prevalence rates of obesity in Maya children in California and in Guatemala were 25.3% and 0.9%, respectively.

The long standing observations of differences in growth between ethnic groups supports the notion that genetic factors are likely involved, although a paucity of data means that the contribution of genetics to this phenomenon is largely unknown (Towne, Demerath & Czerwinski 2002). And the effects of migration on growth suggest that environmental factors are, at least in part, responsible for the observed differences in growth between ethnic groups (Martorell, Mendoza & Castillo 1988). Understanding how genes interact with the environment is essential for a complete understanding of the variation in growth between ethnic groups. Ethnicity serves as an ‘umbrella’ term that not only incorporates the genetic makeup of a group of people, but also the socio-cultural, geographical, and nutritional factors common to that group. It is possible that these factors moderate the effect of ethnicity on growth. For example, it has been hypothesised that Pakistani infants, in the UK, are born small not because they are Pakistani, but because migrated groups tend to form the poorer strata of a community (Rona & Chinn 1986) and low SES impairs growth. In an analysis to determine the true effects of ethnicity on growth it is necessary to consider the factors that are common to the group being studied.

### 2.5 Health and growth inequalities of South Asian populations

South Asian is a term used to describe a group of individuals with ancestry in the countries of the Indian subcontinent, including India, Pakistan, Bangladesh, and Sri Lanka (Bhopal 2004). South Asian individuals comprise an important ethnic group for research because they demonstrate a pattern of growth common to persons most at risk of the MetS and suffer from high prevalence rates of the MetS and all associated NCDs. This section summarises the literature on the health and growth inequalities of South Asian individuals, living in both South Asia and the UK. The vast majority of publications have arisen from studies of Indian populations. However, this
thesis studies Pakistani infants, and where possible the results of studies of individuals with Pakistani ancestry are given.

2.5.1 Health of South Asian Individuals

2.5.1.1 In South Asia
It is well established that the MetS is common among South Asian populations (Misra et al. 2007; Unwin et al. 2007; Wasir & Misra 2004), and prevalence ranges from about 18 to 46% for different age groups in Pakistan (Basit & Shera 2008). Others have reported that the prevalence in India is very similar, ranging from 11 to 41% (Deepa et al. 2002; Gupta et al. 2004; Mohan et al. 2001; Ramachandran et al. 2003). An inordinately high prevalence of the MetS of approximately 50% has been observed in certain groups in South Asia, including intra-country migrants living in the socio-economically deprived slums of North India (Misra et al. 2001a, b) and the Punjabi Bhatia caste in Pakistani and India (Gupta et al. 2004). Moreover, for any given BMI, South Asians have a higher percentage body fat than individuals of European ancestry (Banerji et al. 1999), which means that some diagnostic criteria which include BMI as a measure of fat underestimate the prevalence of the MetS in South Asians by as much as 25 to 50% (Enas et al. 2007). It appears that the high prevalence rates of the MetS in South Asians vary within country by factors such as SES and caste (Misra et al. 2007).

South Asia is experiencing rapidly increasing prevalence rates of CVD and NIDDM, to the extent that these NCDs are said to be epidemic (King, Aubert & Herman 1998; Ramachandran et al. 1997; Reddy & Yusuf 1998). In India, the prevalence of CVD has increased from less than 2.0% in 1960 to 10.5% in 2000 (Gupta & Gupta 1996). Studies in Chennai and Andhra Pradesh have revealed that CVD is responsible for approximately 40% of the deaths in urban areas of India and 30% in rural areas (Gupta 2008). Furthermore, Reddy (1993) has predicted that by 2025 CVD will be the leading cause of death in India. Studies in Pakistan have highlighted a propensity to cardiovascular risk factors (Dennis et al. 2006; Dodani et al. 2005; Khan et
al. 2009) and recommendations have been made to initiate a primary prevention programme (Misra et al. 2006). South Asia has also seen an increase in the prevalence of NIDDM over the last half century and now has more diabetic patients than any other region (Jafar 2006). Ramachandran et al (2001) have reported that in 1970 less than 3.0% of the Indian adult population had NIDDM, and that this prevalence had increased to 12% by 2000. In Pakistani, a similar prevalence of 11.1% has been reported (Shera et al. 1999). Importantly, South Asians are developing CVD and NIDDM at increasingly younger ages (Yoon et al. 2006). Yajnik's (2004b) proposition that this is a consequence of an increase in childhood obesity and overweight has been supported by recent publications, which have demonstrated significant increases in childhood overweight and obesity in both India and Pakistan (Bhardwaj et al. 2008; Jafar et al. 2008).

### 2.5.1.2 In the United Kingdom

South Asians living in the UK also have a high prevalence of the MetS. Unwin et al (2007) reported that prevalence rates of the MetS, according to the WHO diagnostic criteria, in South Asian and European men (25 to 74 years) living in the UK were 49.3% (95% CI 43.1 to 55.4) and 24.9% (95% CI 19.6 to 30.3), respectively. The respective figures for women were 33.9% (95% CI 28.4 to 39.4) and 15.8% (95% CI 11.6 to 19.9). Using data from the Health Survey for England (HSE), Zaninotto et al (2007) have reported that Pakistani men and women in the UK are significantly more likely to have CHD (Odds Ratio (OR) for men 2.09; 95% CI 1.44 to 3.03) and NIDDM (OR for men 4.11; 95% CI 3.12 to 5.43) compared to the general population. Mortality from CHD is 50% higher in first generation Pakistanis in the UK than among the general population (Healthcare Commission 2005). Zaninotto et al (2007) also reported that being Pakistani was not associated with an increased risk for CVD. In fact, after adjusting for covariates, including age, BMI, income, and social class, Pakistani women in the UK were significantly less likely to have CVD compared to the general population (OR 0.58; 95% CI 0.43 to 0.80). This result suggests that part of the relationship between being Pakistani and increased risk for CVD may be explained by other risk factors, such as socioeconomic disadvantage and
the early onset of obesity (Zaninotto, Mindell & Hirani 2007). Saxena et al (2004) reported that Pakistani females, aged 2 to twenty years, in the UK are significantly more likely to be obese than the general population (OR 1.71; 95% CI 1.06 to 2.76) and that Pakistani males, of the same age, are significantly more likely to be overweight (OR 1.36; 95% CI 1.01 to 1.83). A recent publication by Balakrishnan et al (2008) confirmed these findings and concluded that South Asian children in the UK are 27% more overweight and 45% more obese than their white peers.

2.5.2 Growth of South Asian individuals

2.5.2.1 In South Asia
Babies born to South Asian mothers are among the lightest in the world, and therefore a high percentage are classified as LBW. Janjua et al (2009) have reported that the mean birthweight of 540 singleton term infants born in Karachi, Pakistan was 3000g (SD 500), and 18.5% of the sample were LBW. This is nearly 500g less than the mean birthweight of individuals enrolled in the nationally representative UK Millennium Cohort Study (MCS) (Kelly et al. 2009). Even lower mean birthweights are common in other countries in South Asia. For example, mean birthweights have been reported of 2700g (SD 360) and 2690g (SD 360) in India and Bangladesh, respectively (Yajnik et al. 2003; Nahar, Mascie-Taylor & Begum 2007). As a result, it is estimated that between one third and one half of Indian and Bangladeshi infants are born LBW (Yajnik 2004a).

In addition to being born light, South Asian infants are generally small for other anthropometric measurements. Yajnik et al (2003) have reported that infants enrolled in the Pune Maternal Nutrition Study (PMNS) in rural India were smaller for weight (828g); length (2.1cm); head (2.1cm), abdominal (4.0cm), and arm (1.8cm) circumferences; ponderal index (3.7kg/cm³); and subscapular skinfold (0.4cm) compared to infants born in the UK. The largest deficit between the Indian and UK samples was for abdominal circumference (Z-score -2.99; 95% CI -3.09 to -2.89), and the smallest
deficits were for length (Z-score -1.01; 95% CI -1.09 to -0.93) and subscapular skinfold (Z-score -0.53; 95% CI -0.61 to -0.46). These data indicate that, although apparently thin, rural Indian babies have relatively large levels of adiposity. Yajnik (2003) proposed that Indian infants have a ‘thin-fat’ phenotype, characterised by small abdominal viscera and low muscle mass, but a relatively large amount of body fat. The presence of the thin-fat phenotype has also been reported in 663 infants born at Holdsworth Memorial Hospital in the urban setting of Mysore, India (Krishnaveni et al. 2005), but not in any other countries of South Asia. There is currently no internationally accepted criteria to diagnose the thin-fat phenotype, although most publications identify infants as being thin-fat when they are small for all dimensions, but relatively large for length and some indicator of adiposity, normally waist circumference and skinfold thickness measurements (Krishnaveni et al. 2005; Yajnik et al. 2003; Joglekar et al. 2007). No study has used dual x-ray absorptiometry to obtain measures of body fat amount and distribution to confirm the presence of a thin-fat phenotype in South Asian infants.

After birth, the thin-fat phenotype persists through infancy and into childhood. Krishnaveni et al (2005) reported that at one and four years of age, the smaller body size of the Mysore sample, compared to infants in the UK, is more pronounced than at birth. At one year of age, the deficit in size is smallest for length and subscapular skinfold, and by four years of age subscapular skinfold is actually larger for Indian infants than UK infants. Subscapular skinfolds were also larger than the Dutch growth references at both ages (Gerver & de Bruin 1996). Similarly, Joglekar et al (2007) have reported that at one year of age, infants in the PMNS study were light, short, and thin compared to the NCHS/WHO references and WHO standards, and at six years of age had large subscapular skinfolds compared to the UK90 references.

Studies on infant growth and the thin-fat phenotype in other South Asian countries are scarce. In Pakistan, Karlberg et al (1993) demonstrated that the weight and length growth curves of infants, born to upper middle class
parents, are below, and gradually fall away from, the 50th centile of the NCHS/WHO references between birth and two years of age. Whereas, the growth curves of infants from lower SES strata showed greater degrees of growth faltering. Fikree et al (1999) confirmed the effects of SES on growth, by demonstrating that the mean weight and length of 727 infants from the slums of Karachi fell below the 10th percentile of the NCHS/WHO references after 9 months and continued to deteriorate until two years of age. There were also considerable levels of stunting (41.8%) but not wasting (10.6%) in this sample at two years of age (Fikree, Rahbar & Berendes 2000). Cheung et al (2001) have also reported a greater risk of stunting than wasting in Pakistani infants at six months of age. Current literature suggests that Pakistani infants are small compared to western infants, although there is a lack of evidence as to whether they also have relatively larger amounts of fat.

2.5.2.2 In the United Kingdom

There are also noticeable differences in growth between South Asian and White individuals living in the in the UK. Infants born to South Asian mothers are generally 300g lighter than those born to White mothers, and the rates of LBW are up to two and a half times those for Whites (Dhawan 1995; Draper, Abrams & Clarke 1995; Harding, Rosato & Cruickshank 2004; Margetts et al. 2002). Kelly et al (2009) have recently reported that the mean birthweights of Pakistani and White infants enrolled in the MCS were 3110g (95% CI 3060 to 3160) and 3420g (95% CI 3400 to 3430), respectively. In the same sample, the prevalence of LBW in Pakistani infants (13.0%; 95% CI 10.1 to 16.4) was more than double that in White infants (5.2%; 95% CI 4.7 to 5.6). Chetcuti et al (1985) have reported that infants born to South Asian women living in the UK are approximately 300g heavier than those born to native South Asian women. However, there is a lack of agreement whether birthweight increases and risk for LBW decreases, among South Asian populations in the UK, with an increasing number of generations a family lives in the UK (Dhawan 1995; Draper, Abrams & Clarke 1995; Margetts et al. 2002; Chetcuti, Sinha & Levene 1985). The most recent publication on the topic reported that there are no
significant differences in mean birthweights of infants by generational status (Harding, Rosato & Cruickshank 2004). The difference in birthweight between infants of Pakistani mothers who were born in the UK and infants of Pakistani mothers who had migrated to the UK was only 63g, in favour of the latter group.

After birth, the pattern of growth of South Asians in the UK is largely unknown. Using data from the MCS, Tate et al (2006) have reported that, when compared to the UK90 references, South Asian infants (mean Z-score -0.49; SD 1.30) were lighter at nine months of age than White infants (mean Z-score 0.17; SD 1.20). South Asian infants were not only smaller than White infants at nine months, they also demonstrated poorer weight gain between birth and nine months of age. The difference in weight between South Asian and White infants in the MCS, therefore, increased from birth to nine months of age. Analysis of data from the Manchester children’s growth and vascular health study has produced slightly different results (Bansal et al. 2008). South Asians were born small, although they demonstrated significantly greater increases in weight Z-score (mean difference 0.83; 95% CI 0.44 to 1.21) and length Z-score (mean difference 0.75; 95% CI 0.33 to 1.17) from birth to three months compared to White infants. The authors do, however, state that changes in Z-scores were not greater than that predicted by regression to the mean, and by 12 months of age there were no significant differences in weight, length, and BMI between South Asian and White infants (Bansal et al. 2008). After infancy, one published study that shows that Pakistani children aged five to 14 years have mean weight, length, and BMI values between the 50th and 25th centile of the UK90 references (Kelly et al. 2009). In summary, it is generally accepted that South Asian in the UK are born small. However, no publications have reported the presence of a thin-fat phenotype, various publications have come to different conclusions about the effects of generational status on growth, and there is a paucity of information regarding growth patterns during infancy and childhood.
2.6 Growth monitoring

The literature suggests that the growth rate of an infant is not only a good indicator of current health but also an indicator of risk for the MetS later in life. So monitoring growth is an important surveillance tool in all infants, and more specifically among populations with high prevalence rates of NCD, such as Pakistanis. Growth monitoring is recognised as a fundamental component of community paediatric surveillance throughout the world, although at present it is only used to assess current health (Hall 1996). It involves repeated cross-sectional measurement, thus identifying size and rate of change of size. Typically, both weight and height are measured (Hall & Elliman 2003), making it possible to identify any form of growth disorder involving short or tall stature and any nutritional problem involving under or overweight. Growth data are assessed using growth reference or standard charts, and where an individual’s growth indicates a health problem he/she is referred to an appropriate specialist (Garner, Panpanich & Logan 2000).

2.6.1 Growth monitoring in the United Kingdom

In the UK, growth monitoring is an integral component of the NHS, and extensive resources are invested in routinely collecting and recording growth data (Department of Health and Social Security 1974). Since 1991, all new mothers in the UK have been issued with a Personal Child Health Record (PCHR) which, among other things, allows growth monitoring during infancy (Wright & Reynolds 2006). The use of PCHR is endorsed in the National Service Framework for Children (Department of Health 2004), and retention rates among mothers have been reported to be high throughout the UK (Hall & Elliman 2003). Walton et al (2006) reported that 93% (n = 15,733) of mothers enrolled in the MCS were able to produce their PCHR when asked to by an interviewer. The national standard PCHR (Royal College of Paediatrics and Child Health 2004) contains tables and growth charts to allow weight, length, and head circumference to be monitored. Measurement of infants at birth to 28 days, six to eight weeks, and seven to nine months of age is generally recognised as routine practice (Patterson et al. 2006). However, each Primary Care Trust (PCTs are responsible for the
planning and security of primary health services within defined geographical
areas) has the choice to include pages in the PCHR that allow this schedule
of growth monitoring, which means that in some areas infant growth may not
be routinely monitored. Also, in most PCTs there are no mechanisms in
place to provide quality assurance that infants are being routinely measured
at the prescribed age periods and that growth monitoring data are reliable.

Growth data are collected at home visits in the community and at baby
clinics in health centres where babies are measured and immunised, and
mothers can seek the advice of health workers. These data are entered into
PCHR and plotted against growth charts, after which an appropriate
assessment of growth and health can be made. Of course, a correct
interpretation of an infant’s growth can only be made if those responsible for
growth monitoring fully understand the intricacies of the growth charts they
use. A recent change in the UK from a growth reference (UK90) to a chart
that combines both a reference with a standard (UK-WHO) means that the
ability of practitioners to correctly interpret infant and child growth may be
limited if they do not receive adequate training (Fry 2007). It is necessary to
investigate whether the new charts represent the growth of UK infants and,
if they don’t, inform practitioners of the pattern of growth and change in the
frequencies of certain growth characteristics (i.e. failure to thrive and catch-
up growth) they can expect to observe. There are also significant
differences in birthweight between White British and Pakistani babies in the
UK, but little evidence about subsequent growth trajectories. Growth curves
for Pakistani infants in the UK are necessary to assess whether the UK-
WHO charts are appropriate for use in this ethnic group.

Over 90% of PCTs use health visitors to collect growth data (Patterson et al.
2006), although staff nurses, community nursery nurses, and student health
visitors also aid data collection. In general, health visitors will have studied
for either a bachelors or postgraduate degree and will be registered on the
Nursing and Midwifery Council (NMC); staff nurses will have either a
bachelors degree, an advanced diploma, or a registered general nurse
qualification; and community nursery nurses will have either a national
dipлома in child studies, or an equivalent nursery nurse qualification. Hereafter, the term ‘health worker’ will be used to describe all professionals responsible for growth monitoring in the UK.

The benefits of growth monitoring in the UK are not limited to the detection of poor health. A meeting of some 40 professionals, including paediatricians and public health professionals, held in 1998 was organised to develop a consensus on growth monitoring in the UK (Hall & Voss 2000). It was agreed that the potential benefits of growth monitoring include the identification of poor health, provision of reassurance to parents, and the production of data to monitor child health and support future research (Hall & Voss 2000). Patterson et al (2006) reported that 76% of PCTs transfer growth monitoring data to electronic databases, and that there has been an increase, between 2004 and 2006, in the use of these data for public health reports. Growth monitoring in the UK thus provides a repository of data which could be used by researchers with interests in different aspects of growth and health. The development of a standard protocol for the extraction of growth monitoring data will not only allow these data to be used for research but will improve the balance between data collection and data use. Publications by Buchan et al (2007) and Bundred et al (2001) have used routinely collected growth data to report an increase in the prevalence of childhood obesity in the UK. Patterson et al (2006) reported that an improved focus of leadership, resource, and co-ordination to work effectively across government departments will allow growth monitoring data to be developed to research calibre and be utilised to its full extent.

2.6.2 Growth monitoring to determine risk for disease later in life
Growth monitoring is not only important for assessing current health, it provides an already established platform that could be used to screen for individuals who are at high risk of developing the MetS and all associated NCDs. The childhood obesity epidemic is well documented and has been described as one of the most daunting public health threats in the UK (Department of Health 2003), especially considering that obesity has been demonstrated to track from childhood into adulthood (Herman et al. 2008).
Growth monitoring could be utilised to identify obese infants and children who are likely to remain obese during adulthood. Mei et al (2003) have reported that monitoring infant height and weight should be a strategy for preventing obesity in adolescence and adulthood. The pattern of growth that is common to persons most at risk of the MetS is also well documented. It is generally accepted that small size at birth, slow growth during infancy, and rapid growth during childhood are associated with increased disease risk. Utilising routine growth data to screen for unfavourable growth patterns may become an important component of intervention programmes to target those at risk for obesity, CVD, and NIDDM (Summerbell et al. 2005). Among populations, such as Pakistanis in the UK, that are known to suffer more than most from NCD, growth monitoring offers the greatest potential for the early identification of individuals with increased disease risk. Greater knowledge of the factors that influence the size of Pakistani infants will help inform any potential screening or intervention programme.
3 Research in Bradford
3.1 Why is Bradford unique?

3.1.1 Bradford and its population

The city of Bradford is situated in the northern county of Yorkshire, UK. During the industrial revolution of the late 18th and early 19th century Bradford became renowned as an international centre for textile manufacturing. The growth of Bradford’s manufacturing sector led to a rapid increase in population size and civic investment. This prosperity was short lived, and deindustrialisation in the 1950’s and 1960’s resulted in a terminal decline of the textile sector. Bradford faced challenges of economic deprivation, which were ubiquitous in the post-industrial north. At a similar time Bradford was experiencing significant levels of immigration from South Asia. The migration of South Asians to the UK began in the early twentieth century. The first wave of migrants were predominately male, and migrated for either adventure or economic gain. Settlement in the UK was normally temporary and most individuals returned home after three to four years (Aurora 1967). Even as recently as 60 years ago very few South Asians lived in the UK (Robinson 1986). It was not until the 1960’s and 1970’s that migration of South Asians to the UK boomed, largely because of changes in immigration laws and large scale population displacements.

The majority of South Asians in Bradford originate from the Mirpur district of Pakistan (Born in Bradford Collaborative Group 2006). Mirpur district is located in the south-west of the Kashmir region, and is named after the main city. Mirpuris have historically looked abroad for employment, especially during the two world wars. In the 1960’s, a large number of Mirpuris migrated to the UK after being displaced. Mangla dam was built in 1967 to increase water availability for irrigation and to produce electricity. As a result of its construction over 110,000 people from Mirpur district lost their homes. A treaty between the British and Pakistani governments allowed many of those affected by the dam to settle and work in the UK. At the same time, Bradford was experiencing a decline in industry, and many native workers and their families were moving away from the city. Mirpuri migrants acted as a form of industrial replacement working mainly in textile mills. In the 1980’s
and 1990's many Mirpuris decided to bring their families to the UK, and this ‘family reunion’ furthered the growth of Bradford’s South Asian population.

The 2001 UK census (Office for National Statistics 2008a) reported the population of Bradford to be 467,665, of which 22% (n=101,624) classified themselves as being in an ethnic minority. The majority of Bradford’s ethnic minority are of South Asian origin, and the census noted that 14.54% (n=67,994) of Bradford’s population classified themselves as Asian or Asian British: Pakistan. The census also reported that 10.40% (n=48,624) of Bradford’s population were born outside of the European Union, and that 7.8% (n=36,583) were born in South Asia. In 2007, Bradford’s population was estimated to have increased to 497,400, and the percentage of the population who classified themselves as Asian or Asian British: Pakistani was estimated at 16.1% (n=80,000). Like most cities in the UK, Bradford is experiencing outwards migration to neighbouring areas. The large number of annual births at BRI means that Bradford’s young population balances out population drift from the city (Simpson 2003). It is estimated that 50% of the 6000 infants born each year at BRI are to parents of South Asian origin (Born in Bradford Collaborative Group 2006). These infants will form a large strata of Bradford’s adult population and it is, therefore, expected that Bradford’s South Asian adult population will continue to increase.

3.1.2 Health inequalities in Bradford

The 2007/2008 annual report of the joint director of public health in Bradford and Airedale reported that the infant mortality rate (IMR) for the district was 7.2, which is significantly greater than the combined value for England and Wales of 5.3 (Director of public health 2008). There were noticeable differences in IMR rates between White British and Pakistani in Bradford, with values of 7.1 and 12.9, respectively. IMR is a particularly important measure because it is an accurate indicator of the general health of a population (Reidpath & Allotey 2003). The infant mortality commission for Bradford and Airedale have reported that infants in Bradford are more likely to die from congenital abnormalities, infections, and autosomal recessive genetic disorders compared to the national population of infants (Brown &
the Bradford Health Informatics Service team 2008). Data from the National Child Measurement Programme (NCMP) have been used to demonstrate that 10.7% of children aged 4 to 5 years in Bradford are obese compared to the national value of 9.9% (Director of public health 2008). By 10 to 11 years of age, 19.5% of children are obese compared to the national value of 17.5%. During adulthood, 12.5% of Bradford’s population are registered as hypertensive and 3.9% are registered as diabetic (Director of public health 2008). These figures represent the proportion of the population who have been diagnosed and, therefore, underestimate the true prevalence rates of these NCDs. It has been proposed that as much as 12% of Bradford population have undiagnosed hypertension, and the actual prevalence of diabetes is 5.34% (Director of public health 2008). All of these factors contribute to life expectancies in Bradford that are just below the national averages for men (74 Vs. 77 years) and women (79 Vs. 81 years).

3.2 Born in Bradford

3.2.1 Introduction

On the 27th October 2006 Born in Bradford (BiB) was launched. The research project is a collaboration between Bradford Institute for Health Research (BIHR) and Bradford and Airedale teaching PCT (tPCT), and was developed for three main reasons:

- To investigate high levels of poor health in Bradford, with the aim to inform future health planning and development of prevention strategies both locally and nationally.
- To study societal changes in a transitional population, thus improving understanding about acculturation and barriers to integration.
- To build local research capacity.

The BiB project is a unique multi-ethnic longitudinal birth cohort study (Raynor & Born in Bradford Collaborative Group 2008). The primary aim of the project was to recruit all pregnant women booked to deliver at BRI over
a period of two years. The BiB project is utilising routine data to follow the
development of these mother’s babies. As a platform study, health research
groups can make proposals to BiB to investigate specific aspects of infant
and child health. The project has attracted interest from health researchers
throughout the UK, and numerous nested studies have been approved.
Some areas of interest that nested studies will investigate include: the
incidence and prevalence of herpes virus infections, paternal influences on
genotoxic and immunological hazards in newborns, sudden infant death,
and the development and evaluation of interventions against childhood
obesity.

3.2.2 Routine data utilisation
The BiB project has integrated routine health data collected by practitioners
throughout Bradford into NHS information systems to provide a systematic
and cost effective approach to data collection. These data are augmented
by key additional variables and made available to researchers. Some nested
studies also require the collection of additional data on samples of
individuals. The majority of data are collected at BRI or by health workers in
the community. Information including a woman’s medical and obstetric
history; antenatal ultrasound measurements; adverse obstetric outcomes,
including stillbirth and caesarean section; congenital anomalies, such as
shoulder dystocia, nerve injury, and fractures; and anthropometry at birth
are collected at BRI. This information is stored in a maternity information
system called eClipse, which is designed to collect clinical data at the point
of care and in real time from referral to postnatal discharge. In the
community, health workers collect infant and child anthropometry and
information about feeding status. These data are entered into an electronic
database called System One, which stores large amounts of information
from health care centres, dentists, and schools throughout Bradford. The
BiB project utilises data from both eClipse and System One, and in doing so
has enabled the development, extraction, and sharing of information that is
already routinely collected.
3.2.3 Recruitment

3.2.3.1 The recruitment process
Women are recruited into BiB when they attend for a glucose tolerance test (GTT) at BRI at 26 to 28 weeks of gestation. The only exclusion criteria is if a woman has plans to move away from Bradford before giving birth. Firstly, women are asked to give verbal consent to have blood and urine samples taken for the project. If verbal consent to take blood is declined they are nevertheless invited to participate in BiB. Women then have the opportunity to discuss the project with a member of staff and decide whether they are willing to sign a consent form (see Appendix I). If a woman decides she does not wish to participate, the blood and urine samples are destroyed on request. If consent is obtained, women are invited to complete a baseline questionnaire during a semi-structured interview with a trained project worker. Women who do not attend for the GTT are invited to participate in BiB at other opportunities, including appointments at the diabetic clinic, antenatal ward, delivery suite, and postnatal ward. Fathers are also recruited into BiB by health workers in the community. All documentation has been produced in Urdu and Mirpuri, as well as English, and bilingual project workers are employed and used where necessary.

3.2.3.2 Recruitment figures
On the 12th March 2007 BiB began to recruit all women booked to give birth at BRI. Based on pilot work and information from previous birth cohorts, namely ALSPAC, it was anticipated that 80% of the mothers would agree to participate in BiB. There are approximately 6000 births each year at BRI (Born in Bradford Collaborative Group 2006), and it was, therefore, estimated that after two years of births the BiB cohort would consist of just under 10,000 mother-infant dyads. The first BiB baby was born in June 2007, and by the end of June 2009 the cohort included 7246 mother-infant dyads. The BiB team have been able to recruit 87% of pregnant women who had been approached for recruitment, although because not all pregnant women were approached this only equates to 58% of all births at BRI. The project now aims to have a cohort of 13,000 individuals by the end of 2010.
As of the 30th September 2008, the date of data extraction from eClipse for this thesis, 5595 mothers had been recruited into the study and 4603 BiB babies had been born (see Table 3.1).

Table 3.1. Number of women recruited into Born in Bradford and the total number of births, as of the 30th September 2008

<table>
<thead>
<tr>
<th>Approached (GTT)</th>
<th>Declined (GTT)</th>
<th>Not able to recruit (GTT)</th>
<th>Recruited (GTT)</th>
<th>Recruited elsewhere</th>
<th>Total number recruited</th>
<th>Total number of births</th>
</tr>
</thead>
<tbody>
<tr>
<td>6334</td>
<td>926</td>
<td>274</td>
<td>5134</td>
<td>461</td>
<td>5595</td>
<td>4603</td>
</tr>
<tr>
<td>(14.6%)</td>
<td>(4.3%)</td>
<td>(81.1%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.2.4 External validity
In order to assess if women recruited into BiB are representative of all pregnant women in Bradford, Parslow (2008) has compared summary data from the general population of women (n=3990) who delivered at BRI between Sept 2007 and April 2008 to data on women (n=4533) who were recruited into BiB before May 2008. For both groups, the mean age of women was 27, and the distributions of ages were similar. The SES of the BiB group was compared to that for the general population group using the Index of Multiple Deprivation (IMD) 2004 (Noble et al. 2004), by linking home address postcode via the National Statistics Postcode Directory (NSPD) (Office for National Statistics 2008b) to census Lower layer Super Output Areas (LSOA). No statistically significant differences were found in IMD, and all domains of the IMD, between the two groups. The mean IMD of BiB women was significantly lower than the mean value for England and Wales, indicating that BiB women are significantly more deprived than the national population. A comparison of ethnic composition between the two groups could not be completed because this variable was coded differently for each group and a large proportion (20%) of women in the general population group were listed as ‘not known’. For the general population 30% of mothers were ‘Pakistani’ and 27% were ‘British’. Whereas, 50% of the BiB women were ‘Asian or Asian British’ and 40% were ‘White’. Informed by
these results, Parslow (2008) concluded that women enrolled in BiB are representative of the population of mothers giving birth in Bradford.

3.3 Phase 2- Postnatal Growth
Phase 2-Postnatal Growth (P2PG) is a nested study within BiB that comprises this PhD thesis. The proposal to develop and utilise routinely collected growth monitoring data to investigate differences in growth between White British and Pakistani infants was approved by a BiB advocacy and scrutiny committee in January 2007.
4 Methods
4.1 Data provided by Born in Bradford

Data came from two sources within the NHS. Firstly, information about a women’s pregnancy (e.g. gestational age, parity, GDM) and neonatal anthropometry are routinely collected at BRI. Secondly, infant anthropometry and infant feeding status data are routinely collected in the community by health workers. The use of two unique identifiers (baby NHS number and baby hospital number) on records at BRI and in the community means these data can be easily merged. The description of the data available for analysis and details about data extraction, sample selection, and data cleaning are separated into three groups: birth data, postnatal anthropology, and infant feeding status.

4.1.1 Birth data

Birth data are collected by various health professionals at BRI. Information about a woman’s pregnancy is typically recorded by a midwife at an antenatal visit at 24 to 28 weeks of gestation, and neonatal anthropometry is typically recorded by a midwife or paediatrician within six hours of birth. This information is recorded as either raw data (i.e. paper forms with hand written results) which are subsequently entered into eClipse or as electronic data (i.e. data that are entered directly into eClipse). Both the raw data and print-outs from eClipse are stored in baby notes. These notes are folders which contain every piece of information collected on an individual during a visit to BRI. Approximately one month after, baby notes are sent to St Luke’s hospital for storage. For each infant, a birth notification including the birth data collected at BRI is sent from eClipse to System One (see Figure 4.1).
4.1.1.1 Postcode
Postcode is reported by women when they arrive at BRI to deliver their baby. This is checked against previous records, and if it does not match the woman is asked if she has recently changed address.

4.1.1.2 Diabetes
This variable includes information about NIDDM and GDM during the current pregnancy. At an antenatal visit every woman is asked whether she has NIDDM. At the same visit fasting blood glucose level is measured to assess whether the woman has GDM. There are three possible responses for this variable: not diabetic, NIDDM, or GDM.

4.1.1.3 Obstetric history of gestational diabetes
This variable includes information about GDM during previous pregnancies. At an antenatal visit every woman is asked by a midwife whether she has had GDM during any previous pregnancies. There are two possible responses for this variable: no history of GDM or history of GDM.
4.1.1.4 Gravidity
The number of pregnancies (including the current one) is self-reported by the mother during an antenatal visit. There is no way of checking whether the number a mother reports is correct, unless it appears in a mother’s hospital notes from previous pregnancies or there is clinical evidence to the contrary e.g. caesarean section scar.

4.1.1.5 Parity (registerable and non-registerable)
Parity is self-reported by the mother during an antenatal visit, and is scored as para 0, para 1, para 2, and so on. There are two different types of parity, registerable and non-registerable. Registerable parity refers to births where the foetus has shown signs of life at some stage of pregnancy, and/or the baby is born still or alive beyond 24 weeks of gestation. Non-registerable parity refers to births before 24 weeks of gestation where the foetus has not shown any signs of life.

4.1.1.6 Gestational age
After birth, a midwife will work out gestational age, in weeks and days, as the time between conception and delivery. Date of conception will have previously been estimated either from the first day of the last menstrual period minus two weeks or by a dating scan, which uses anthropometry to calculate current gestational age and thus date of conception. eClipse also automatically calculates gestational age when date of birth is entered into the system. The gestational ages calculated by the midwife and eClipse are checked for discrepancies.

4.1.1.7 Sex
Sex is recorded at birth, and there are three possible responses for this variable: male, female, or indeterminate.

4.1.1.8 Ethnicity
Ethnicity of a baby is reported by the mother following birth. The ethnic categories are the same as those used in the 2001 UK census (National Health Service 2009).
4.1.1.9 Date of Birth
Time and date of birth is recorded by a midwife.

4.1.1.10 Weight
Infants are weighed naked to the last completed 10g using Seca baby scales.

4.1.1.11 Abdominal circumference
Abdominal circumference is measured, at the level of the umbilicus, to the last completed 0.1cm using lassos (Harlow Health Care, London, UK). All midwives and paediatricians responsible for this measurement have been told to ensure the lasso is horizontal, not twisted, and does not compress any soft tissue.

4.1.1.12 Head circumference
Head circumference is measured to the last completed 0.1cm using lassos (Harlow Health Care, London, UK). All midwives and paediatricians responsible for this measurement have been told to ensure the lasso crosses the most anterior part of the head (midway between the eyebrows and the hair line) and the most posterior part of head (occipital prominence).

4.1.2 Postnatal anthropometry
After discharge from BRI, parents are visited by health workers in the community and anthropometry of infants is recorded in PCHRns for the purposes of growth monitoring. The health visitor manual for Bradford and Airedale tPCT states that weight, head circumference, and length should be measured on all infants at prescribed age periods of birth to 28 days, six to eight weeks, and seven to nine months. An additional measurement form has been added to PCHRns in Bradford, which allows health workers to record any additional measurements that are taken. Health workers have been asked to measure abdominal circumference on all infants, not just those enrolled in BiB, at all three prescribed age periods. Abdominal circumference is a good indicator of total body fat and fat distribution (Cameron 1984), and is therefore particularly relevant considering the
increasing prevalence of childhood obesity and central adiposity. Health workers have also been asked to perform their first visits between ten and 14 days of age, instead of birth to 28 days. In the first few days of life an average infant loses between 3.5% and 6.6% of their birth weight, and this weight is not regained until about seven days of age (Macdonald et al. 2003). The ten to 14 day age period was chosen to ensure that infants are only measured when they have regained weight that is lost in the first few days of life.

The measurement protocol, the instruments which are used by health workers, and the level of precision for weight, abdominal circumference, and head circumference are the same as described in section 4.1.1. Length is measured to the last completed 0.5cm using a standard issue neonatometer (Harlow Health Care, London, UK), and all health workers have been trained to ensure the head is placed in the Frankfurt plane and legs are fully extended. Carbon copies of the anthropometry collected by health workers in PCHRs are posted to the Child Health department at Bradford and Airedale tPCT. These data are entered into System one and the paper records are filed and stored for two years (see Figure 4.2).

4.1.3 Infant feeding status
Health workers also record information about infant feeding status. These data should be collected at the first two prescribed age periods (i.e. birth to 28 days and six to eight weeks). At each visit the parent(s) is asked whether the infant is totally breastfed, partially breastfed, or not breastfed at all. These data are collected on the same pages in PCHRs as the postnatal anthropometry. Carbon copies are sent to Child Health, where the data are entered into System One and the paper records are filed and stored for two years (see Figure 4.2). The responses for this variable are relabelled at Child Health and hereafter will be referred to as: exclusively breastfed, partially breastfed, and bottle-fed.
Methods

Figure 4.2. Data trail for the collection of postnatal anthropometry and infant feeding status

4.2 Anthropometric training, and the collection and reliability of postnatal anthropometry

Two measurement training workshops were organised in collaboration with the Child Growth Foundation (CGF), one for paediatricians and midwives who are responsible for measuring infants at BRI and one for health workers who are responsible for growth monitoring in the community. Community practice teachers (CPTs are senior health visitors who train student health visitors during their community placement and mentor newly qualified staff) and health workers who attended a workshop organised training days at their own health centres. At least one member of the P2PG team attended all health centre training events.

A measurement protocol which provides precise step by step instruction on how to measure and record each dimension was produced and disseminated (see Appendix II). A growth monitoring standard (see Appendix III) for health workers was written to incorporate the new measurement protocol and to provide detailed information about growth monitoring. Among other things, the standard included a rationale for each
Methods

measurement, information on how to record and plot data on growth reference charts, and guidance on when an infant should be referred to a specialist. The amount of routine growth data that are collected at prescribed age periods, and the reliability of these data, were assessed. These analyses are presented in self contained chapters five and six.

4.3 Data extracts and collection
To address the research aims of this thesis a number of data extracts were taken from eClipse and System One during 2008 and 2009. In addition, test-retest data on infants were collected by health workers in 2007. The datasets used in this thesis are listed below in the order that they were obtained. Further details about the first two extracts and what the data were used for are given in the self contained chapters. The rest of this chapter refers only to the use of the last three data extracts.

- June 2007, test-retest data collected by health workers (used to assess the reliability of growth monitoring data, see Chapter six)
- 14th February 2008 postnatal anthropometry from System One (used to assess routine data collection, see Chapter five)
- 30th September 2008 birth data from eClipse
- 30th October 2008 postnatal anthropometry from System One
- 31st January 2009 infant feeding data from System One

4.4 Birth data: extraction, sample selection, and data cleaning

4.4.1 Preliminary data extract and missing data
On the 30th September 2008 birth data were extracted from eClipse for all infants enrolled in BiB (n = 4707). Technical problems with eClipse meant that the variables ‘ethnicity’ and ‘postcode’ were not included in the extract. Instead, these variables were extracted from System One and merged into the dataset. This preliminary data extract was used to determine the frequency of infants who did not have datum for each variable (i.e. missing data) (see Table 4.1). A large percentage of infants had missing data for the
variables ‘baby hospital number’, ‘diabetes’, ‘obstetric history of GDM’, ‘abdominal circumference’, and ‘head circumference’. The BiB project has two ongoing processes, commonly referred to as ‘back-logging’, that are being used to reduce the frequency of missing data.

- Mother’s hospital notes, for BiB mothers, are being pulled from storage at St Luke’s hospital and taken to BRI. A pro-forma has been produced detailing what data from the mother notes should be in eClipse. Where a recording for a variable is in the notes, but not in eClipse, it is entered into the system.

- Baby notes for infants enrolled in BiB, who have no anthropometry in eClipse, are being pulled from storage at St Luke’s and taken to BRI. Anthropometric data that are in the baby notes but for some reason have not been entered into eClipse are entered into the system.

At the time of the preliminary data extract, both of these back-logging processes had not been completed for all infants enrolled in BiB. Three weeks were spent working with the BiB team to complete these processes for infants enrolled in BiB up until the 30th September 2008. This ensured that the final data extract would include all data that had been collected.

4.4.2 Final data extract and missing data

The final birth data were subsequently extracted from eClipse for the same group of 4707 infants, enrolled in BiB between 12th March 2007 and the 30th September 2008, for which the preliminary data extract was performed. Again, these data were merged with ethnicity and postcode from System One, and the percentages of infants with missing data were calculated (see Table 4.1).
Methods

Table 4.1. The frequency of infants (n=4707) with missing data

<table>
<thead>
<tr>
<th>Variable</th>
<th>Percentage of infants with missing or incomplete data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Preliminary data extract</td>
</tr>
<tr>
<td>Baby hospital number</td>
<td>66.75</td>
</tr>
<tr>
<td>Baby NHS number</td>
<td>0.02</td>
</tr>
<tr>
<td>Maternal indicators of diabetes</td>
<td>97.09</td>
</tr>
<tr>
<td>Obstetric history of GDM</td>
<td>97.39</td>
</tr>
<tr>
<td>Baby date of birth</td>
<td>0.00</td>
</tr>
<tr>
<td>Sex</td>
<td>0.00</td>
</tr>
<tr>
<td>Gestational age</td>
<td>0.02</td>
</tr>
<tr>
<td>Gravidity</td>
<td>0.87</td>
</tr>
<tr>
<td>Registerable parity</td>
<td>8.12</td>
</tr>
<tr>
<td>Non-registerable parity</td>
<td>18.95</td>
</tr>
<tr>
<td>Birthweight</td>
<td>0.02</td>
</tr>
<tr>
<td>Abdominal circumference</td>
<td>61.97</td>
</tr>
<tr>
<td>Head circumference</td>
<td>61.06</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>4.42</td>
</tr>
<tr>
<td>Postcode</td>
<td>4.33</td>
</tr>
</tbody>
</table>

†percentages that decreased from preliminary data extract

The first back-logging process employed by BiB reduced the percentage of infants with missing data for registerable and non-registerable parity. Whilst, the second process reduced the percentage of infants with missing data for head circumference and abdominal circumference from 61.97% to 16.95% and from 61.06% to 14.09%, respectively. Technical work on System One also reduced the number of infants with missing data for ethnicity and postcode. Despite this, there were still 3142 infants who had a missing (n=3086) or incomplete (n=56) baby hospital number. The baby notes stored at St Luke’s are filed by hospital number. It was particularly important that missing and incomplete baby hospital numbers were found so that baby notes could be located for data cleaning. The baby NHS numbers for infants with a missing/ incomplete hospital number were sent to Database Support, Information Services at BRI. Baby NHS numbers were matched with the iPM patient administration system to reveal baby hospital numbers. Baby hospitals numbers were matched for 2304 infants, which meant that only 838 infants had missing or incomplete baby hospital numbers. The issue of missing baby hospital numbers was passed on to a data quality team to investigate why these data were not in eClipse.
A large percentage of infants had no recording for the variables, ‘diabetes’ (97.09%) and ‘obstetric history of GDM’ (97.39%). These variables were on the pro-forma used in the first back-logging process, and all information about diabetes and obstetric history of GDM in mothers’ notes had therefore been entered into eClipse. It is possible that a result for these variables was only entered into eClipse if a mother had diabetes or history of GDM. A senior midwife confirmed that this was what probably happened. Therefore, infants with no recording for the variable ‘diabetes’ were recoded as not being diabetic, and infants with no recording for the variable ‘obstetric history of GDM’ were recoded as having no history. Assumptions were used to reduce the amount of missing data for the parity (registerable and non-registerable) variables. Results for parity and gravidity were recorded at antenatal appointments, at a time when BiB women would have been pregnant. Both parities added together should have, therefore, equalled one less than gravidity, unless the woman had previously had a multiple birth. Infants with no result for both registerable and non-registerable parity were scored para zero for each variable, and infants with a result for one parity variable but no result for the other were scored para zero for the missing parity, as long as both parities added together equalled one less than gravidity. At some point after parity was recorded, women gave birth to their babies, which meant that registerable parity had to be increased by a score of one (i.e. para zero became para one).

4.4.3 Sample selection
Out of the 4707 infants with data, a sample was selected who had no missing data, apart from baby hospital number (see Figure 4.3). There was a relatively large number of infants with no baby hospital number (n=838) and removing these infants would have drastically reduced the total sample size. If an infant’s hospital number was later needed to find baby notes at St Luke’s hospital, and baby hospital number for that infant was missing, he/she was then removed from the sample (see Figure 4.4). Infants born to mothers with diabetes or GDM demonstrate different patterns of foetal and postnatal growth (Mello et al. 1997; Plagemann, Harder & Dudenhausen 2008) compared to infants born to mothers with normal glucose/insulin
metabolism. Therefore, infants whose mothers had diabetes (n=137) or obstetric history of GDM (n=123) were removed from the sample. Offspring of multiple births also demonstrate different patterns of infant growth compared to singletons (van Dommelen et al. 2008). Therefore, twins (n=110) and triplets (n=6) were deleted from our sample. One infant was withdrawn from the study, and all his/her data were deleted. All infants whose ethnicity was not ‘White British’ or ‘Asian or Asian British: Pakistani’ were also removed from the sample (n=751).

**Figure 4.3. Sample selection**

All infants (n) → 4707 → Missing baby NHS number (n=1) → 4706 → Missing mothers hospital number (n=32) → 4674 → Missing abdominal circumference (n=788) → 3886 → Missing head circumference (n=156) → 3730 → Missing ethnicity (n=40) → 3690 → Missing gravidity (n=28) → 3662 → Missing registerable parity (n=235) → 3427 → Missing non-registerable parity (n=150) → 3277 → Indicators of diabetes or history of GDM (n=140) → 3173 → Withdrawn from BiB (n=1) → 3172 → Not White British or Pakistani (n=517) → 2655 → Twins (n=24) → 2631 → Selected sample (n)
4.4.4 Phase 2-Postnatal Growth data cleaning checks

4.4.4.1 Identifying erroneous data by detecting outliers

Potentially erroneous data were identified by flagging outliers. For each anthropometric measurement, any case that was outside ± two SDs from the mean was identified. This process identified 103, 62, and 102 cases that were potentially erroneous for the weight, abdominal circumference, and head circumference variables, respectively. Some infants had cases flagged for more than one measurement, and overall this process identified 202 infants with potentially erroneous data. Where possible, baby hospital numbers were used to locate baby notes and each potentially erroneous case was checked against the raw data. Twenty-four infants did not have a baby hospital number and we could not, therefore, locate their baby notes. Baby notes were not found for 19 infants, and for one infant we found baby notes but the raw data were missing. These infants were removed from the sample (see Figure 4.4). In total 158 sets of baby notes, with raw data, were found. When our data were checked against the raw data in the baby notes there was one discrepancy for weight and nine discrepancies for both abdominal circumference and head circumference. Where discrepancies were found, the recording in our dataset was changed to the recording found in the baby notes (see Appendix IV).

Weight was measured to the last completed 10g, and each recording should have therefore ended in a zero (i.e. 2720g not 2722g). A frequency distribution flagged eight cases where weight did not end in zero. Where possible, baby hospital numbers were used to locate baby notes and each case was checked against the raw data. Baby notes were found for seven infants and no discrepancies between our data and the raw data were found. However, to ensure consistency between infants, weight was rounded to the nearest 10g (see Appendix IV). Baby notes for one infant could not be found, and this infant was removed from our sample (see Figure 4.4). Abdominal and head circumference were measured with the precision of one decimal place. A frequency distribution did not flag any
cases where abdominal or head circumference was not recorded to one decimal place.

All other variables were categorical. Frequency distributions were used to flag cases that fell outside the expected range. For example, sex was coded as one for male and two for female. The frequency distribution demonstrated that no infants had values other than one or two for the sex variable. Values were within the expected range for all categorical variables.

4.4.4.2 Identifying erroneous data within the normal distribution of the data

Flagging extreme outliers does not identify all erroneous data. It is likely that some erroneous data are contained within the normal distribution of the data. For this reason it was necessary to check 5% of the data against the raw data. However, apart from anthropometry, it was not known which variables could be found as raw data in the baby notes and which variables were inputted directly into eClipse (i.e. electronic data). We located baby notes for a random one percent of the sample (n=26) to determine what data were inputted straight into eClispe. Sex, gestational age, birthweight, abdominal circumference, head circumference, and postcode were found in 100% of baby notes. Babies’ date of birth was only found in 61.5% of the notes, and gravidity, registerable parity, non registerable parity, and ethnicity were not found in any of the notes.

For variables which were found in 100% of baby notes (sex, gestational age, birthweight, abdominal circumference, head circumference, and postcode) we randomly selected 5% (n=129) of cases within each variable to check against raw data in the baby notes. For gestational age, abdominal circumference, head circumference, and postcode there were errors in 1.55% (n=2), 2.33% (n=3), 1.55% (n=2), and 13.18% (n=17) of the selected cases, respectively. For sex and birthweight there were no errors in the data. Due to the nature of the data, we enforced a 3% error rate within each variable, meaning that if there were errors in more than 3% of the selected cases, for any one variable, then the process would be repeated for another
5% of cases for all variables. All of our error rates were below this level apart from that for postcode. Error rates within the postcode variable may be so high because of families changing address. When a family changes address this information is changed in eClipse and System One. Our data therefore reflected the most recent postcode to which an infant was registered. For this reason we did not to perform another 5% check of cases for this variable. For the same reason, we did not change the recording in our dataset for the recording in the baby notes for the 17 cases where errors were found. For the other variables, where errors were found, the recording in our dataset was changed to the recording found in the baby notes (see Appendix IV).

### 4.4.5 Final sample
The data cleaning process flagged cases that were checked against the raw data in baby notes. Twenty-four infants did not have a baby hospital number, which meant that their baby notes could not be located. Baby notes were not found for another 20 infants, even though we had baby hospital numbers for these infants. Finally, for one infant we found baby notes but the raw data needed for checking were missing. All of these infants were deleted from our sample. At the end of the birth data cleaning process our sample size had reduced from 2631 to 2586 (see Figure 4.4). These 2586 infants formed the core analysis group.

**Figure 4.4. Final sample**
4.5 Postnatal anthropometry: Extraction, sample selection, and data cleaning

4.5.1 Data extract
On the 30th October 2008 anthropometric data were extracted from System One for all infants enrolled in BiB. In total, four datasets were produced, one for each measurement (weight, abdominal circumference, head circumference, and length). Additional variables in each of the four datasets included baby NHS number, baby date of birth, date of assessment, and date entered into System One. Decimal age at assessment was calculated as the time between date of birth and date of assessment. There were a different number of infants in each dataset, and within each dataset infants had a variable number of recordings. A data analyst from Child Health had already removed duplicates from the data, which were identified as observations where baby NHS number, date of assessment, and the measurement were the same. Duplicates probably arose as the result of a double checking process employed by Child Health at the point of data entry.

4.5.2 Sample selection
Datasets were merged with the final selected birth data using baby NHS number as a unique identifier. Data for infants who could not be merged with the selected birth data were deleted. This process ensured that only postnatal anthropometry for infants with complete birth data were included in each dataset. The birth data were then removed from each dataset leaving postnatal data for weight (n=2363), abdominal circumference (n=2155), head circumference (n=2322), and length (n=2327) for our selected sample.

4.5.3 P2PG data cleaning checks
The raw data (carbon copies from PCHRs) are filed in bundles by event entered data at the Child Health department. These bundles are stored in one of three types of box: initial health worker review (i.e. birth to 28 days), six to eight week or seven to nine month review, or extra measurement form. The data we received did not indicate the type of box in which the raw
data for each case was stored. To find a record at first required searching through three types of box, with the possibility of finding three or more bundles of records with the appropriate entered date. To then find the exact record involved searching through the bundle(s) of records and identifying ones that also matched with baby NHS number. This, however, required NHS number to be written onto each record by the health worker. A preliminary inspection of the records found that baby NHS number was not always written onto the records. This complicated process meant that a less stringent data cleaning process was employed.

4.5.3.1 Identifying erroneous cases
Potentially extreme erroneous data were identified by flagging outliers. Age at assessment was categorised into months. For each month where there were more than 20 cases, any case that was outside ± three SDs from the mean of a given dimension was identified. For the weight, abdominal circumference, head circumference, and length datasets 24, 24, 18, and 36 cases were flagged, respectively. In total there were 102 potentially erroneous cases. Baby NHS numbers and the ‘date entered’ variable were used to locate the records, and each potentially erroneous case was checked against the raw data. Only 36.27% (n=37) of records were found, of which discrepancies between the raw data and our data were found for 27.03% (n=10) of the cases and were not found for 72.97% (n=27) of the cases. Where discrepancies were found, the recording in our dataset was changed to the recording found in the baby notes (see Appendix IV). The other 65 (63.73%) cases for which raw data could not be found for were deleted. For months with less than 20 cases, all cases were checked against witness variables to ensure the results were feasible. For example, if an infant has a relatively large recording for one dimension you would expect other dimensions to be similarly large at the same age. Generally, you would also expect infants to increase in weight between measurements. This process was completed for each of the four datasets, and all cases were deemed feasible.
Weight was measured to the last completed 10g, and each recording should have therefore ended in a zero. Similarly, abdominal and head circumferences should have the precision of one decimal place, and length should have been recorded to the last completed 0.5cm. Frequency distributions were used to flag cases that violated these considerations. In total, 69 potentially erroneous cases were flagged (weight n=28, abdominal circumference n=7, head circumference n=10, length n=24,). These cases were not checked against the raw data, because of the known difficulties of locating records. To ensure consistency between infants, each case was rounded up or down to the appropriate level of precision for that dimension (see Appendix IV).

A check of a random 5% sample against the raw data was also not completed because of the known difficulties of locating records. However, Child Health double check 5% of data they input from the PCHRIs into System One. There is, therefore, already an inbuilt mechanism, at the point of data entry, to identify potentially erroneous data. Unfortunately, the percentage of data that are found to be erroneous is not recorded.

4.5.3.2 Longitudinal data cleaning
Age at assessment was used to ensure all data were entered in correct chronological order. Longitudinal research designs investigate change between two or more time points. It is expected that an infant will increase in size between measurements. For each dataset, flag variables were created to identify negative growth increments between measurements. For the weight, abdominal circumference, head circumference, and length datasets 77, 66, 32, and 16 infants had negative increments between measurements, respectively. These infants were deleted from their respective datasets.

4.5.4 Final sample
Potentially erroneous data were identified by flagging outliers, that were checked against the raw data from PCHRIs. Cases for which records could not be found were deleted from each dataset. This process only reduced the number of data points for certain infants and did not reduce the sample
sizes for each dataset. Longitudinal data cleaning flagged infants who had negative growth increments between measurements, and these infants were deleted from their respective dataset. This process reduced the sample sizes of the datasets for weight (n=2286), abdominal circumference (n=2089), head circumference (n=2290), and length (n=2311). 1939 infants had one or more recording for each of the dimensions.

4.6 Infant feeding status: extraction, sample selection, data cleaning

4.6.1 Extraction
On the 31st January 2009 infant feeding data were extracted from System One for all infants enrolled in BiB. Additional variables included baby NHS number, baby date of birth, and date of assessment. Decimal age at assessment was calculated as the time between date of birth and date of assessment. Infants had a variable number of recordings for infant feeding status.

4.6.2 Sample selection
The dataset was merged with the final selected birth data using baby NHS number as a unique identifier. Data for infants who could not be merged with the selected birth data were deleted. This process ensured that only feeding status for infants with complete birth data were included in our sample. The birth data were then removed from the dataset leaving infant feeding data for 2414 infants.

4.6.3 Phase 2-Postnatal Growth data cleaning checks
Infant feeding data are recorded on the same pages of the PCHR as the postnatal anthropometry. It is a complicated process to locate records at Child Health, and when cleaning the postnatal anthropometric data only 36.27% of records were found. Therefore, a less stringent data cleaning process was employed.
4.6.3.1 Identifying erroneous cases
Infant feeding data are categorical, and frequency distributions did not flag any cases that were outside the expected range. A check of a random 5% sample against the raw data was not completed, although the double checking process at Child Health, at the point of data entry, will have helped limit the amount of erroneous data within the normal distribution of the data.

4.6.3.2 Longitudinal data cleaning
Age at assessment was used to ensure all data were entered in correct chronological order. It is expected that an infant will progress from one feeding status to another in a natural order (i.e. exclusively breastfed to partially breastfed to bottle-fed). Flag variables were created to identify infants whose feeding status changed from bottle-fed to partially breastfed (n=41), bottle-fed to exclusively breastfed (n=19), or partially breastfed to exclusively breastfed (n=45), between two recordings. These infants (n=105) were deleted from the dataset.

4.6.4 Final sample
The longitudinal data cleaning process identified 105 infants with potentially erroneous data. These infants were deleted from the infant feeding dataset, leaving a final sample of 2309 infants with infant feeding data.

4.7 Analysis samples
After data cleaning, the selected sample consisted of 2586 infants with complete birth data (see Figure 4.5). 2286, 2089, 2290, 2311 of these infants had one or more postnatal recordings for weight, abdominal circumference, head circumference, and length, respectively. For all dimensions, the median number of postnatal recordings was two. 2309 infants also had one or more recordings for infant feeding status. The median number of recordings for feeding status was two. There were 1825 infants with complete birth data, one or more recording for each of the postnatal dimensions, and one or more recording for infant feeding status.
There were two analysis strands within this study. The core sample of 2586 infants were used to investigate factors that influence weight, abdominal circumference, and head circumference at birth. A second analysis sample of infants with a normal gestational age were used to produce growth curves, via multilevel model (MLM) analysis, to investigate differences in growth between White British and Pakistani infants. Predictions of anthropometry at specified ages made it possible to use univariable and multivariable linear regression models to investigate factors that influence weight, abdominal circumference, and head circumference at birth; length and BMI at 12 days of age; and all dimensions at nine months of age. The growth of the second analysis sample was also compared to the UK90 references and WHO standards.

4.7.1 Sample and effect size

In order to perform a univariable linear regression, performing significance tests at $\alpha=0.05$ (95% confidence) with a medium effect size ($r^2=0.1304$) and 80% power, a sample of 85 is needed (Cohen 1992). For a small effect size
(r^2=0.0196) a sample of 783 is needed. Similarly, to perform a multivariable linear regression with eight independent variables, performing significance tests at \( \alpha=0.05 \) with a medium effect size and 80% power, a sample of 107 is needed (Cohen 1992). For a small effect size a sample of 757 is needed. All of the univariable and multivariable regression analyses in this thesis had sample sizes sufficient to detect a small effect, apart for those where the outcomes were length or BMI, which were only large enough to detect a medium effect. To perform sample size calculations for a MLM analysis an estimate of both the within and between level variance is needed. These data were not available in the literature, so sample size calculation could not be performed. By accounting for between level variance, MLMs result in lower standard error of the estimate (SE) compared to traditional regression models (see section 4.7.1.). Therefore, a sample that is sufficiently powered for a multivariable regression analysis, will also be sufficiently powered for a MLM analysis (Rabe-Hesketh & Skrondal 2008).

4.8 Analyses

Data analyses were undertaken using the Statistical Package for the Social Sciences version 16 (SPSS Inc., Chicago, IL, USA) and Stata Inter-Cooled version 10 (StataCorp LP., College Station, TX, USA).

4.8.1 Multilevel growth modelling

Fitting a mathematical model to growth data is a powerful tool in the study of human growth (Simondon et al. 1992). When fitted to longitudinal growth data, conventional regression models provide a single regression equation or growth curve for a group of individuals. ANCOVA can then be used for inter-group comparisons, although it cannot indicate which growth characteristic within a group explains the differences between groups (Baxter-Jones & Mirwald 2004). Repeated measures ANOVA can also be used to analyse longitudinal growth data, although time-dependent covariates can not be fitted and each individual needs the same number of measurements at the same ages (i.e. cells have to be balanced).
Multilevel models differ from conventional regression models in that they allow the incorporation of individual growth characteristics (Goldstein 1989). With multilevel growth models there are usually two levels, the measurement occasions are the level-one units, and the level-two units are the individuals themselves (Rabe-Hesketh & Skrondal 2008). MLMs predict level-two growth curves, i.e. a growth curve for each individual. As such, each individual has their own intercept and coefficients. This approach can be used to investigate inter-group effects whilst controlling for individual differences in growth (Baxter-Jones & Mirwald 2004). MLMs also allow for time-dependent covariates to be fitted and do not require individuals to have the same number of measurements at the same ages (i.e. cells do not have to be balanced). Missing data therefore do not pose a problem, unless of course they are missing but not at random, in which case they will increase uncertainty and may bias results.

With conventional regression models it is generally accepted that in order to fit a growth curve for an individual there should be one more data point available than the number of parameters in the model (i.e. with a four parameter model five repeat measurements are needed) (Baxter-Jones & Mirwald 2004). With MLMs it is possible to combine all available data on any number of individuals and predict individual growth curves. A probability function is used to describe the relative likelihood of each continuous random variable occurring at a given point in the observation space (Rabe-Hesketh & Skrondal 2008). Thus, it is possible to use multilevel modelling to predict growth curves for individuals with one, two, three or any number of repeat measurements, although the amount of data available for each individual and the total amount of data available will of course influence model accuracy.

MLMs are commonly referred to as random-effects models (REMs) (Rabe-Hesketh & Skrondal 2008). In conventional regression models the intercept and coefficients are fixed (i.e. values do not vary between individuals), and random variation only occurs within individuals and not between them. Regression models, therefore, only explain group effects of how things are,
they do not explain why things are (i.e. you can not determine the effects of each independent variable on the outcome at a specified age) (Baxter-Jones & Mirwald 2004). With MLMs the intercept and/or coefficients can be specified as random (i.e. values vary between individuals), which means random variation occurs both within and between individuals. This allows independent variables to have time-dependent effects, which means that the effect of a variable on the outcome at a specific age can be determined. MLMs can be used to explain why an individual or group of individuals demonstrate a particular pattern of growth. It is for these reasons that including individual growth characteristics in a model is imperative in the study of human growth (Kreft & de Leeuw 1998).

4.8.1.1 Finding the curve
A preliminary analysis was performed to find a mathematical model that provided the best fit for the growth data. Three different regression models were developed into MLMs. The Count (1943) model has three parameters and was specifically proposed for modelling anthropometry. The Reed 1st order model (Berkey & Reed 1987) includes an additional fourth parameter, which allows an inflexion point. Whereas, the quadratic model is a second degree polynomial, that can be easily fitted to growth data. Unlike the other models, it is a non-structural model which does not postulate a particular form of the growth curve. More sophisticated non-structural models could have also been fitted to the data although they tend to have a large number of parameters with no biological interpretation and are usually unstable at the extremities of the data (Hauspie & Molinari 2004). One approach would be to fit a fractional polynomial to derive a piecewise linear spline model, which consists of a series of connected lower order polynomials. These models are used to model local variations in growth, such as the mid-growth spurt (Pan & Goldstein 1998), and are thus not normally necessary to model growth during infancy.
Methods

**Quadratic**

\[ y = \beta_1 + \beta_2(X) + \beta_3(X^2) \]

**Count**

\[ y = \beta_1 + \beta_2(X) + \beta_3\ln(X) \]

**Reed 1st order**

\[ y = \beta_1 + \beta_2(X) + \beta_3\ln(X) + \beta_4/X \]

Where \( y \) is size and \( X \) is age.

When the intercept and all the coefficients of these conventional regression models are allowed to be random (i.e. vary between individuals) they become MLMs and are expressed as:

**Quadratic MLM**

\[
y_{ij} = \beta_1 + \beta_2(X_{ij}) + \beta_3(X_{ij}^2) + \zeta_{1j} + \zeta_{2j}(X_{ij}) + \zeta_{3j}(X_{ij}^2) + E_{ij}
\]

fixed part \hspace{10pt} random part

**Count MLM**

\[
y_{ij} = \beta_1 + \beta_2(X_{ij}) + \beta_3\ln(X_{ij}) + \zeta_{1j} + \zeta_{2j}(X_{ij}) + \zeta_{3j}\ln(X_{ij}) + E_{ij}
\]

fixed part \hspace{10pt} random part

**Reed 1st order MLM**

\[
y_{ij} = \beta_1 + \beta_2(X_{ij}) + \beta_3\ln(X_{ij}) + \beta_4/X_{ij} + \zeta_{1j} + \zeta_{2j}(X_{ij}) + \zeta_{3j}\ln(X_{ij}) + \zeta_{4j}/(X_{ij}) + E_{ij}
\]

fixed part \hspace{10pt} random part

Where, \( y_{ij} \) is the size of child \( j \) at occasion \( i \); \( X_{ij} \) is the corresponding age; \( \zeta_{1j} \) is a random intercept; \( \zeta_{2j}, \zeta_{3j}, \) and \( \zeta_{4j} \) are random coefficients; and \( E \) is an error term.
For the dimensions, weight, abdominal circumference, and head circumference, birth and postnatal anthropometry were merged together. Length was not recorded at birth, so infants were selected who had a recording in the first 14 days of life. If a younger cut off point was used the sample size would have probably been too small to fit a MLM (Rabe-Hesketh & Skrondal 2008). Infants who did not have a normal gestational age (37 to 41 weeks) were then deleted from each dataset. For each dataset, only a small number of infants had a recording after 0.8 decimal years of age. This was expected as the last prescribed data collection period ends at nine months (i.e. 0.75 decimal years) of age. Any recordings taken after 0.8 decimal years of age were deleted from their respective datasets. This ensured that recordings for a small number of infants, who may have had characteristics that make them unrepresentative of the population, taken at the extremity of the age range, did not influence the shape of the growth curve. For weight, abdominal circumference, and head circumference 2464 infants were included in the analysis, and for length 520 infants were included.

As this was a preliminary analysis it was decided that growth models would only be fitted to anthropometry for one sex and ethnic specific group. It was decided to fit growth models to data for White British girls because they had the smallest sample sizes for each dimension (weight, abdominal circumference, and head circumference n=544; length n=101) and would, therefore, probably be the hardest sex and ethnic specific group for which to find an appropriate growth model.

The Count and Reed 1st order MLMs posed a potential problem as they are not defined at age zero (Simondon et al. 1992), which makes the inclusion of birth data difficult (i.e. ln(0) = -∞ and 1/(0) = +∞). To resolve this problem the age scale was shifted using the age transformation $x = \text{decimal age} + 0.001$. The quadratic MLM does not pose this problem because age at birth (i.e. zero) can be squared. The three MLMs were then fitted for each of the four dimensions using the ‘xtmixed’ command in Stata, where the default method of fitting is maximum restricted likelihood.
At first only the intercept was specified as random, then the model was refitted allowing the intercept and the first coefficient to be random, and then allowing the intercept and the first and second coefficients to be random, and so on. The SD of the residuals at each stage of model development was compared to that for the previous stage to ensure that specifying another coefficient to be random improved the fit. In some cases, Stata was not able to fit a model when all coefficients were allowed to be random. At all stages the p-values were checked to ensure each parameter was a significant (p<0.05) or borderline significant (p<0.10) predictor of the outcome, which they were for all models. Each MLM was therefore developed to provide the best possible fit for the data.

Table 4.2. Comparison of three multilevel models fitted to anthropometry of White British girls (n=544)

<table>
<thead>
<tr>
<th>Model Type</th>
<th>Number of coefficients specified as random</th>
<th>Log restricted likelihood</th>
<th>Standard deviation of the residuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadratic MLM</td>
<td>Weight (g)</td>
<td>2</td>
<td>-12876.477</td>
</tr>
<tr>
<td></td>
<td>Abdominal circumference (cm)</td>
<td>2</td>
<td>-3011.528</td>
</tr>
<tr>
<td></td>
<td>Head circumference (cm)</td>
<td>1</td>
<td>-2302.622</td>
</tr>
<tr>
<td></td>
<td>Length (cm)</td>
<td>2</td>
<td>-538.232</td>
</tr>
<tr>
<td>Count MLM</td>
<td>Weight (g)</td>
<td>2</td>
<td>-13195.535</td>
</tr>
<tr>
<td></td>
<td>Abdominal circumference (cm)</td>
<td>2</td>
<td>-3070.177</td>
</tr>
<tr>
<td></td>
<td>Head circumference (cm)</td>
<td>1</td>
<td>-2357.721</td>
</tr>
<tr>
<td></td>
<td>Length (cm)</td>
<td>2</td>
<td>-542.698</td>
</tr>
<tr>
<td>Reed 1st order MLM</td>
<td>Weight (g)</td>
<td>3</td>
<td>-12810.858</td>
</tr>
<tr>
<td></td>
<td>Abdominal circumference (cm)</td>
<td>2</td>
<td>-2996.908</td>
</tr>
<tr>
<td></td>
<td>Head circumference (cm)</td>
<td>2</td>
<td>-2242.227</td>
</tr>
<tr>
<td></td>
<td>Length (cm)</td>
<td>1</td>
<td>-541.202</td>
</tr>
<tr>
<td>Reed 1st order MLM**</td>
<td>Weight (g)</td>
<td>3</td>
<td>-12820.786</td>
</tr>
<tr>
<td></td>
<td>Abdominal circumference (cm)</td>
<td>2</td>
<td>-2986.379</td>
</tr>
<tr>
<td></td>
<td>Head circumference (cm)</td>
<td>2</td>
<td>-2228.055</td>
</tr>
<tr>
<td></td>
<td>Length (cm)</td>
<td>1</td>
<td>-536.088</td>
</tr>
</tbody>
</table>

*All models had a random intercept, but the number of coefficients that could be specified as random varied.

**fitted using maximum likelihood estimation, as opposed to maximum restricted likelihood

In general, the Reed 1st order MLM provided the best fit for anthropometry of White British girls, the quadratic MLM provided the second best fit for the data, and the Count MLM provided the worst fit for the data (see Table 4.2).
For weight, abdominal circumference, and head circumference the SDs of the residuals were the smallest for the Reed 1st order MLM. For length, the quadratic MLM provided a marginally better fit for the data than the Reed 1st order MLM. This is probably because Stata could not fit the Reed 1st order MLM to the length data when more than one coefficient was made random.

The Reed 1st order MLMs were then re-fitted using maximum likelihood estimation, as opposed to maximum restricted likelihood, to determine which estimation method resulted in a model that provided the best fit for the data. Using maximum likelihood estimation resulted in marginally smaller SDs of the residuals for all dimensions (see Table 4.2). The covariance matrices of the fixed effects from these MLMS were used to produce weight-for-age (WFA), abdominal circumference-for-age (ACFA), head circumference-for-age (HCFA), and length-for-age (LFA) mean constant growth curves between birth and nine months of age. For each dimension, in the first few days of life there was an unexpected decrease in size, followed by rapid growth (see Figure 4.6). This problem occurred because the age transformation had not shifted the age scale enough to combat the problems of including size at age zero. The 3rd and 4th parameters of the Reed 1st order MLM were producing numbers that were small and large enough, respectively, (i.e, ln(0.001) = -6.908 and 1/(0.001) = 1000) to cause this ‘tick’ in the growth curves. The ‘tick’ was also present in the LFA growth curve which suggests an age transformation, and one larger than adding 0.001, is needed even if size at age zero is not included in the data used for modelling.
An attempt to refit the models using the age transformation $x = \text{decimal age} + \text{one}$, as recommended by Simondon et al (1992) and Hauspie and Molinari (2004), was made. However, this transformation meant that Stata could no longer fit the Reed 1st MLM to any of the dimensions, even if no random coefficients were specified. Stata’s inability to fit models may occur because adding one rather than 0.001 to decimal age increases collinearity between covariates, thus model stability is more at risk. Fitting Reed 1st order MLMs to data for all infants (i.e. not sex and ethnic specific models) to increase the amount of information available for modelling resolved this problem.

**4.8.1.2 Multilevel model building**

Information from the preliminary analysis was used to develop a final set of MLMs. Reed 1st order MLMs were fitted to anthropometry for all infants with a normal gestational age (37 to 41 weeks) using maximum likelihood estimation and the age transformation ‘decimal age + one’. For length, infants were selected who had a recording in the first 14 days of life. Recordings taken after 0.8 decimal years of age were not included in the analysis. For weight, abdominal circumference, and head circumference 2464 infants were included in the analysis, and for length 520 infants were included. Table 4.3. shows the number of infants with one, two, three, four, and five or more recordings, for each dimension. It was not possible to complete sensitivity analysis by restricting the modelling procedure to infants.
with between, say, three and six recordings for a given dimension because
this reduced the sample sizes and the total amount of data available for
modelling to the extent that Stata could not fit the models.

**Table 4.3. The number of term infants with one, two, three, four, and five or
more recordings, for each dimension**

<table>
<thead>
<tr>
<th>Number of repeat measurements</th>
<th>Weight</th>
<th>Abdominal circumference</th>
<th>Head Circumference</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>178</td>
<td>375</td>
<td>174</td>
<td>31</td>
</tr>
<tr>
<td>2</td>
<td>611</td>
<td>805</td>
<td>671</td>
<td>267</td>
</tr>
<tr>
<td>3</td>
<td>1002</td>
<td>891</td>
<td>1080</td>
<td>180</td>
</tr>
<tr>
<td>4</td>
<td>452</td>
<td>333</td>
<td>538</td>
<td>26</td>
</tr>
<tr>
<td>5 or more</td>
<td>221</td>
<td>60</td>
<td>1</td>
<td>16</td>
</tr>
</tbody>
</table>

At first, only the intercept was specified as random (see Equation 1). Then
the MLMs were re-fitted allowing both the intercept and the first coefficient to
be random (see Equation 2). When the MLMs were refitted for a third time,
specifying a random intercept and two random coefficients, Stata was
unable to fit a model for all dimensions. To investigate if there were any
systematic differences in size between Pakistani and White British infants a
dummy variable $\omega_j$ for Pakistanis was added to the fixed part of the MLMs
(see Equation 3). A second dummy variable $\nu_j$ for girl was added to
investigate systematic differences in size between sexes (see Equation 4).
A natural extension of the MLMs was to include Pakistani as a covariate
also in the slope part of the equation. This would allow the shape of the
growth curve to vary between ethnicities. It was decided to add Pakistani
dummy variables for all three coefficients, as the growth curve is determined
by a combination of all three coefficients. The first coefficient dummy
variable $\omega_j(X_{ij})$ allows the gradient of the growth curve to vary between
ethnicities, the second coefficient dummy variable $\omega_j\ln(X_{ij})$ affects the shape
of the curve, and the third coefficient dummy variable $\omega_j/X_{ij}$ allows each
ethnicity to have a separate inflexion point. The three coefficient dummy
variables were created and added to the MLMs (see Equation 5). These
variables were then removed and dummy variables that allowed each sex to
have their own coefficients were added to the MLMs (see Equation 6).
Equation 1. Random intercept

\[ y_{ij} = \beta_1 + \beta_2(X_{ij}) + \beta_3\ln(X_{ij}) + \beta_4/X_{ij} + \zeta_{1j} + E_{ij} \]

Equation 2. Random intercept and one random coefficient

\[ y_{ij} = \beta_1 + \beta_2(X_{ij}) + \beta_3\ln(X_{ij}) + \beta_4/X_{ij} + \zeta_{1j} + \zeta_{2j}(X_{ij}) + E_{ij} \]

Equation 3. Random intercept, one random coefficient, and dummy variable for Pakistani

\[ y_{ij} = \beta_1 + \beta_2(X_{ij}) + \beta_3\ln(X_{ij}) + \beta_4/X_{ij} + \beta_5\omega_j + \zeta_{1j} + \zeta_{2j}(X_{ij}) + E_{ij} \]

Equation 4. Random intercept, one random coefficient, and dummy variables for Pakistani and girl

\[ y_{ij} = \beta_1 + \beta_2(X_{ij}) + \beta_3\ln(X_{ij}) + \beta_4/X_{ij} + \beta_5\omega_j + \beta_6\nu_j + \zeta_{1j} + \zeta_{2j}(X_{ij}) + E_{ij} \]

Equation 5. Random intercept, one random coefficient, dummy variables for Pakistani and girl, and three dummy variables for Pakistani coefficients

\[ y_{ij} = \beta_1 + \beta_2(X_{ij}) + \beta_3\ln(X_{ij}) + \beta_4/X_{ij} + \beta_5\omega_j + \beta_6\nu_j + \beta_7\nu_j(X_{ij}) + \beta_8\nu_j\ln(X_{ij}) + \beta_9\nu_j/X_{ij} + \beta_{10}\omega_j(X_{ij}) + \zeta_{1j} + \zeta_{2j}(X_{ij}) + E_{ij} \]

Equation 6. Random intercept, one random coefficient, dummy variables for Pakistani and girl, and three dummy variable for girls coefficients

\[ y_{ij} = \beta_1 + \beta_2(X_{ij}) + \beta_3\ln(X_{ij}) + \beta_4/X_{ij} + \beta_5\omega_j + \beta_6\nu_j + \beta_7\nu_j(X_{ij}) + \beta_8\nu_j\ln(X_{ij}) + \beta_9\nu_j/X_{ij} + \zeta_{1j} + \zeta_{2j}(X_{ij}) + E_{ij} \]

The SD of the residuals and the log likelihood of a model, at each stage of development, were compared to the previous stage to check whether each stage improved the fit of the model. At all stages the p-values were checked to ensure each parameter was a significant (p<0.05) or borderline significant
(p<0.10) predictor of the outcome. The final MLMs were those that had the smallest residuals and had p-values that were significant/ borderline significant. For all dimensions, the coefficient dummy variables for sex were not significant predictors of the outcome, and this is why models that included coefficient dummy variables for both ethnicity and sex were not fitted.

After the final MLMs had been fitted, histograms of the residuals and the random-effect parameters were produced (see Appendix V) to check the validity of the models. With the histograms for weight, there was one potential outlier in each of the three histograms. This infant had a very large WFA recording. Further investigation found that the data point had been checked against the raw records during data cleaning and was correct. Similarly, one infant with large measurements was identified as a potential outlier in the abdominal circumference and head circumference histograms. These measurements had also been checked during data cleaning and were correct. Finally, the length histograms identified one infant with a very small length measurement that had been certified as being correct during data cleaning. Otherwise, histograms demonstrated reasonable normal distributions.

The covariance matrices of the fixed effects from the MLMS were used to produce WFA, ACFA, HCFA, and LFA ethnic and sex specific mean constant growth curves and limits within which 95% of individual growth curves lie. For weight, abdominal circumference, and head circumference these mean constant curves were produced between birth and nine months of age. Whereas, for length, curves were produced between 12 days and nine months of age. Growth curves are likely to be unreliable outside the age range of the data used to fit the model (Hauspie & Molinari 2004). Twelve days of age was chosen as the starting point for the LFA growth curves because this was the mean age that infants in the length sample had their first recording. Mean constant growth curves where then plotted against the actual data, for the respective dimension/ethnic/sex specific group, to allow visual inspection of how well each curve fitted the data.
Ethnic and sex specific mean residuals were computed for each month between birth (12 days for length) and nine months of age, for each dimension. Mean monthly residuals were then plotted on graphs as deviations from the mean constant growth curves. Non-parametric Wald Wolfowitz runtests were also performed, for each dimension/ethnic/sex specific group, to determine whether the mean monthly residuals were serially independent. The results were used to determine whether the MLMs predicted fitted values (i.e. linear predictions of the fixed part of the model plus contributions based on predicted random-effects) that were systematically larger or smaller than the actual values. A runtest counts how many runs there are above and below a threshold, which in this case was specified as the mean. A small number of runs indicates positive serial correlation, whereas a large number indicates negative serial correlation. As there were fewer than ten observations in each analysis group, a continuity correction was made and the critical values provided by Swed and Eisenhart (1943) were used.

4.8.1.3 Prediction
For each MLM, the best linear unbiased predictions (BLUPs) of the random-effects were predicted. In this case BLUPs were each infant’s values for the parameters $\zeta_{1j} + \zeta_{2j}$. When combined with the fixed part of a MLM, it is possible to calculate an individual’s size at any specified age. For example, the weight of a Pakistani girl at 0.5 (1.5 after performing the age transformation) decimal years of age (i.e. six months) can be calculated as:

$$y_{ij} = \beta_1 + \beta_2(X_{ij}) + \beta_3\ln(X_{ij}) + \beta_4X_{ij} + \beta_5\omega_j + \beta_6\nu_j + \zeta_{1j} + \zeta_{2j}(X_{ij})$$

$$y_{ij} = -22850.3 + -58197.8(1.5) + 152630.3\ln(1.5) + 84504.5/1.5 + -205.3 + -161.6 + -3787.8 + 3814.5(1.5)$$

$$y_{ij} = 6787.1g$$

Weight, abdominal circumference, head circumference, and length were calculated at one, two, three……nine months, for each infant (n=2464). Weight and length were also calculated for infants, in the length dataset (n=520), at 12 days of age. Finally, BMI was then calculated at 12 days and one, two, three……nine months of age.
4.8.2 Multivariable linear regression analysis

Two sets of multivariable linear regression models were built. The first set of models were built to investigate factors that influence size at birth, and to determine the effects of ethnicity on size at birth after adjusting for other covariates. The second set of models investigated factors that influence size at nine months of age. Similarly, these models were used to determine the effects of ethnicity on size at nine months after adjusting for other covariates. All outcome variables (see Table 4.4) were reasonably normally distributed, and for this reason were not converted to Z-scores.

4.8.2.1 Predictor variables

Ethnicity and sex were binary variables with the responses: White British and Pakistani and male and female, respectively. Term was a categorical variable determined by the number of completed weeks of gestation. The responses were preterm (≤36 weeks), term (37 to 41 weeks), and post-term (≥42 weeks). The sex specific cut-off points recommended by the WHO (Williams et al. 1982) were used to categorise infants into size for gestational age groups. Infants with a birthweight below the 10th percentile or above the 90th percentiles, for each gestational age in completed weeks, were classified as small for gestational age (SGA) and large for gestational age (LGA), respectively. All other infants were classified as appropriate for gestational age (AGA). Size for gestational age was, therefore, a categorical variable with the responses: SGA, AGA, and LGA. Parity was a categorical variable, which only included the registerable births a mother had delivered. The responses were para one, para two, and para ≥ three. IMD was a categorical variable, which was produced by linking infant postcodes via the NSPD (Office for National Statistics 2008b) to LSOA to produce ranks. The most recent indices of deprivation, which are for 2007, were used (Noble et al. 2008). The IMD is a rank from one to 32,482, with one being the most deprived LSOA and 32,482 being the least deprived LSOA. As a rank, IMD had to be treated as a categorical variable. It was decided to categorise IMD into tertiles to allow easy interpretation of coefficients. In regression models the references groups were White British, male, term, AGA, para one, and the 3rd IMD tertile (i.e. the least deprived third of the sample).
Infant feeding status at two months (±two weeks) of age was a categorical variable with the outcomes: exclusively breastfed, partially breastfed, bottle-fed, and missing data. Infant feeding status should be routinely collected at birth to 28 days and six to eight weeks of age. The correlation between infant feeding status at these two ages, for individuals who had recordings, was 0.725. It was, therefore, not possible to include infant feeding status at both ages in regression models due to potential problems with collinearity. A single variable that incorporates infant feeding status at both ages could have been created (for example, breastfeeding at birth to 28 days and bottle feeding at six to eight weeks), although this would require infants to have recordings at both ages and would make interpretation of regression models complicated. A variable that only focused on data collected between birth and 28 days of age would mean that infants who were only exclusively or partially breastfed for a few days would be included in the exclusively breastfed group or partially breastfed group, respectively. Total duration of breastfeeding is negatively correlated with slower growth in the first year of life (Gunnarsdottir et al. 2009; Michaelsen et al. 1994; Nielsen, Thomsen & Michaelsen 1998). Therefore, a single variable that focused on infant feeding status captured at the second prescribed age period was created. Histograms (not shown) of ‘age at assessment’ showed that the majority of recordings for infant feeding status were taken close to but not within the prescribed age periods, and followed a positively skewed distribution. The second age period was therefore extended to six to ten weeks of age (i.e. two months ± two weeks) to capture as much data as possible. Of the 2464 infants included in the second set of regression models, 1119 had one recording for infant feeding status within this age range, and 51 infants had two recordings. Where infants (n=48) had the same feeding status at each age one of the recordings was deleted, and where infants (n=3) had different feeding status’ at each age the second recording was deleted. Infants with either no data or no recording at two months (± two weeks) (n=1345) were classified as ‘missing data’. In regression models the reference group was exclusively breastfed.
Birthweight, abdominal and head circumferences at birth, and length and BMI at 12 days of age were continuous variables. Conditional weight, conditional abdominal circumference, conditional head circumference, conditional length, and conditional BMI at two months of age were also continuous variables. All anthropometric and conditional anthropometric predictor variables were reasonably normally distributed. Anthropometric variables were centered about the mean. All conditional variables were calculated using the same methods, and the calculation of conditional weight will be used as the example in this section. Conditional weight is the component of weight at any given age that is uncorrelated with weight at a previous age(s) (Keijzer-Veen et al. 2005). Including conditional weight in regression models eliminated the statistical problems of modelling highly correlated weight variables. This meant that regression models could include birthweight and a measure of weight at two months of age as predictors of weight at nine months of age. Conditional weight was calculated as the residuals from sex specific linear regressions of weight at two months of age on birthweight:

\[ W_2 - c^*rW_1 \]

Where, \( W_2 \) was weight at nine months of age, \( W_1 \) was weight at birth, and \( c \) and \( r \) were the intercept and coefficient, respectively, from regressing \( W_2 \) on \( W_1 \).

Conditional weight at two months of age was, therefore, the deviation of each individual’s weight from its expected value, given the individual’s birthweight. When a conditional variable is included in a multivariable linear regression, with the variable it is conditional on, it can be interpreted as change in weight above or below that predicted by regression to the mean over the prior time interval (Adair et al. 2009). It is, therefore, a useful way to assess catch-up and catch-down growth (Cameron, Preece & Cole 2005). Upon creation of a conditional variable, the correlation between the conditional variable and the respective variable at birth was calculated. For all dimensions correlation coefficients were zero, meaning that the process of calculating conditional variables had been successful.
Methods

Table 4.4. Available variables for multivariable linear regression analyses

<table>
<thead>
<tr>
<th>Outcome variables</th>
<th>Predictor variables</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Set 1. Factors that influence size at birth</strong></td>
<td></td>
</tr>
<tr>
<td>Birthweight (g)</td>
<td>Ethnicity</td>
</tr>
<tr>
<td>Abdominal circumference at birth (cm)</td>
<td>Sex</td>
</tr>
<tr>
<td>Head circumference at birth (cm)</td>
<td>Term</td>
</tr>
<tr>
<td>Length at 12 days (cm)</td>
<td>Size for gestational age</td>
</tr>
<tr>
<td>BMI at 12 days</td>
<td>Parity</td>
</tr>
<tr>
<td></td>
<td>Index of Multiple Deprivation tertile</td>
</tr>
<tr>
<td></td>
<td>Ethnicity* Index of Multiple Deprivation tertile</td>
</tr>
<tr>
<td><strong>Set 2. Factors that influence size at nine months of age</strong></td>
<td></td>
</tr>
<tr>
<td>Weight at 9 months (g)</td>
<td>Ethnicity</td>
</tr>
<tr>
<td>Abdominal circumference at 9 months (cm)</td>
<td>Sex</td>
</tr>
<tr>
<td>Head circumference at 9 months (cm)</td>
<td>Size for gestational age</td>
</tr>
<tr>
<td>Length at 9 months (cm)</td>
<td>Parity</td>
</tr>
<tr>
<td>BMI at 9 months</td>
<td>Index of Multiple Deprivation tertile</td>
</tr>
<tr>
<td></td>
<td>Infant feeding status at 2 months</td>
</tr>
<tr>
<td></td>
<td>Birthweight (g)</td>
</tr>
<tr>
<td></td>
<td>Conditional weight at 2 months (g)</td>
</tr>
<tr>
<td>Abdominal circumference at birth (cm)</td>
<td>Conditional abdominal circumference at 2 months (cm)</td>
</tr>
<tr>
<td>Head circumference at birth (cm)</td>
<td>Conditional head circumference at 2 months (cm)</td>
</tr>
<tr>
<td>Length at 12 days (cm)</td>
<td>Conditional length at 2 months (cm)</td>
</tr>
<tr>
<td>BMI at 12 days</td>
<td>Conditional BMI at two months (cm)</td>
</tr>
</tbody>
</table>

4.8.2.2 Model building

Model building was theory driven rather than using statistically built models (i.e. stepwise methods) which retain variables solely on the strength of their association with the outcome. Review of the infant growth literature (see Chapter two) highlighted a number of factors that are associated with specific patterns of infant growth. There are various problems associated with statistical methods of model building (Derksen & Keselman 1992). For example, the stepwise method yields R-squared values that are badly biased to be high. Studenmund and Cassidy (1987) argue that for theory based models, the enter method of linear regression is the only appropriate technique. For this reason, the enter method was used to fit the models.
Bivariate analysis was used to decide which variables would be included in each regression model. For each set of regression models, each available predictor variable was regressed on each of the outcome variables. Those variables that were significant (p<0.05) or were borderline significant (p<0.10) predictors of the outcome were retained in the analysis. All significant predictor variables of size at birth were correlated against each other to address issues of multicollinearity. Similarly, all significant predictors of size at nine months were correlated against each other. For the first set of models, none of the correlations between predictor variables were statistically significant. Whereas, for the second set of models, the correlations between anthropometric variables at birth (or 12 days), and the correlations between conditional anthropometric variables at two months of age were statistically significant.

Where birthweight was the model outcome, size for gestational age was not included as a predictor variable. Due to these potential problems with multicollinearity the only anthropometric variables at birth and at two months of age included in each model were the same dimension as the outcome (i.e. birth weight and conditional weight at two months were the only anthropometry included when the model outcome was weight at nine months). Where ethnicity and IMD were significant predictors of an outcome, the multivariable model was refitted adding an interaction variable ethnicity*IMD. This interaction was not theory based but was included to determine whether socioeconomic status differs in its relationship to size at birth and nine months by whether infants are Pakistani or White British.

Upon creation of a model, a number of diagnostic checks were undertaken to assess model validity. Variance Inflation Factor (VIF) and tolerance values were checked and in no cases violated assumptions. Diagnostics highlighted individual cases with standardised residuals greater or less than three. For these cases, the Cooks Distance and leverage values were checked, and in no cases were these values close to exceeding problematic levels. Where a predictor was significantly associated with the outcome,
95% CI were checked to ensure that the effect of the predictor on the outcome was estimated with good precision.

4.8.3 Comparison to the UK90 references and WHO standards

4.8.3.1 Visual comparison
The growth curves of term infants, produced by multilevel modelling, were compared to the UK90 references and WHO standards. Least Mean Squares data provided by the CGF (London, UK) were used to reproduce the UK90 references and WHO standards WFA, HCFA, and LFA centile charts in Stata. The sex-specific centile curves (91st, 75th, 50th, 25th, 9th) of both the UK90 references and WHO standards, for each dimension, were defined in terms of the LMS curves as follows:

$$M(1+L*S*z)^{1/L}$$

Where, z is the z-score corresponding to the required centile.
Sex and ethnic specific mean constant WFA, HCFA, and LFA growth curves, between birth and nine months of age, were plotted against the UK90 references and WHO standards centile charts.

4.8.3.2 External Z-scores
Age and sex adjusted external Z-scores for weight, head circumference, length, and BMI were calculated by comparison with both the UK90 and WHO 2006 growth data, using software provided by the CGF (London, UK). External Z-scores were calculated at monthly intervals between birth (12 days for length and BMI) and nine months of age, for term (37 to 41 weeks of gestation) infants who were included in the MLM analysis.

There was an option to adjust the Z-scores for gestational age. For Z-scores relative to the WHO standards, this adjustment required infants to have a gestational age greater than 39 weeks, thus resulting in smaller samples sizes. When the analysis was re-run adjusting for gestational age, mean Z-scores were very similar to those produced when the adjustment had not
been made. For these reasons, only the Z-scores which were not adjusted for gestational age are reported in this thesis.

4.8.3.3 Relative risk
External Z-scores, relative to the UK90 references, that were below the 2\textsuperscript{nd} centile (i.e. -2.05 Z-scores) were classified as underweight. Similarly, external BMI-for-age (BMIFA) Z-scores above the 98\textsuperscript{th} centile were classified as obese. The same process was then performed for Z-scores relative to the WHO standards. The percentages of infants classified as underweight or obese, according to UK90 references or the WHO standards, were then calculated at monthly intervals between birth (12 days for obese) and nine months of age. This information was used to work out the RR of underweight and obesity using the WHO standards compared to the UK90 references.

To calculate the RR of failure to thrive using the WHO standards compared to the UK90 references, conditional weight Z-scores at nine months of age was calculated to account for regression to the mean. At first, weight Z-scores at nine months of age, conditional on weight at birth (Z-scores), were calculated using the formula proposed by Cameron et al (2005):

$$Z_2 - rZ_1$$

Where, $Z_2$ was Z-score at nine months of age, $Z_1$ was Z-score at birth, and $r$ was the correlation between them (N.B. the coefficient from regressing $Z_2$ on $Z_1$ should have provided the same number).

Conditional weight Z-scores at nine months of age were calculated using sex specific correlation coefficients. If the equation had worked you would expect conditional weight Z-scores at nine months of age to be perfectly uncorrelated with the variables it was conditional on (i.e. weight Z-scores at birth), although this was not the case. The equation had not worked because the external Z-scores were not perfect Z-scores with a mean of zero and SD of one. To resolve this problem, conditional weights were
calculated as the residuals from sex specific linear regressions of weight Z-scores at nine months of age on weight Z-scores at birth:

\[ Z_2 - c + rZ_1 \]

Where, c and r were the intercept and coefficient, respectively, from regressing \( Z_2 \) on \( Z_1 \).

Conditional weight Z-scores at nine months of age were correlated against weight Z-scores at birth, and in all cases the correlation coefficient was zero. Poor infant weight gain was defined as a conditional weight Z-score at nine months of age less than -1.33, which is equivalent to downward crossing through two major centile lines on a growth chart. Infants who demonstrated poor infant weight gain were identified. The percentages of infants classified as demonstrating poor infant weight gain, according to the UK90 references and the WHO standards, between birth and nine months of age were calculated. This information was used to work out the RR of poor infant weight gain using the WHO standards compared to the UK90 references.

4.9 Ethics

Ethical approval for P2PG was granted by Bradford Research Ethics Committee on the 16th May 2007, and research governance approval was provided by BTHT and Bradford and Airedale tPCT on the 26th March 2007 and the 4th December 2007, respectively.
5 Routine growth data collection
5.1 Routine data collection in Bradford

5.1.1 Introduction and aims
Health workers in Bradford are largely responsible for monitoring the growth of infants. Growth data are collected during visits to infants’ homes and at baby clinics, which are organised at health centres across Bradford. The health visitor manual for Bradford and Airedale state that routine measurement should occur between birth and 28 days, six to eight weeks, and seven to nine months, although BiB have asked health workers to perform their first visit between ten and 14 days. The BiB project has also introduced a new measurement, abdominal circumference, to growth monitoring practice.

Growth monitoring data are sent to Child Health at Bradford and Airedale tPCT, where they are entered onto System One. These data could be used to provide the tPCT with information about routine data collection and health visitor performance. Despite this, Bradford and Airedale tPCT have never produced any information to assess what data are collected, and it is therefore unknown whether growth data are collected at the prescribed age periods. The aims of this study are:

- To calculate the percentages of eligible infants measured during each prescribed age period, and the ten to 14 day age period prescribed by BiB, separately and for each dimension.

- To calculate the percentage of eligible infants measured during both of the first two prescribed age periods (i.e. birth to 28 days and six to eight weeks), for each dimension.

- To calculate the percentage of eligible infants measured during all three prescribed age periods (i.e. birth to 28 days, six to eight weeks, and seven to nine months), for each dimension.
5.1.2 Methods

On the 14th February 2008 Child Health extracted postnatal anthropometric data for all infants enrolled in the BiB project from System One. In total four datasets were produced, one for each measurement (weight, abdominal circumference, head circumference, and length). Additional variables in each of the four datasets included baby NHS number, date of birth, and date of assessment. There were a different number of infants in each dataset, and within each dataset infants had a variable number of recordings. Baby NHS number was needed as a unique identifier, and cases with no NHS number were removed. Duplicate cases were removed from the data. These were identified as cases where baby NHS number, date of assessment, and the measurement were the same. The final sample included weight data on 1813, abdominal circumference data on 1616 infants, head circumference data on 1773 infants, and length data on 1769 infants (see Table 5.1). For weight, head circumference, and length the median number of recordings an infant had was two. Whereas, the median number of recordings for abdominal circumference was only one.

Table 5.1. Data selection

<table>
<thead>
<tr>
<th></th>
<th>Weight</th>
<th>Abdominal circumference</th>
<th>Head circumference</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cases</td>
<td>3245</td>
<td>2453</td>
<td>2724</td>
<td>2891</td>
</tr>
<tr>
<td>Cases with Missing NHS number</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Duplicates cases</td>
<td>100</td>
<td>90</td>
<td>0</td>
<td>101</td>
</tr>
<tr>
<td>Selected cases</td>
<td>3144</td>
<td>2362</td>
<td>2723</td>
<td>2789</td>
</tr>
<tr>
<td>Selected infants</td>
<td>1813</td>
<td>1616</td>
<td>1773</td>
<td>1769</td>
</tr>
</tbody>
</table>

Prescribed age periods were decimalised, and were inclusive. For example, the first day of the sixth week to the last day of the eight week.

- birth to 28 days = 0.000 to 0.074
- ten to 14 days = 0.025 to 0.036
- six to eight weeks = 0.112 to 0.151
- seven to nine months = 0.501 to 0.748
To determine whether an infant was measured within a prescribed age period decimal age at assessment was needed. This was calculated as the time between date of birth and date of assessment. Decimal age was also needed to determine if an infant was eligible for assessment (e.g. an infant who was five weeks old would have been eligible for assessment at ten to 14 days, but not at six to eight weeks or seven to nine months). This was calculated as the time between date of birth and the most recent date of assessment, in each measurement dataset.

Infants who were eligible for assessment at an age period and who had a recording in that age period were identified. For example, with the ten to 14 day age period, infants with ages greater than 0.036, and an age at assessment between 0.025 and 0.036 were identified. Percentages were then calculated as the number who were correctly measured divided by the total number who were eligible (*100). Similarly, to calculate the percentage of infants who were measured in the first two or all three age periods, the number who were correctly measured in each age period was divided by the number of those who were eligible (*100). Infants with more than one recording for a dimension were only counted once in an analysis.

5.1.3 Results
For each dimension, histograms of age of assessment showed two clear peaks, the first at four weeks of age and the second at ten weeks (see Figure 5.1). There were also very small peaks around eight months. For approximately one month after each peak there were a large number of infants being measured. Patterns observed in the histograms suggest that the majority of measurements are taken close to but not within the prescribed age periods, and follow a positively skewed distribution.
Between birth and 28 days, approximately 80% of eligible infants had a recording for any one dimension (see Table 5.2). During the other prescribed age periods (six to eight weeks and seven to nine months) 30% to 35% of eligible infants had a recording. Similarly, in the ten to 14 day age period imposed by BiB approximately 30% of eligible infants had a recording.
Table 5.2. Percentages of infants measured during any one prescribed age period

<table>
<thead>
<tr>
<th></th>
<th>Number of infants eligible for measurement</th>
<th>Number of eligible infants measured</th>
<th>Percentage of eligible infants measured</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weight (n =1813)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 to 28 days</td>
<td>1812</td>
<td>1489</td>
<td>82.1</td>
</tr>
<tr>
<td>10 to 14 days</td>
<td>1813</td>
<td>592</td>
<td>32.7</td>
</tr>
<tr>
<td>6 to 8 weeks</td>
<td>1642</td>
<td>611</td>
<td>37.2</td>
</tr>
<tr>
<td>7 to 9 months</td>
<td>16</td>
<td>6</td>
<td>37.5</td>
</tr>
<tr>
<td><strong>Abdominal Circumference (n =1616)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 to 28 days</td>
<td>1615</td>
<td>1292</td>
<td>79.9</td>
</tr>
<tr>
<td>10 to 14 days</td>
<td>1616</td>
<td>526</td>
<td>31.1</td>
</tr>
<tr>
<td>6 to 8 weeks</td>
<td>1436</td>
<td>437</td>
<td>34.8</td>
</tr>
<tr>
<td>7 to 9 months</td>
<td>3</td>
<td>1</td>
<td>36.4</td>
</tr>
<tr>
<td><strong>Head circumference (n =1773)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 to 28 days</td>
<td>1772</td>
<td>1416</td>
<td>79.9</td>
</tr>
<tr>
<td>10 to 14 days</td>
<td>1771</td>
<td>552</td>
<td>31.1</td>
</tr>
<tr>
<td>6 to 8 weeks</td>
<td>1576</td>
<td>548</td>
<td>34.8</td>
</tr>
<tr>
<td>7 to 9 months</td>
<td>11</td>
<td>4</td>
<td>36.4</td>
</tr>
<tr>
<td><strong>Length (n =1769)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 to 28 days</td>
<td>1768</td>
<td>1409</td>
<td>79.7</td>
</tr>
<tr>
<td>10 to 14 days</td>
<td>1769</td>
<td>541</td>
<td>30.6</td>
</tr>
<tr>
<td>6 to 8 weeks</td>
<td>1572</td>
<td>566</td>
<td>36.0</td>
</tr>
<tr>
<td>7 to 9 months</td>
<td>9</td>
<td>3</td>
<td>33.3</td>
</tr>
</tbody>
</table>

For each dimension, under a third of eligible infants had recordings during both of the first two prescribed age periods (see Table 5.3). Slightly more infants were measured in both age periods for weight compared to the other dimensions, and in turn more infants were measured for head circumference and length compared to abdominal circumference. For each dimension, no infants were measured in all three prescribed age periods.
Table 5.3. Percentages of infants measured during the first two prescribed age periods

<table>
<thead>
<tr>
<th></th>
<th>Number of infants eligible for measurement</th>
<th>Number of eligible infants measured</th>
<th>Percentage of eligible infants measured</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Weight (n=1813)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 to 28 days and 6 to 8 weeks</td>
<td>1642</td>
<td>472</td>
<td>28.8</td>
</tr>
<tr>
<td><strong>Abdominal circumference (n=1616)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 to 28 days and 6 to 8 weeks</td>
<td>1436</td>
<td>305</td>
<td>21.2</td>
</tr>
<tr>
<td><strong>Head circumference (n=1773)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 to 28 days and 6 to 8 weeks</td>
<td>1576</td>
<td>395</td>
<td>25.1</td>
</tr>
<tr>
<td><strong>Length (n=1769)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 to 28 days and 6 to 8 weeks</td>
<td>1572</td>
<td>411</td>
<td>26.2</td>
</tr>
</tbody>
</table>

5.1.4 Discussion

In Bradford, the majority of growth monitoring data are not collected within the age periods prescribed by the tPCT or BIB. Data suggest that health workers concentrate their measurements at the end of each prescribed age period and continue to measure infants for about a month after each age period. For each measurement dataset, approximately 80% of infants were measured during the first prescribed age period. However, only 30% of infants were measured during the second prescribed age period. A post-hoc investigation found that when the ten to 14 day and six to eight week age periods were expanded to seven to 21 days and five to ten weeks, respectively, the percentages of eligible infants with a correct recording increased from 30% to approximately 60%. This means that over one third of infants were not correctly measured even when the age periods were expanded. The seven to nine month age period was not expanded because of the small number of infants who were eligible for measurement (i.e. the majority of infants in the sample had not reached nine months of age). Results for the third age period should be interpreted with caution.

At baby clinics, as well as being measured, infants are immunised for diphtheria, tetanus, and other communicable diseases. One might expect peaks in the number of infants measured at a particular age to coincide with the ages that infants are immunised. In the UK, infants are immunised at
eight weeks, 12 weeks, 16 weeks, and 12 months (RCPCH 2004). It is surprising, therefore, that a larger percentage of infants were measured during the birth to 28 days age period compared to the six to eight week period. Infants are vulnerable to poor health and nutrition, and health workers may place more emphasis on collecting growth data during the first age period compared to the other age periods.

All anthropometry for this analysis was extracted from System One on the same date, and therefore there should have been the same number of individuals in each measurement dataset. The data extracts provided by Bradford and Airedale tPCT do not include infants who have no recordings. There were 1812 infants with recordings for weight, which means that there should have been 1812 infants with recordings for abdominal circumference, head circumference, and length. Using 1812 as the denominator to calculate the percentage of infants with a recording in the first age period gives smaller percentages. For example, it means that 71.3% (not 80%) of infants had a recording for abdominal circumference during the birth to 28 day age period. To summarise, these results are percentages of infants, with at least one recording, who have been measured in a prescribed age period.

Ethnicity was not available at this point in the study and was not included in the extract used to assess routine data collection. It was, therefore, not possible to examine whether percent coverage differed by ethnicity or indeed any other defining factor (i.e. sex, LSOA etc), but further projects could be done in this area.

Growth monitoring is used to assess the growth of an individual between two or more time points, and thus depends on a series of recordings (Hall & Voss 2000). It is therefore essential that infants have more than one recording for each measurement, and ideally they should have a recording during each of the three prescribed age periods. Our data suggest that this is not the case for the normal infant in Bradford, and we can conclude that routine growth monitoring data are not collected according to the prescribed age periods. If Bradford and Airedale tPCT believe that growth monitoring is
necessary to monitor child health, data collection needs to be improved, monitored, and enforced.

5.2 Should Primary Care Trusts regularly produce information about routine data collection?

Along with opting to include the pages in the PCHR that allow growth monitoring, the tPCT has supported the changes BiB has introduced to growth monitoring practice. However, without audit there is no assurance that growth monitoring data are collected at prescribed age periods. The lack of data at prescribed age periods was not a problem for this current research because the multilevel approach allowed the inclusion of all data, even those outside of the recommended age ranges. Nevertheless, the statistics presented in this chapter were fed back to health workers and the tPCT to provide information about the collection of growth data. The statistics also provided BiB with an understanding of what data are available to future researchers. Similar information should be regularly produced by Child Health to monitor, and thus provide an ongoing audit of, data collection. Information about data collection could also be used to provide feedback to health workers. Individual performance related statistics could provide an impetus to improve data collection. The benefits of regular producing information about routine data collection are, therefore, threefold. Child Health and BiB are working together to decide what information would provide good feedback for health visitors and quality assurance for the tPCT.
6 The reliability of routine growth data
6.1 Why assess the reliability of routine growth data?

Anthropometry provides a quick and simple way to assess the growth, and therefore health, of a child. There is a wealth of literature regarding methods of anthropometric techniques and interpretation (Cameron 1984; Lohman, Roche & Martorell 1988; Ulijaszek & Mascie-Taylor 1994). However, the extent to which reliability can influence both measurement and interpretation is not considered in many publications reporting anthropometry (Ulijaszek & Kerr 1999). The difference between repeat measurements, taken either by the same observer or different observers, has been termed measurement error. Large measurement error can influence interpretation and limit the usefulness of anthropometry. For some studies, a large number of individuals may be needed to collect anthropometry, and this is likely to increase measurement error (Ulijaszek & Kerr 1999). In the UK, a large number of health workers are responsible for collecting growth data on infants. The utility of the data health workers collect is dependent on its reliability. Despite the extensive resources invested in recording growth measurements in the UK, there has been little research into reliability.

The P2PG study utilised infant growth data collected in the community by health workers, during routine health assessments. There are 192 health workers responsible for growth monitoring in Bradford, and these individuals have various levels of training and experience. Prior to any intervention by BiB, there were no standard instruments used by all health workers to measure infants. Also, the health visitor manual lacked a clear and precise measurement protocol, which would have helped standardise measurement technique and reduce measurement error. Routine growth data are likely to be less reliable than anthropometry collected by trained anthropometrists for specific research projects. The current study assessed the reliability of infant growth data collected by health workers. Measuring the magnitude of measurement error helped determine if growth data were suitable to use for research purposes. Moreover, if routine growth data are to be used to inform health service policies and recommendations reliability must be quantified.
Assessing the reliability of growth data is a major element of quality control (Goto & Mascie-Taylor 2007) and is recommended as routine practice.

6.2 The reliability of routine infant growth data

6.2.1 Introduction and aims
In June 2007, P2PG assessed the reliability of routine infant growth data collected by health workers. The study had two aims:

- To assess the reliability of routine infant growth data for weight, abdominal circumference, head circumference, and length, following the initial training of health workers responsible for collecting these data.

- To determine whether being observed by an external administrator during data collection influenced health worker’s reliability.

6.2.2 Methods
Following training in anthropometry, all health workers were asked to complete a test retest reliability study. This involved taking anthropometric measurements on five infants aged less than two years old. Discussions with Bradford and Airedale tPCT concluded that, for this reliability study, health workers could feasibly collect data on a maximum of five infants. Each infant had three sets of anthropometry (weight, abdominal circumference, head circumference, and length) recorded, two by the health worker and the third by a peer health worker. Each health worker was provided with a form on which to record these data.

One health worker from each health centre was randomly selected to be observed by a study administrator when collecting their data. A study administrator organised to visit these selected health workers at baby clinics, which all health centres in Bradford organise on a weekly basis. The study administrator was instructed to simply observe health workers whilst
they collected their test-retest data. The study administrator ensured that each health worker understood what was asked of them, but apart from this had no other contact with the health worker during data collection. Following data collection any questions regarding the study were answered. Forms were returned by hand or via post to the study administrator, and were divided between two groups of health workers: observed and non-observed.

The resulting data were used to produce technical error of measurements (TEMs). The TEM is the SD of differences between repeated measures, uncorrelated for bias (Mueller & Martorell 1988). In practice, this means that 95% of repeat results will fall within +/- 1.96 x TEM. In the test-retest study the differences between the first two measurements were used to produce individual intra-observer TEMs for each measurement. Similarly, the differences between the first and third measurements were used to calculate health workers inter-observer TEMs. In total, eight TEMs were calculated for each health worker (four intra-observer and four inter-observer). Mean TEMs were calculated for the observed and non-observed groups, and for the whole sample (see Tables 6.1 and 6.2). The majority of variables were not normally distributed, and demonstrated significant positive skewing. Therefore, Mann-Whitney tests were performed to check for statistical significance between observed and non-observed data (see Tables 6.3 and 6.4).

6.2.3 Results
Of the 192 health workers in Bradford, 44.3% (n=85) returned forms and 36.5% (n=70) had complete data. Twenty-two health workers were observed during data collection, and 48 were not.
Table 6.1. Intra-observer technical error of measurements (TEMs)

<table>
<thead>
<tr>
<th></th>
<th>Weight (g)</th>
<th>Abdominal circumference (cm)</th>
<th>Head circumference (cm)</th>
<th>Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total (n=70)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean TEM</td>
<td>20.8</td>
<td>0.44</td>
<td>0.28</td>
<td>0.43</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>50.3</td>
<td>0.30</td>
<td>0.32</td>
<td>0.55</td>
</tr>
<tr>
<td>Coefficient of reliability</td>
<td>1.00</td>
<td>0.99</td>
<td>0.99</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Observed (n=22)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean TEM</td>
<td>46.2</td>
<td>0.65</td>
<td>0.47</td>
<td>0.60</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>72.2</td>
<td>0.31</td>
<td>0.46</td>
<td>0.89</td>
</tr>
<tr>
<td>Coefficient of reliability</td>
<td>1.00</td>
<td>0.97</td>
<td>0.98</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Non-observed (n=48)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean TEM</td>
<td>9.1</td>
<td>0.34</td>
<td>0.19</td>
<td>0.35</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>30.69</td>
<td>0.25</td>
<td>0.16</td>
<td>0.26</td>
</tr>
<tr>
<td>Coefficient of reliability</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 6.2. Inter-observer technical error of measurements (TEMs)

<table>
<thead>
<tr>
<th></th>
<th>Weight (g)</th>
<th>Abdominal circumference (cm)</th>
<th>Head circumference (cm)</th>
<th>Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total (n=70)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean TEM</td>
<td>21.2</td>
<td>0.61</td>
<td>0.37</td>
<td>0.56</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>50.1</td>
<td>0.35</td>
<td>0.28</td>
<td>0.35</td>
</tr>
<tr>
<td>Coefficient of reliability</td>
<td>1.00</td>
<td>0.98</td>
<td>0.99</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Observed (n=22)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean TEM</td>
<td>43.2</td>
<td>0.81</td>
<td>0.60</td>
<td>0.66</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>72.8</td>
<td>0.31</td>
<td>0.28</td>
<td>0.29</td>
</tr>
<tr>
<td>Coefficient of reliability</td>
<td>1.00</td>
<td>0.96</td>
<td>0.97</td>
<td>0.99</td>
</tr>
<tr>
<td><strong>Non-observed (n=48)</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean TEM</td>
<td>11.1</td>
<td>0.52</td>
<td>0.27</td>
<td>0.51</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>31.4</td>
<td>0.32</td>
<td>0.21</td>
<td>0.37</td>
</tr>
<tr>
<td>Coefficient of reliability</td>
<td>1.00</td>
<td>0.99</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

None of the TEMs were excessively large, and coefficients of reliability ranged from 0.96 to 1.00 (see Tables 6.1 and 6.2). Measurement error was generally higher for abdominal circumference, followed by length, and then head circumference. For example, the mean intra-observer TEM for all health workers was 0.44cm for abdominal circumference, compared to 0.28cm for head circumference. In practice this means that 95% of repeat measures for abdominal circumference and head circumference will fall within +/- 0.86cm and +/- 0.55cm, respectively (i.e. 1.96 x TEM). All inter-observer TEMs, apart from weight in the observed group, were larger than
The reliability of routine growth data

the respective intra-observer TEMs. Measurement error was larger in the observed group, and this is reflected by larger TEMs. For example, the observed group’s intra-observer TEMs for weight, abdominal circumference, head circumference, and length (46.2g, 0.65cm, 0.47cm, 0.60cm) were larger than the non-observed group’s TEMS (9.1g, 0.34cm, 0.19cm, 0.35cm). This pattern was present for both intra-observer and inter-observer data.

Table 6.3. Mann-Whitney test comparing intra-observer technical error of measurements (TEMs) for observed and non-observed health workers

<table>
<thead>
<tr>
<th></th>
<th>Weight (g)</th>
<th>Abdominal circumference (cm)</th>
<th>Head circumference (cm)</th>
<th>Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Observed (n=22)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median TEM</td>
<td>14.5</td>
<td>0.62</td>
<td>0.33</td>
<td>0.37</td>
</tr>
<tr>
<td>(range)</td>
<td>(233.8)</td>
<td>(1.35)</td>
<td>(2.16)</td>
<td>(4.43)</td>
</tr>
<tr>
<td><strong>Non-observed (n=48)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median TEM</td>
<td>0.0</td>
<td>0.30</td>
<td>0.16</td>
<td>0.32</td>
</tr>
<tr>
<td>(range)</td>
<td>(208.7)</td>
<td>(1.13)</td>
<td>(0.72)</td>
<td>(1.30)</td>
</tr>
<tr>
<td>Mann-Whitney U</td>
<td>184.5</td>
<td>204.0</td>
<td>192.0</td>
<td>411.0</td>
</tr>
<tr>
<td>P-value</td>
<td>&lt;0.001**</td>
<td>&lt;0.001**</td>
<td>&lt;0.001**</td>
<td>0.137</td>
</tr>
</tbody>
</table>

* Significant at alpha 5% level
** Significant at alpha 1% level

Table 6.4. Mann-Whitney test comparing inter-observer technical error of measurements (TEMs) for observed and non-observed health workers

<table>
<thead>
<tr>
<th></th>
<th>Weight (g)</th>
<th>Abdominal circumference (cm)</th>
<th>Head circumference (cm)</th>
<th>Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Observed (n=22)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median TEM</td>
<td>9.8</td>
<td>0.88</td>
<td>0.51</td>
<td>0.67</td>
</tr>
<tr>
<td>(range)</td>
<td>(229.3)</td>
<td>(1.18)</td>
<td>(1.21)</td>
<td>(1.33)</td>
</tr>
<tr>
<td><strong>Non-observed (n=48)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median TEM</td>
<td>0.0</td>
<td>0.49</td>
<td>0.21</td>
<td>0.46</td>
</tr>
<tr>
<td>(range)</td>
<td>(208.7)</td>
<td>(1.45)</td>
<td>(1.25)</td>
<td>(1.86)</td>
</tr>
<tr>
<td>Mann-Whitney U</td>
<td>253.50</td>
<td>264.50</td>
<td>101.50</td>
<td>358.00</td>
</tr>
<tr>
<td>P-value</td>
<td>0.001**</td>
<td>0.001**</td>
<td>&lt;0.001**</td>
<td>0.031*</td>
</tr>
</tbody>
</table>

* Significant at alpha 5% level
** Significant at alpha 1% level

There were significant differences between the observed and the non-observed groups’ TEMs (see Tables 6.3 and 6.4). Generally, measurement error was significantly higher in the observed group compared to the non-
observed group. Intra-observer TEMs for weight, abdominal circumference, and head circumference were significantly larger for the observed group than the non-observed group (p<0.001). Intra-observer TEMs for length were not significantly different between the two groups (p=0.137). Similarly, all inter-observer TEMs were significantly larger for the observed group at alpha 1% (p<0.001), apart from length which was significantly larger at alpha 5% (p=0.031).

6.2.4 Discussion
After training in basic anthropometry, TEMs from health workers were comparable to published TEMs from research studies that reported acceptable levels of reliability (Ulijaszek & Kerr 1999). A general conclusion that health workers can reliably measure infant growth can be made, even though health workers who were observed by a study administrator during data collection had higher levels of measurement error than those who were not observed.

All health workers responsible for growth monitoring in the community were included in the study, making the total sample externally valid. Only 36.5% of health workers returned forms with complete data. However, we have no reason to believe that these individuals differed in any way from the total health worker population (e.g. sex, level of education attained, and duration of employment as a health worker). Complete data were collected from health workers from different geographical locations across Bradford. Our sample did not, therefore, neglect health workers who monitor growth in areas of Bradford which have important defining characteristics. For example, areas with high levels of deprivation or areas that are predominantly occupied by South Asian populations. For these reasons we believe our total sample was representative of all health workers in Bradford. The study administrator aimed to observe one health worker from each health centre, although time constraints meant that this was not possible. Individuals in the observed group were selected at random and were likely to be representative of health workers with varying levels of enthusiasm to participate in the study. Whereas, it is likely that only the most
enthusiastic health workers in the non-observed group returned forms. There may have, therefore, been selection bias in the non-observed group. If the reliability of all health workers was routinely assessed data from the less enthusiastic individuals could be collected.

The design of the study meant that health workers second measurements could obviously not be blinded from their first. Health workers were however instructed that the third measurement should be blinded from the first two (i.e. the peer health worker who took the third measurement, that was used to assess inter-observer reliability, did not know the results that his/her colleague had obtained). In the observed group this process was supervised, although we could not be certain that the non-observed group strictly followed this protocol. Due to the high work load and competing demands of health workers it was not practical to impose a certain amount of time to be taken between repeat measurements, and adherence to this would have been impossible to monitor in the non-observed group.

A paucity of research reporting age specific TEMs meant that power calculations could not be performed. Whilst our total sample was representative of health workers in Bradford, a larger sample size would have further increased the power to detect statistically significant differences in TEMs. This study only assessed the reliability of health workers in Bradford, and no comparable age-specific TEMs from health workers in other cities or counties have been published. It is important to reiterate that health workers and their involvement in growth monitoring are not unique to Bradford. Health workers with similar levels of education, training, and experience measure infant growth at prescribed age periods in other cities and counties, and for this reason we would expect similar levels of reliability throughout the UK.

The large number of health workers in health services responsible for collecting anthropometric data increases the likelihood that one person’s measurements will differ significantly from another’s (Ulijaszek & Kerr 1999). The difference between repeat measurements has been termed
measurement error, and in this context has been used to explain the extent to which repeat measures give the same value (Habicht, Yarbrough & Martorell 1979). Large measurement error can influence interpretation and limit the usefulness of growth data (Ulijaszek & Kerr 1999). Growth monitoring is used to assess the growth of an individual between two or more time points, and thus depends on a series of recordings. Small measurement error for any one recording is unlikely to have clinical significance, but systematic measurement error for two or more recordings will decrease the ability of growth monitoring to identify failure to thrive. The measurement error of growth data has clinical importance which, in part, determines the validity of growth monitoring.

The TEM is the statistic most commonly used to explain measurement error (Mueller & Martorell 1988) and can provide sufficient information to determine whether a set of anthropometric measurements are reliable. The coefficient of reliability (r) reveals what proportion of variance is free from measurement error. Coefficients above 0.95 are indicative of good quality control (Goto & Mascie-Taylor 2007).

The TEMs from this study are similar to acceptable levels of reliability found in anthropometric literature, and all coefficients of reliability were above 0.95. For these reasons our TEMs indicate good reliability of growth measures. Compared to the mean TEMs reported in Ulijaszek and Kerr’s (1999) review, our TEMs for weight and abdominal circumference were smaller. This is surprising considering that Ulijaszek and Kerr conducted a review of research studies, where data was collected by trained anthropometrists. Our intra-observer TEM for length (0.43cm) was within the range (0.10cm to 0.80 cm) reported in Ulijaszek and Kerr’s review (1999), and our inter-observer TEM for length (0.56cm) was just outside the range (0.1cm to 0.5cm). Compared to reliability data, on anthropometrists trained to measure infants in the MGRS (WHO Multicentre Growth Reference Study Group 2006b), our TEMs for length and head circumference were similar.
Ulijaszek and Kerr’s (1999) review reported mean TEMs for infants, children, and adults. As the absolute measurement increases it is likely that absolute measurement error also increases. It could, therefore, be assumed that TEMs from data on adults would be larger than TEMs from data on infants. This may be why our TEMs for weight and abdominal circumference are smaller than those reported by Ulijaszek and Kerr. There may be a need for age specific TEMs. It is, however, unlikely that the magnitude of the dimension will affect reliability within our age range (birth to two years). The MGRS have reported age specific TEMs for length and head circumference for infants aged zero to 24 hours, and another set for infants aged zero to one year (WHO Multicentre Growth Reference Study Group 2006b). Our TEMs for length and head circumference were comparable to those produced by the MGRS for infants aged zero to one year. Other studies have reported age specific (one to two years) intra-observer and inter-observer TEMs for length of 0.4cm and 0.5cm, respectively (Ulijaszek; Pelletier, Low & Msukwa 1991). Our mean TEMs for all health workers were almost identical to these data (0.43cm, 0.56cm). There are no published age specific TEMs for weight and abdominal circumference during infancy.

In general, the intra-observer TEMs from this study were marginally smaller than the inter-observer TEMs. It might also be expected that the difference between two recordings taken by the same person should be smaller than the difference if two people took one recording each. However, it is far from universally the case that intra-observers TEMs are smaller than inter-observer TEMs (Ulijaszek & Lourie 1994). Using data from the Malawi Maternal and Child Health Survey, Pelletier et al (1991) found intra-observer error to be greater than inter-observer error for length and arm circumference. Larger intra-observer errors have also been reported for subscapular skinfolds in a USA population (Johnston, Hamill & Lemeshow 1972).

The observed group’s TEMs were, in general, significantly larger than the non-observed group’s. There are a number of possible reasons for this. Firstly, the presence of an observer distracted or intimidated health workers
resulting in larger TEMS. Secondly, health workers in the non-observed group felt like they were being judged and reported more favourable results to appear more reliable. Throughout the study health workers were assured that variability is an inherent part of the measurement process. However, health workers had never been asked to complete a reliability study before and may have felt expectations to report high reliability. Health workers in the non-observed group were more likely than those in the observed group to report both their first and second recording, for a measurement, to be the same (weight 85.4 Vs. 44.5%, abdominal circumference 45.0 Vs. 9.1%, head circumference 57.9 Vs. 19.1%, length 54.6 Vs. 34.5%). There were also more occurrences in the non-observed data compared to the observed data where all three recordings were the same (weight 77.9 Vs. 23.6%, abdominal circumference 0.0 Vs. 0.0%, head circumference 38.8 Vs. 2.7%, length 27.5 Vs. 11.8%). Also, health workers in the non-observed group reported head and abdominal circumferences to the nearest 0.5cm more frequently than health workers in the observed group. If this is because of terminal digit preference, health workers in the non-observed group did not measure to the full precision of the instruments. For these reasons we believe that self-reported reliability checks may produce favourable results, thus TEMs for the non-observed group should be interpreted with caution. The results of this study should be used to emphasise the normal variation expected between repeat measurements in future documentation and training of anthropometry.

6.2.5 Conclusions
TEMs from routine growth data collected by health workers indicate acceptable levels of measurement error. TEMs were calculated from data collected by health workers, after they had been trained in basic anthropometry. This was, in effect, an intervention study, and reliability after training is acceptable. Training in anthropometry and the production of a measurement protocol may have helped to standardise measurement technique of health workers, improving reliability. Although, without test-retest data available prior to training this hypothesis cannot be tested.
Extensive resources are invested in collecting and recording growth measurements in developed and developing countries throughout the world. In the UK, there has been no research into the reliability of these measurements. Growth monitoring produces an unexploited source of data for public health surveillance, and our results suggest that with initial training in measurement techniques these data can be of research calibre.

Health care commissioners require reliable growth data if they are going to make evidence based decisions on local policy and provision of services. Reliability checks reinforce the importance of good practice and act as a quality assurance mechanism with feedback to practitioners. For these reasons, reliability checks including external observation of intra-observer and inter-observer error should be considered as part of routine practice.

### 6.3 Routine reliability assessments to provide training and quality assurance

The BiB project has invested resources to standardise growth monitoring by providing new measuring instruments, disseminating a new measurement protocol, and training health workers in basic anthropometry. The results of the reliability study, that concluded that routinely collected infant growth data are reliable, have now been published in the International Journal of Nursing Studies (Johnson et al. 2009a). Following this, another research team working on the ALSPAC have reported that routine growth data at four, eight, and 43 months of age were accurate (Howe, Tilling & Lawlor 2009). It is unknown whether the reliability of infant growth data collected by health workers improved as the result of intervention by BiB. Similarly, without future reliability assessments it will not be known if measurement error remains constant, deteriorates, or improves.

Routinely assessing the reliability of infant growth data would provide the tPCT with quality insurance and information about individual and team performance that could be feedback to health workers. If reliability did
deteriorate, data from the assessments could be used to identify individuals or groups of individuals to re-train in anthropometry. The process of assessing reliability acts as a form of anthropometric training. For these reasons, we strongly advocate routine reliability assessments and believe they should be commissioned by the tPCT. The involvement of the tPCT in designing and developing reliability assessments would reinforce the importance of good practice and of growth monitoring itself.

Following the completion of the reliability study, P2PG have been meeting with the tPCT to discuss the need for routine reliability assessments, and subsequently to develop a cost-effective and feasible design. It has been decided that the design should consider: a minimal amount of work that will not create unnecessary additional work for health workers, little or no analysis so that information can be feedback quickly to health workers, and how to incorporate a training aspect to the assessments. The recommendation of P2PG to the tPCT is to assess the reliability of all health workers twice a year. A research health worker, who is trained in anthropometry, would be employed to visit each health worker during a one month assessment period. Inter-observer test-retest data for weight, head circumference, abdominal circumference, and length would be collected on two infants. The research health worker could provide instant feedback to each health worker about measurement technique, why there are differences between his/her recording and the research health worker’s recording (for example, the research health worker may record a larger measurement for length because the health worker did not correctly place the infants head in the Frankfurt plane), and how measurement technique should be changed to reflect protocol. Taking test-retest measurements on two infants every six months should not be seen as an unnecessary amount of additional work. In terms of cost, this design would only require the employment of a research health worker for two months a year. The fact that feedback is provided by a peer health worker and not management may also bear some significance. An alternative suggestion that one health worker from each health centre is trained to replace the role of the research health workers has been made. Both designs would not produce vast
amounts of data that would need to be analysed to produce reliability statistics, that may have little meaning to health workers. Instead they would provide ongoing training for health workers, and quality assurance for the tPCT that something is being done to ensure levels of reliability remain high. The tPCT has shown interest in commissioning routine reliability assessments, and discussions about the final design are ongoing.
7 Results: The growth of Bradford infants
7.1 Birth characteristics and anthropometry at birth

Of the 4707 infants who were delivered at BRI between the 12th March 2007 and the 30th September 2008, and who were enrolled in BiB, our sample consisted of 2586 singleton White British or Pakistani infants, with complete birth data. Table 7.1 shows the birth characteristics of this sample split by ethnic group. There were slightly more Pakistani (54.5%, n=1410) than White British infants (45.5%, n=1176) in the sample. There was very little difference in mean gestational age between the two ethnic groups. However, Pakistani infants were more than twice as likely to be classified as SGA (17.3%, n=244) compared to White British infants (8%, n=94). The majority of infants in the White British group were born to first time mothers (50.3%, n=591), whereas the greatest percentage of Pakistani infants were born to mothers with a parity of three or greater (39.6%, n=559). There were noticeable socio-economic inequalities, with the largest proportion of Pakistani infants (46.1%, n=649) being in the lowest IMD tertile, compared to the White British group where the majority of infants (53.1%, n=625) were in the highest IMD tertile.

Table 7.1. Birth characteristics

<table>
<thead>
<tr>
<th></th>
<th>White British n=1176 (45.5%)</th>
<th>Pakistani n=1410 (54.5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>n(%) 604 (51.4)</td>
<td>720 (51.1)</td>
</tr>
<tr>
<td>Female</td>
<td>n(%) 572 (48.6)</td>
<td>690 (48.9)</td>
</tr>
<tr>
<td>Gestational age in weeks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preterm (≤36 week)</td>
<td>mean(SE) 39.53 (0.044)</td>
<td>39.27 (0.037)</td>
</tr>
<tr>
<td>Term (37 to 41 weeks)</td>
<td>n% 45 (3.8)</td>
<td>49 (3.5)</td>
</tr>
<tr>
<td>Post-term (≥42 weeks)</td>
<td>n% 1114 (94.7)</td>
<td>1350 (95.7)</td>
</tr>
<tr>
<td></td>
<td>n% 17 (1.4)</td>
<td>11 (0.8)</td>
</tr>
<tr>
<td>Size for gestational age</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SGA</td>
<td>n% 94 (8.0)</td>
<td>244 (17.3)</td>
</tr>
<tr>
<td>AGA</td>
<td>n% 988 (84.0)</td>
<td>1121 (79.5)</td>
</tr>
<tr>
<td>LGA</td>
<td>n% 94 (8.0)</td>
<td>45 (3.2)</td>
</tr>
<tr>
<td>Registerable parity</td>
<td>median(range) 1 (7)</td>
<td>2 (9)</td>
</tr>
<tr>
<td>Para 1</td>
<td>n% 591 (50.3)</td>
<td>457 (32.4)</td>
</tr>
<tr>
<td>Para 2</td>
<td>n% 371 (31.5)</td>
<td>394 (27.9)</td>
</tr>
<tr>
<td>Para ≥3</td>
<td>n% 214 (18.2)</td>
<td>559 (39.6)</td>
</tr>
<tr>
<td>Index of Multiple Deprivation</td>
<td>median(range) 9513 (32222)</td>
<td>2064 (29597)</td>
</tr>
<tr>
<td>1st tertile</td>
<td>n% 230 (19.6)</td>
<td>649 (46.1)</td>
</tr>
<tr>
<td>2nd tertile</td>
<td>n% 321 (27.3)</td>
<td>528 (37.4)</td>
</tr>
<tr>
<td>3rd tertile</td>
<td>n% 625 (53.1)</td>
<td>233 (16.5)</td>
</tr>
<tr>
<td>Low Birth Weight (&lt;2500g)</td>
<td>n% 45 (3.8)</td>
<td>95 (6.7)</td>
</tr>
</tbody>
</table>
Table 7.2. shows the mean and SE for weight, abdominal circumference, and head circumference of the sample at birth, split by ethnic group and sex. Pakistani infants were consistently smaller than White British infants. For example, Pakistani boys and girls were, on average, 236.2g and 162.3g lighter than White British boys and girls at birth, respectively. The prevalence of LBW was, therefore, greater in Pakistani infants (6.7%, n=95) than White British infants (3.8%, n=45) (see Table 7.2). The difference between ethnicities was larger than the differences between sexes for weight and abdominal circumference, but not for head circumference. Chapter 8 includes univariable regression models that show that the differences between ethnic groups in size at birth were statistically significant.

Table 7.2. Anthropometry at birth

<table>
<thead>
<tr>
<th></th>
<th>White British</th>
<th>Pakistani</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boys (n=604)</td>
<td>Girls (n=572)</td>
</tr>
<tr>
<td></td>
<td>Boys (n=720)</td>
<td>Girls (n=690)</td>
</tr>
<tr>
<td>Weight (g)</td>
<td>mean 3450.3 (20.6)</td>
<td>3299.1 (20.6)</td>
</tr>
<tr>
<td></td>
<td>(SE)</td>
<td>(SE)</td>
</tr>
<tr>
<td></td>
<td>3214.1 (18.0)</td>
<td>3136.8 (18.4)</td>
</tr>
<tr>
<td>Abdominal</td>
<td>mean 32.44 (0.10)</td>
<td>32.06 (0.10)</td>
</tr>
<tr>
<td>circumference (cm)</td>
<td>(SE)</td>
<td>(SE)</td>
</tr>
<tr>
<td></td>
<td>31.15 (0.09)</td>
<td>31.11 (0.09)</td>
</tr>
<tr>
<td>Head Circumference (cm)</td>
<td>mean 34.81 (0.06)</td>
<td>34.14 (0.06)</td>
</tr>
<tr>
<td></td>
<td>(SE)</td>
<td>(SE)</td>
</tr>
<tr>
<td></td>
<td>34.20 (0.06)</td>
<td>33.77 (0.06)</td>
</tr>
</tbody>
</table>

7.2 Multilevel models

MLMs were fitted to anthropometric data of term infants. Details of the birth characteristics and anthropometry at birth of this group is given in Appendix VI. Details for the 520 infants included in the MLMs for length are also given in Appendix VI. T-tests for continuous variables and chi-squared tests for categorical variables showed that there were no significant differences between the two analysis groups for the majority of the variables. Birthweight and head circumference at birth were significantly larger for term infants (3298.8g and 34.30cm) compared to the core analysis group (3267.4g and 34.21cm), at alpha five percent. This difference in birthweight, also meant that the prevalence of LBW was significantly lower for term infants (3.6%) compared to the core analysis group (5.4%), at alpha one.
Results: The growth of Bradford infants

percent. Similarly, mean birthweight was significantly larger for the 520 infants included in the MLMs for length at alpha five percent, and the prevalence of LBW was significantly lower at alpha one percent, compared to the core analysis group.

The parameters of the MLM shown below correspond to the coefficients in Tables 7.3, 7.4, 7.5, and 7.6.

\[ y_{ij} = \beta_1 + \beta_2(X_{ij}) + \beta_3\ln(X_{ij}) + \beta_4/X_{ij} + \beta_5\omega_{ij} + \beta_6\nu_{ij} + \beta_7\omega_{ij}(X_{ij}) + \beta_8\omega_{ij}\ln(X_{ij}) + \beta_9\omega_{ij}/X_{ij} + \beta_{10}\nu_{ij}(X_{ij}) + \beta_{11}\nu_{ij}\ln(X_{ij}) + \beta_{12}\nu_{ij}/X_{ij} + \zeta_{ij} + \zeta_2(X_{ij}) + E_{ij} \]

The use of dummy variables made it possible to produce ethnic and sex specific WFA, ACFA, HCFA, and LFA growth curves, with the limits within which 95% of individual growth trajectories lie (see Figures 7.1, 7.4, 7.7, 7.10, 7.13, 7.16, 7.19, and 7.22). The dummy variables for Pakistani (\( \beta_5\omega_{ij} \)) and girl (\( \beta_6\nu_{ij} \)) were significant or borderline significant in all of the MLMs. The intercept of the mean constant growth curves, therefore, varied depending on ethnicity and sex. The dummy variables for Pakistani coefficients (\( \beta_7\omega_{ij}(X_{ij}) + \beta_8\omega_{ij}\ln(X_{ij}) + \beta_9\omega_{ij}/X_{ij} \)) were significant predictors in the weight and abdominal circumference MLMs, but not in the head circumference and length MLMs. The gradient, shape, and inflexion point of WFA and ACFA growth curves, therefore, varied between ethnic groups. Interestingly, the dummy variables for girl coefficients (\( \beta_{10}\nu_{ij}(X_{ij}) + \beta_{11}\nu_{ij}\ln(X_{ij}) + \beta_{12}\nu_{ij}/X_{ij} \)) were not significant in any the MLMs.

Residual diagnostics were also analysed by sex and ethnic group. Plots of the mean constant growth curves against the actual data, for the respective dimension/ethnic/sex specific group, demonstrated that the MLMs provided a good fit, with approximately the same number of cases above and below each curve (see Figures 7.2, 7.5, 7.8, 7.11, 7.14, 7.17, 7.20, and 7.23). There were, however, less data between prescribed measurement periods (i.e. three to seven months). As a result, the mean monthly residuals were largest at these ages (see Figures 7.3, 7.6, 7.9, 7.12, 7.15, 7.18, 7.21, and 7.24). For example, the mean monthly residuals for weight were largest in
month five for White British boys (-100.2g), Pakistani boys (-100.2g), and Pakistani girls (-191.3g); and in month six for White British girls (-72.5g). Wald Wolfowitz runtests reported that mean monthly dimension/ethnic/sex specific residuals were serially independent (p-values less than critical values proposed by Swed and Eisenhart (1943). MLMs did not, therefore, predict fitted values that were systematically larger or smaller than the actual values.

7.2.1 Weight-for-age
Table 7.3 shows the development of a MLM for weight. Model 3 had the lowest residual error and the best log likelihood, although the three dummy variables for girl coefficients were insignificant and their inclusion meant that the dummy variable for girl was also insignificant. Therefore, model 2 was chosen as the final model. This model included dummy variables for Pakistani coefficients, all of which were significant, and had lower residual error than model 1. This model described girls as being 161.4g lighter than boys, and this difference in size between sexes can be seen in the mean constant growth curves (see Figures 7.1 and 7.4). The difference in size between ethnic groups varied depending on age. This is because the coefficients, and thus shape of the mean constant growth curves, varied by ethnic group. Figures 7.1 and 7.4 do not show a large difference in the shape of the mean constant growth curves between ethnic groups. However, using the fixed effect part of the MLM equation it was calculated that Pakistani infants were 210.3g lighter than White British infants at birth, 252.6g lighter at three months, 321.7g lighter at six months, and 232.7g lighter at 9 months.
Table 7.3. Weight-for-age (g) multilevel models (n=2464)

<table>
<thead>
<tr>
<th>Fixed part</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B(SE)</td>
<td>P</td>
<td>B(SE)</td>
</tr>
<tr>
<td>β₁[constant]</td>
<td>-22850.3 (1844.3)</td>
<td>&lt;0.001</td>
<td>-27473.6 (2732.7)</td>
</tr>
<tr>
<td>β₂[age]</td>
<td>-58197.8 (3020.7)</td>
<td>&lt;0.001</td>
<td>-65965.8 (4554.9)</td>
</tr>
<tr>
<td>β₃[ln age]</td>
<td>152630.3 (7735.7)</td>
<td>&lt;0.001</td>
<td>172549.4 (11622.8)</td>
</tr>
<tr>
<td>β₄[inverse age]</td>
<td>84504.5 (4842.7)</td>
<td>&lt;0.001</td>
<td>96898.4 (7253.3)</td>
</tr>
<tr>
<td>β₅ω[pakistani]</td>
<td>-205.3 (18.5)</td>
<td>&lt;0.001</td>
<td>8192.6 (3708.5)</td>
</tr>
<tr>
<td>β₆ν[girl]</td>
<td>-161.6 (18.4)</td>
<td>&lt;0.001</td>
<td>-161.4 (18.4)</td>
</tr>
<tr>
<td>β₇ω[pakistani*age]</td>
<td>13933.9 (6095.2)</td>
<td>0.022</td>
<td></td>
</tr>
<tr>
<td>β₈ω[pakistani*ln age]</td>
<td>-35820.6 (15597.9)</td>
<td>0.022</td>
<td></td>
</tr>
<tr>
<td>β₉ω[pakistani*inverse age]</td>
<td>-22336.8 (9758.4)</td>
<td>0.022</td>
<td></td>
</tr>
<tr>
<td>β₁₀ν[girl*age]</td>
<td>10540.4 (5895.9)</td>
<td>0.174</td>
<td></td>
</tr>
<tr>
<td>β₁₁ν[girl*ln age]</td>
<td>-21517.7 (15097.0)</td>
<td>0.154</td>
<td></td>
</tr>
<tr>
<td>β₁₂ν[girl*inverse age]</td>
<td>-8608.5 (9450.0)</td>
<td>0.362</td>
<td></td>
</tr>
<tr>
<td>Random part</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ζ₁ sd[constant]</td>
<td>1622.0 (46.0)</td>
<td>1621.6 (46.0)</td>
<td>1532.3 (43.0)</td>
</tr>
<tr>
<td>ζ₂ sd[age]</td>
<td>1611.0 (43.8)</td>
<td>1611.09 (43.8)</td>
<td>1516.6 (40.9)</td>
</tr>
<tr>
<td>E sd[residual]</td>
<td>223.9 (2.7)</td>
<td>223.6 (2.7)</td>
<td>218.2 (2.6)</td>
</tr>
<tr>
<td>Log likelihood</td>
<td>-57363.829</td>
<td>-57392.2</td>
<td>-57164.788</td>
</tr>
</tbody>
</table>
Results: The growth of Bradford infants

**Figure 7.1.** Weight-for-age: White British (n=570) and Pakistani (n=688) boys mean constant curves and limits of 95% trajectory bands

**Figure 7.2.** Weight-for-age: White British (n=570) and Pakistani (n=688) boys mean constant curves and cases

**Figure 7.3.** Weight-for-age: White British (n=570) and Pakistani (n=688) boys mean constant curves and mean monthly residuals
Results: The growth of Bradford infants

**Figure 7.4. Weight-for-age: White British (n=544) and Pakistani (n=662) girls mean constant curves and limits of 95% trajectory bands**

**Figure 7.5. Weight-for-age: White British (n=544) and Pakistani (n=662) girls mean constant curves and cases**

**Figure 7.6. Weight-for-age: White British (n=544) and Pakistani (n=662) girls mean constant curves and mean monthly residuals**
7.2.2  Abdominal circumference-for-age

The development of a MLM for abdominal circumference (see Table 7.4) was very similar to the model development for weight. Models 3 provided the best fit for the data, although five of the covariates were insignificant. Model 2 was chosen as the final model because it provided a slightly better fit than model 1 and all of the covariates were significant. This MLM described that abdominal circumference was 0.32cm smaller for girls compared to boys. Figures 7.7 and 7.10 show that the shape of the mean constant growth curves, produced from the MLM, were noticeably different for each ethnic group. The abdominal circumference growth of White British infants was linear between four and nine months of age and showed a constant increase in size. Whereas, the growth of Pakistani infants was represented in smooth curves that were nearly horizontal to the x-axis at nine month of age, approaching asymptotic values. Using the fixed effect part of the MLM equation it was calculated that abdominal circumference was 1.15cm smaller at birth, 0.98cm smaller at three months, 0.39cm smaller at six months, and 1.57cm smaller at nine months, for Pakistani infants compared to White British infants.
Table 7.4. Abdominal circumference-for-age (cm) multilevel models \((n=2464)\)

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2 (final model)</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed part</td>
<td>B(SE)</td>
<td>P</td>
<td>B(SE)</td>
</tr>
<tr>
<td>(\beta_1[\text{constant}])</td>
<td>214.235 (19.475)</td>
<td>&lt;0.001</td>
<td>266.482 (29.659)</td>
</tr>
<tr>
<td>(\beta_2[\text{age}])</td>
<td>85.322 (33.206)</td>
<td>&lt;0.001</td>
<td>172.196 (52.075)</td>
</tr>
<tr>
<td>(\beta_3[\text{ln age}])</td>
<td>-297.329 (84.517)</td>
<td>&lt;0.001</td>
<td>-519.837 (131.784)</td>
</tr>
<tr>
<td>(\beta_4[\text{inverse age}])</td>
<td>-267.049 (52.554)</td>
<td>&lt;0.001</td>
<td>-406.213 (81.533)</td>
</tr>
<tr>
<td>(\beta_5[\text{pakistani}])</td>
<td>-1.226 (0.078)</td>
<td>&lt;0.001</td>
<td>-99.619 (39.854)</td>
</tr>
<tr>
<td>(\beta_6[\text{girl}])</td>
<td>-0.324 (0.077)</td>
<td>&lt;0.001</td>
<td>-0.323 (0.077)</td>
</tr>
<tr>
<td>(\beta_7[\text{pakistani*age}])</td>
<td>-160.805 (68.523)</td>
<td>0.019</td>
<td></td>
</tr>
<tr>
<td>(\beta_8[\text{pakistani*ln age}])</td>
<td>413.316 (174.120)</td>
<td>0.018</td>
<td></td>
</tr>
<tr>
<td>(\beta_9[\text{pakistani*inverse age}])</td>
<td>259.277 (108.115)</td>
<td>0.016</td>
<td></td>
</tr>
<tr>
<td>(\beta_{10}[\text{girl*age}])</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\beta_{11}[\text{girl*ln age}])</td>
<td>30.706 (66.340)</td>
<td>0.643</td>
<td></td>
</tr>
<tr>
<td>(\beta_{12}[\text{girl*inverse age}])</td>
<td>-67.520 (168.851)</td>
<td>0.689</td>
<td></td>
</tr>
</tbody>
</table>

Random part

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(\zeta_1[\text{sd[constant]}])</td>
<td>3.225 (0.274)</td>
<td>3.198 (0.273)</td>
<td>3.221 (0.273)</td>
</tr>
<tr>
<td>(\zeta_2[\text{sd[age]}])</td>
<td>3.072 (0.214)</td>
<td>3.052 (0.213)</td>
<td>3.063 (0.213)</td>
</tr>
<tr>
<td>(E[\text{sd[residual]}])</td>
<td>1.851 (0.024)</td>
<td>1.850 (0.024)</td>
<td>1.850 (0.024)</td>
</tr>
<tr>
<td>Log likelihood</td>
<td>-13647.231</td>
<td>-13644.206</td>
<td>-13631.818</td>
</tr>
</tbody>
</table>
Results: The growth of Bradford infants

**Figure 7.7. Abdominal circumference-for-age: White British (n=570) and Pakistani (n=688) boys mean constant curves and limits of 95% trajectory bands**

![White British boys](image1)

![Pakistani boys](image2)

**Figure 7.8. Abdominal circumference-for-age: White British (n=570) and Pakistani (n=688) boys mean constant curves and cases**

![White British boys](image3)

![Pakistani boys](image4)

**Figure 7.9. Abdominal circumference-for-age: White British (n=570) and Pakistani (n=688) boys mean constant curves and mean monthly residuals**

![White British boys](image5)

![Pakistani boys](image6)
Results: The growth of Bradford infants

Figure 7.10. Abdominal circumference-for-age: White British (n=544) and Pakistani (n=662) girls mean constant curves and limits of 95% trajectory bands

Figure 7.11. Abdominal circumference-for-age: White British (n=544) and Pakistani (n=662) girls mean constant curves and cases

Figure 7.12. Abdominal circumference-for-age: White British (n=544) and Pakistani (n=662) girls mean constant curves and mean monthly residuals
7.2.3 Head circumference-for-age

Table 7.5 shows the development of a MLM for head circumference. In model 1, all covariates were significant predictors of head circumference. The addition of dummy variables for Pakistani coefficients in model 2 and dummy variables for girl coefficients in model 3 resulted in various covariates being insignificant. Model 1 was, therefore, chosen as the final model. This MLM described that head circumference was 0.78cm smaller for girls compared to boys, and 0.57cm smaller for Pakistani infants compared to White British infants. These differences in size between sexes and ethnic groups can be seen in the mean constant growth curves (see Figures 7.13 and 7.16). The limits within which 95% of infant’s growth curves lie was much narrower for head circumference compared to abdominal circumference, suggesting that there is less variance in this dimension in the first nine months of age.
### Table 7.5. Head circumference-for-age (cm) multilevel models (n=2464)

<table>
<thead>
<tr>
<th>Fixed part</th>
<th>Model 1 (final model)</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B(SE)</td>
<td>P</td>
<td>B(SE)</td>
</tr>
<tr>
<td><em>constant</em></td>
<td>167.729</td>
<td>&lt;0.001</td>
<td>174.757</td>
</tr>
<tr>
<td>age</td>
<td>116.697</td>
<td>&lt;0.001</td>
<td>129.141</td>
</tr>
<tr>
<td>ln age</td>
<td>-327.776</td>
<td>&lt;0.001</td>
<td>-359.078</td>
</tr>
<tr>
<td>inverse age</td>
<td>-249.402</td>
<td>&lt;0.001</td>
<td>-268.904</td>
</tr>
<tr>
<td>pakistani</td>
<td>-0.569</td>
<td>(0.045) &lt;0.001</td>
<td>-10.334</td>
</tr>
<tr>
<td>girl</td>
<td>-0.780</td>
<td>(0.045) &lt;0.001</td>
<td>-0.781</td>
</tr>
<tr>
<td>pakistani*age</td>
<td>-17.030</td>
<td>(25.589) 0.506</td>
<td></td>
</tr>
<tr>
<td>pakistani*ln age</td>
<td>42.867</td>
<td>(65.254) 0.511</td>
<td></td>
</tr>
<tr>
<td>pakistani*inverse age</td>
<td>26.848</td>
<td>(40.663) 0.509</td>
<td></td>
</tr>
<tr>
<td>girl*age</td>
<td>-20.332</td>
<td>(24.966) 0.415</td>
<td></td>
</tr>
<tr>
<td>girl*ln age</td>
<td>59.030</td>
<td>(63.707) 0.354</td>
<td></td>
</tr>
<tr>
<td>girl*inverse age</td>
<td>42.853</td>
<td>(39.722) 0.281</td>
<td></td>
</tr>
</tbody>
</table>

### Random part

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>constant</em></td>
<td>1.786</td>
<td>(0.095)</td>
<td>1.793</td>
</tr>
<tr>
<td>age</td>
<td>1.104</td>
<td>(0.089)</td>
<td>1.110</td>
</tr>
<tr>
<td>residual</td>
<td>0.839</td>
<td>(0.010)</td>
<td>0.838</td>
</tr>
<tr>
<td>Log likelihood</td>
<td>-10228.238</td>
<td>-10224.097</td>
<td>-10191.243</td>
</tr>
</tbody>
</table>
Results: The growth of Bradford infants

Figure 7.13. Head circumference-for-age: White British (n=570) and Pakistani (n=688) boys mean constant curves and limits of 95% trajectory bands

Figure 7.14. Head circumference-for-age: White British (n=570) and Pakistani (n=688) boys mean constant curves and cases

Figure 7.15. Head circumference-for-age: White British (n=570) and Pakistani (n=688) boys mean constant curves and mean monthly residuals
Results: The growth of Bradford infants

Figure 7.16. Head circumference-for-age: White British (n=544) and Pakistani (n=662) girls mean constant curves and limits of 95% trajectory bands

Figure 7.17. Head circumference-for-age: White British (n=544) and Pakistani (n=662) girls mean constant curves and cases

Figure 7.18. Head circumference-for-age: White British (n=544) and Pakistani (n=662) girls mean constant curves and mean monthly residuals
7.2.4 Length-for-age

The development of a MLM for length (see Table 7.6) was very similar to the model development for head circumference. Model 1 was chosen as the final MLM because this was the only model where all covariates were significant or borderline significant. The dummy variable for Pakistani was only borderline significant, and the MLM described that Pakistani infants were 0.32cm shorter than White British infants. Whereas, the sex difference in length of 1.42cm was much greater. These differences in size between sexes and ethnic groups can be seen in the mean constant growth curves (see Figures 7.19 and 7.22). The limits within which 95% of infant’s growth curves lie were also much narrower for length compared to abdominal circumference.
Results: The growth of Bradford infants

Table 7.6. Length-for-age (cm) multilevel models (n=520)

<table>
<thead>
<tr>
<th></th>
<th>Model 1 (final model)</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B(SE)</td>
<td>P</td>
<td>B(SE)</td>
</tr>
<tr>
<td><strong>Fixed part</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta_1$[constant]</td>
<td>170.259 (27.310)</td>
<td>&lt;0.001</td>
<td>174.989 (40.007)</td>
</tr>
<tr>
<td>$\beta_2$[age]</td>
<td>84.073 (42.406)</td>
<td>0.047</td>
<td>103.648 (63.723)</td>
</tr>
<tr>
<td>$\beta_3$[ln age]</td>
<td>-228.353 (109.804)</td>
<td>0.038</td>
<td>-273.790 (164.016)</td>
</tr>
<tr>
<td>$\beta_4$[inverse age]</td>
<td>-203.727 (69.599)</td>
<td>0.003</td>
<td>-227.835 (103.493)</td>
</tr>
<tr>
<td>$\beta_5$[pakistani]</td>
<td>-0.316 (0.172)</td>
<td>0.067</td>
<td>-43.159 (56.437)</td>
</tr>
<tr>
<td>$\beta_6$[girl]</td>
<td>-1.424 (0.168)</td>
<td>&lt;0.001</td>
<td>-1.424 (0.169)</td>
</tr>
<tr>
<td>$\beta_7$[pakistani*age]</td>
<td>-85.753 (88.220)</td>
<td>0.331</td>
<td></td>
</tr>
<tr>
<td>$\beta_8$[pakistani*ln age]</td>
<td>214.207 (228.095)</td>
<td>0.348</td>
<td></td>
</tr>
<tr>
<td>$\beta_9$[pakistan*inverse age]</td>
<td>128.341 (144.405)</td>
<td>0.374</td>
<td></td>
</tr>
<tr>
<td>$\beta_{10}$[girl*age]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta_{11}$[girl*ln age]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta_{12}$[girl*inverse age]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Random part</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\zeta_1$ sd[constant]</td>
<td>2.794 (0.321)</td>
<td></td>
<td>2.774 (0.318)</td>
</tr>
<tr>
<td>$\zeta_2$ sd[age]</td>
<td>2.150 (0.254)</td>
<td></td>
<td>2.113 (0.254)</td>
</tr>
<tr>
<td>E sd[residual]</td>
<td>1.277 (0.041)</td>
<td></td>
<td>1.275 (0.040)</td>
</tr>
<tr>
<td>Log likelihood</td>
<td>-2689.0778</td>
<td></td>
<td>-2670.7852</td>
</tr>
</tbody>
</table>
Results: The growth of Bradford infants

Figure 7.19. Length-for-age: White British (n=102) and Pakistani (n=164) boys mean constant curves and limits of 95% trajectory bands

![Figure 7.19](image1)

Figure 7.20. Length-for-age: White British (n=102) and Pakistani (n=164) boys mean constant curves and cases

![Figure 7.20](image2)

Figure 7.21. Length-for-age: White British (n=102) and Pakistani (n=164) boys mean constant curves and mean monthly residuals

![Figure 7.21](image3)
Results: The growth of Bradford infants

Figure 7.22. Length-for-age: White British (n=101) and Pakistani (n=153) girls mean constant curves and limits of 95% trajectory bands

Figure 7.23. Length-for-age: White British (n=101) and Pakistani (n=153) girls mean constant curves and cases

Figure 7.24. Length-for-age: White British (n=101) and Pakistani (n=153) girls mean constant curves and mean monthly residuals
7.3 Postnatal anthropometry

Using the MLMs it was possible to calculate anthropometry for each infant at any specified age. Table 7.7 shows the mean and SE of each dimension at three, six, and nine months of age; and length and BMI at 12 days, split by ethnic group and sex. Pakistani infants were smaller than White British infants for all dimensions and at all ages. At nine months of age Pakistani infants (sexes combined) had smaller mean values for weight (233.1g), abdominal circumference (1.57cm), head circumference (0.60cm), length (0.11cm), and BMI (0.216kg/m²), compared to White British infants.
Table 7.7. Anthropometry at three, six, and nine months of age, and length and BMI at 12 days of age, split by ethnicity and sex

<table>
<thead>
<tr>
<th></th>
<th>White British</th>
<th></th>
<th>Pakistani</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boys (n=570)</td>
<td>Girls (n=544)</td>
<td>Boys (n=688)</td>
<td>Girls (n=662)</td>
</tr>
<tr>
<td><strong>Weight (g)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 months</td>
<td>6183.9 (24.0)</td>
<td>5832.4 (23.2)</td>
<td>5899.4 (20.8)</td>
<td>5613.8 (19.4)</td>
</tr>
<tr>
<td>6 months</td>
<td>8302.2 (34.5)</td>
<td>7807.3 (32.7)</td>
<td>7944.4 (29.3)</td>
<td>7524.3 (27.1)</td>
</tr>
<tr>
<td>9 months</td>
<td>9251.0 (46.1)</td>
<td>8612.6 (43.4)</td>
<td>8978.1 (38.7)</td>
<td>8423.5 (36.0)</td>
</tr>
<tr>
<td><strong>Abdominal</strong></td>
<td>mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 months</td>
<td>40.81 (0.05)</td>
<td>40.38 (0.05)</td>
<td>39.77 (0.05)</td>
<td>39.476 (0.045)</td>
</tr>
<tr>
<td>6 months</td>
<td>43.27 (0.06)</td>
<td>42.79 (0.06)</td>
<td>42.80 (0.06)</td>
<td>42.484 (0.054)</td>
</tr>
<tr>
<td>9 months</td>
<td>44.89 (0.07)</td>
<td>44.38 (0.07)</td>
<td>43.23 (0.07)</td>
<td>42.895 (0.064)</td>
</tr>
<tr>
<td><strong>Head circumference (cm)</strong></td>
<td>mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 months</td>
<td>40.96 (0.03)</td>
<td>40.13 (0.03)</td>
<td>40.34 (0.03)</td>
<td>39.63 (0.03)</td>
</tr>
<tr>
<td>6 months</td>
<td>43.64 (0.03)</td>
<td>42.79 (0.03)</td>
<td>43.02 (0.03)</td>
<td>42.27 (0.03)</td>
</tr>
<tr>
<td>9 months</td>
<td>46.06 (0.03)</td>
<td>45.19 (0.03)</td>
<td>45.43 (0.03)</td>
<td>44.65 (0.03)</td>
</tr>
<tr>
<td><strong>Length (cm)</strong></td>
<td>mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 days</td>
<td>52.30 (0.15)</td>
<td>50.90 (0.14)</td>
<td>52.00 (0.12)</td>
<td>50.57 (0.12)</td>
</tr>
<tr>
<td>3 months</td>
<td>61.41 (0.16)</td>
<td>59.92 (0.14)</td>
<td>61.16 (0.13)</td>
<td>59.66 (0.13)</td>
</tr>
<tr>
<td>6 months</td>
<td>67.96 (0.18)</td>
<td>66.39 (0.15)</td>
<td>67.76 (0.14)</td>
<td>66.19 (0.14)</td>
</tr>
<tr>
<td>9 months</td>
<td>73.18 (0.20)</td>
<td>71.52 (0.17)</td>
<td>73.04 (0.15)</td>
<td>71.40 (0.15)</td>
</tr>
<tr>
<td><strong>BMI (kg/m²)</strong></td>
<td>mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 days</td>
<td>13.807 (0.103)</td>
<td>13.821 (0.102)</td>
<td>13.219 (0.073)</td>
<td>13.206 (0.090)</td>
</tr>
<tr>
<td>3 months</td>
<td>16.508 (0.112)</td>
<td>16.188 (0.105)</td>
<td>15.956 (0.080)</td>
<td>15.768 (0.086)</td>
</tr>
<tr>
<td>6 months</td>
<td>18.192 (0.146)</td>
<td>17.573 (0.137)</td>
<td>17.578 (0.106)</td>
<td>17.200 (0.108)</td>
</tr>
<tr>
<td>9 months</td>
<td>17.563 (0.179)</td>
<td>16.626 (0.170)</td>
<td>17.171 (0.130)</td>
<td>16.569 (0.131)</td>
</tr>
</tbody>
</table>
8  Results: Factors that influence the size of Bradford infants
8.1 Factors that influence size at birth

In the unadjusted regression models for birthweight, abdominal circumference at birth, and head circumference at birth, each independent variable was a significant predictor of the outcome. Whereas, parity was not a significant or borderline significant predictor in the unadjusted model for length at 12 days of age, and sex was not a significant or borderline significant predictor of BMI at 12 days of age. In general, size for gestational age and term explained the most variance in each dimension. There was some evidence for a positive association between SES and size at birth, with infants in the lowest IMD tertile generally being smaller than infants in the highest IMD tertile. Spearman’s rank correlations between IMD and each dimension, apart from length, were significant at alpha one percent. When all significant variables were adjusted for in multivariable regression models, the amount of variance explained ranged between 19.3% and 35.8%. In the adjusted models for weight, abdominal circumference, and BMI, the effects of ethnicity were larger than the effects of sex. IMD only remained significant in the adjusted model for birthweight, and the interaction variable ethnicity*IMD was therefore added to this model.
Results: Factors that influence the size of Bradford infants

Table 8.1. Predictors of birth weight (g) (n=2586): unadjusted models

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B(SE)</td>
<td>P</td>
<td>B(SE)</td>
<td>P</td>
<td>B(SE)</td>
</tr>
<tr>
<td>Constant</td>
<td>3376.7</td>
<td>&lt;0.001</td>
<td>3321.9</td>
<td>&lt;0.001</td>
<td>3298.8</td>
</tr>
<tr>
<td></td>
<td>(14.4)</td>
<td></td>
<td>(13.7)</td>
<td></td>
<td>(9.5)</td>
</tr>
<tr>
<td>Ethnicity (Pakistani Vs. White British)</td>
<td>-200.5</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(19.5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex (female Vs. male)</td>
<td>-150.1</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(19.7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Term (preterm Vs. term)</td>
<td>-931.4</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(49.5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>234.1</td>
<td>0.009</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(89.6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parity (para 2 Vs. para 1)</td>
<td>89.1</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(23.8)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>83.2</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(23.8)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index of Multiple Deprivation (1st tertile Vs. 3rd tertile)</td>
<td>-133.9</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(24.0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-122.6</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(24.2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.039**</td>
<td>0.012**</td>
<td>0.122**</td>
<td>0.006**</td>
<td>0.014**</td>
</tr>
</tbody>
</table>

Model significance: *p<0.05 **p<0.01
8.1.1 Birth weight

The unadjusted models (see Table 8.1) show that the effect of ethnicity on birthweight was larger than the effect of sex, with Pakistani infants being 200.5g lighter than White British infants and girls being 150.1g lighter than boys. The effect of IMD was similar to that of sex, with infants in the first and second IMD tertiles being 133.9g and 122.6g lighter, respectively, than infants in the third IMD tertile. When all significant independent variables were adjusted for, 19.0% of the variance in birthweight was explained (see Table 8.2). The interaction variable ethnicity*IMD was a significant predictor and its addition to the model marginally increased the amount of variance that was explained to 19.3%. IMD, therefore, moderates the effect of ethnicity on birthweight. Figure 8.1 shows that White British infants in the first and second IMD tertiles were lighter than White British infants in the third IMD tertile. Whereas, Pakistani infants in the first and second IMD tertiles were heavier than Pakistani infants in the third tertile. One way ANOVAs with Bonferroni post hoc multiple comparisons were performed for each ethnic group to test for significant differences in birthweight between IMD tertiles. For the White British group, infants in the 1st and 2nd IMD tertiles were significantly lighter than infants in the 3rd tertile, at alpha five percent. The difference in birthweight between infants in the 1st and 2nd IMD tertiles was not significant. For the Pakistani group, there were no significant differences in birthweight between any two tertiles. After adjusting for other covariates, the effect of ethnicity on birthweight was even larger than that found in the unadjusted model, with Pakistani infants being 301.3g lighter than White British infants.
Table 8.2. Predictors of birth weight (g) (n=2586): adjusted models

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1a B(SE)</th>
<th>P</th>
<th>Model 1b B(SE)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>3429.2 (20.6)</td>
<td>&lt;0.001</td>
<td>3453.9 (22.1)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Ethnicity (Pakistani Vs. White British)</td>
<td>-211.3 (20.0)</td>
<td>&lt;0.001</td>
<td>-301.3 (35.2)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Sex (female Vs. male)</td>
<td>-115.1 (17.8)</td>
<td>&lt;0.001</td>
<td>-117.6 (17.8)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Term (preterm Vs. term)</td>
<td>-929.1 (47.6)</td>
<td>&lt;0.001</td>
<td>-929.7 (47.5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>231.8 (86.2)</td>
<td>0.007</td>
<td>230.8 (86.2)</td>
<td>0.007</td>
</tr>
<tr>
<td>Parity (para 2 Vs. para 1)</td>
<td>102.9 (21.6)</td>
<td>&lt;0.001</td>
<td>103.3 (21.6)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>142.5 (22.2)</td>
<td>&lt;0.001</td>
<td>146.3 (22.2)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Index of Multiple Deprivation</td>
<td>-46.6 (23.6)</td>
<td>0.049</td>
<td>-122.8 (35.0)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>(1&lt;sup&gt;st&lt;/sup&gt; tertile Vs. 3&lt;sup&gt;rd&lt;/sup&gt; tertile)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-49.7 (23.0)</td>
<td>0.031</td>
<td>-83.8 (31.1)</td>
<td>0.007</td>
</tr>
<tr>
<td>Ethnicity*Index of Multiple Deprivation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>((Pakistani Vs. White British)*(1&lt;sup&gt;st&lt;/sup&gt; Vs. 3&lt;sup&gt;rd&lt;/sup&gt; IMD tertile))</td>
<td>159.4 (49.2)</td>
<td>0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>((Pakistani Vs. White British)*(2&lt;sup&gt;nd&lt;/sup&gt; Vs. 3&lt;sup&gt;rd&lt;/sup&gt; IMD tertile))</td>
<td>105.1 (47.3)</td>
<td>0.026</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted R²</td>
<td><strong>0.190</strong></td>
<td></td>
<td><strong>0.193</strong></td>
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</tr>
</tbody>
</table>

Model significance: *p<0.05 **p<0.01

* H<sub>0</sub> states that the mean for each of the four groups will be equal to the values predicted by the main effects.
Results: Factors that influence the size of Bradford infants

Figure 8.1. Interaction between ethnicity and deprivation

![Graph showing interaction between ethnicity and deprivation](image-url)
### Table 8.3. Predictors of abdominal circumference (cm) at birth (n=2586): unadjusted models

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
<th>Model 6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B(SE)</td>
<td>B(SE)</td>
<td>B(SE)</td>
<td>B(SE)</td>
<td>B(SE)</td>
<td>B(SE)</td>
</tr>
<tr>
<td>Constant</td>
<td>32.265</td>
<td>31.749</td>
<td>31.736</td>
<td>31.808</td>
<td>31.415</td>
<td>32.000</td>
</tr>
<tr>
<td></td>
<td>(0.068)</td>
<td>(0.066)</td>
<td>(0.047)</td>
<td>(0.048)</td>
<td>(0.074)</td>
<td>(0.082)</td>
</tr>
<tr>
<td><strong>P</strong></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Ethnicity (Pakistani Vs. White British)</td>
<td>-1.123</td>
<td>-1.123</td>
<td>-1.123</td>
<td>-1.123</td>
<td>-1.123</td>
<td>-1.123</td>
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<tr>
<td></td>
<td>(0.092)</td>
<td>(0.092)</td>
<td>(0.092)</td>
<td>(0.092)</td>
<td>(0.092)</td>
<td>(0.092)</td>
</tr>
<tr>
<td><strong>P</strong></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Sex (female Vs. male)</td>
<td>-0.198</td>
<td>-0.198</td>
<td>-0.198</td>
<td>-0.198</td>
<td>-0.198</td>
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<tr>
<td></td>
<td>(0.095)</td>
<td>(0.095)</td>
<td>(0.095)</td>
<td>(0.095)</td>
<td>(0.095)</td>
<td>(0.095)</td>
</tr>
<tr>
<td><strong>P</strong></td>
<td>0.037</td>
<td>0.037</td>
<td>0.037</td>
<td>0.037</td>
<td>0.037</td>
<td>0.037</td>
</tr>
<tr>
<td>Term (preterm Vs. term)</td>
<td>-2.906</td>
<td>-2.906</td>
<td>-2.906</td>
<td>-2.906</td>
<td>-2.906</td>
<td>-2.906</td>
</tr>
<tr>
<td></td>
<td>(0.246)</td>
<td>(0.246)</td>
<td>(0.246)</td>
<td>(0.246)</td>
<td>(0.246)</td>
<td>(0.246)</td>
</tr>
<tr>
<td><strong>P</strong></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Term (post-term Vs. term)</td>
<td>1.246</td>
<td>1.246</td>
<td>1.246</td>
<td>1.246</td>
<td>1.246</td>
<td>1.246</td>
</tr>
<tr>
<td></td>
<td>(0.445)</td>
<td>(0.445)</td>
<td>(0.445)</td>
<td>(0.445)</td>
<td>(0.445)</td>
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<td>0.005</td>
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</tr>
<tr>
<td>Size for gestational age</td>
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<td></td>
<td>-2.323</td>
<td>-2.323</td>
<td>-2.323</td>
<td>-2.323</td>
</tr>
<tr>
<td>(SGA Vs. AGA)</td>
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<td>(0.128)</td>
<td>(0.128)</td>
<td>(0.128)</td>
<td>(0.128)</td>
</tr>
<tr>
<td></td>
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<tr>
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<tr>
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<td>(0.191)</td>
<td>(0.191)</td>
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</tr>
<tr>
<td><strong>P</strong></td>
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<td>0.385</td>
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<td></td>
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<td>(0.114)</td>
<td>(0.114)</td>
<td>(0.114)</td>
</tr>
<tr>
<td><strong>P</strong></td>
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<td></td>
<td></td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Parity (para ≥3 Vs. para 1)</td>
<td></td>
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<td></td>
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<td>0.384</td>
<td>0.384</td>
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<td></td>
<td></td>
<td></td>
<td>(0.114)</td>
<td>(0.114)</td>
</tr>
<tr>
<td><strong>P</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Index of Multiple Deprivation (1st tertile Vs. 3rd tertile)</td>
<td>-0.527</td>
<td>-0.527</td>
<td>-0.527</td>
<td>-0.527</td>
<td>-0.527</td>
<td>-0.527</td>
</tr>
<tr>
<td></td>
<td>(0.115)</td>
<td>(0.115)</td>
<td>(0.115)</td>
<td>(0.115)</td>
<td>(0.115)</td>
<td>(0.115)</td>
</tr>
<tr>
<td><strong>P</strong></td>
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<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Index of Multiple Deprivation (2nd tertile Vs. 3rd tertile)</td>
<td>-0.540</td>
<td>-0.540</td>
<td>-0.540</td>
<td>-0.540</td>
<td>-0.540</td>
<td>-0.540</td>
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<td></td>
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<td>(0.116)</td>
<td>(0.116)</td>
<td>(0.116)</td>
<td>(0.116)</td>
</tr>
<tr>
<td><strong>P</strong></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.054**</td>
<td>0.001*</td>
<td>0.054**</td>
<td>0.179**</td>
<td>0.005**</td>
<td>0.010**</td>
</tr>
</tbody>
</table>

*Model significance: *p<0.05 **p<0.01
8.1.2 **Abdominal circumference at birth**

The unadjusted models show that (see Table 8.3) the effect of ethnicity was approximately six times greater than the effect of sex, with abdominal circumference at birth being 1.12cm smaller for Pakistani infants compared to White British infants and 0.12cm smaller for girls compared to boys. The effect of IMD was also greater than that of sex, with infants in the first and second IMD tertiles having abdominal circumferences that were 0.53cm and 0.54cm smaller, respectively, than those of infants in the third IMD tertile. When all significant independent variables were adjusted for, over a quarter of the variance in abdominal circumference was explained and IMD became insignificant (see Table 8.4). Adjusting for covariates also meant that abdominal circumference was 0.91cm less for Pakistani infants compared to White British infants and 0.27cm less for girls compared to boys.
Results: Factors that influence the size of Bradford infants

Table 8.4. Predictors of abdominal circumference (cm) at birth (n=2586): adjusted model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1a</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>B(SE)</td>
<td>P</td>
</tr>
<tr>
<td>Constant</td>
<td>32.289</td>
<td>(0.097)</td>
<td>0.000</td>
</tr>
<tr>
<td>Ethnicity (Pakistani Vs. White British)</td>
<td>-0.911</td>
<td>(0.093)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Sex (female Vs. male)</td>
<td>-0.269</td>
<td>(0.082)</td>
<td>0.001</td>
</tr>
<tr>
<td>Term (preterm Vs. term)</td>
<td>-2.672</td>
<td>(0.218)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>(post-term Vs. term)</td>
<td>1.196</td>
<td>(0.395)</td>
<td>0.002</td>
</tr>
<tr>
<td>Size for gestational age</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(SGA Vs. AGA)</td>
<td>-2.074</td>
<td>(0.123)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>(LGA Vs. AGA)</td>
<td>2.289</td>
<td>(0.183)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Parity (para 2 Vs. para 1)</td>
<td>0.285</td>
<td>(0.099)</td>
<td>0.004</td>
</tr>
<tr>
<td>(para ≥3 Vs. para 1)</td>
<td>0.457</td>
<td>(0.102)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Index of Multiple Deprivation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1st tertile Vs. 3rd tertile)</td>
<td>0.024</td>
<td>(0.108)</td>
<td>0.826</td>
</tr>
<tr>
<td>(2nd tertile Vs. 3rd tertile)</td>
<td>-0.043</td>
<td>(0.105)</td>
<td>0.826</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.259**</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Model significance: *p<0.05 **p<0.01
### Results: Factors that influence the size of Bradford infants

#### Table 8.5. Predictors of head circumference (cm) at birth (n=2586): unadjusted models

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
<th>Model 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>34.480 (0.045)</td>
<td>34.480 (0.042)</td>
<td>34.299 (0.030)</td>
<td>34.294 (0.031)</td>
<td>34.108 (0.048)</td>
<td>34.415 (0.053)</td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Ethnicity (Pakistani Vs. White British)</td>
<td>-0.488 (0.061)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex (female Vs. male)</td>
<td>-0.546 (0.060)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Term (preterm Vs. term)</td>
<td></td>
<td>-2.512 (0.156)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Term (post-term Vs. term)</td>
<td></td>
<td>0.522 (0.281)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.064</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size for gestational age</td>
<td></td>
<td></td>
<td>-1.327 (0.084)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(SGA Vs. AGA)</td>
<td></td>
<td></td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(LGA V.s AGA)</td>
<td></td>
<td></td>
<td></td>
<td>1.734 (0.125)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parity (para 2 Vs. para 1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.170 (0.074)</td>
<td>0.021 (0.074)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.021</td>
<td>0.021</td>
</tr>
<tr>
<td>(para ≥3 Vs. para 1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.186 (0.074)</td>
<td>0.011 (0.074)</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>0.011</td>
<td>0.011</td>
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<tr>
<td>Index of Multiple Deprivation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1st tertile Vs. 3rd tertile)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.340 (0.074)</td>
<td>&lt;0.001 (0.074)</td>
</tr>
<tr>
<td>(2nd tertile Vs. 3rd tertile)</td>
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<td></td>
<td></td>
<td></td>
<td>-0.260 (0.075)</td>
<td>0.001 (0.075)</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.024**</td>
<td>0.030**</td>
<td>0.092**</td>
<td>0.159**</td>
<td>0.002*</td>
<td>0.008**</td>
</tr>
</tbody>
</table>

Model significance: *p<0.05 **p<0.01
8.1.3 **Head circumference at birth**

Ethnicity and sex explained approximately the same amount of variance in the unadjusted models (see Table 8.5). Head circumference was 0.49cm less for Pakistani infants compared to White British infants, and 0.55cm less for girls compared to boys. Infants in the first and second IMD tertiles had head circumferences that were 0.34cm and 0.26cm smaller, respectively, than those of infants in the third IMD tertile. When all significant or borderline significant predictors were adjusted for, 28.6% of the variance in head circumference was explained and IMD and para two became insignificant (see Table 8.6). The coefficient for ethnicity was marginally smaller than the coefficient from the respective unadjusted model. Whereas, the coefficient for sex was marginally larger than the coefficient from the respective unadjusted model. This meant that, after adjusting for covariates, the effect of sex on head circumference at birth was nearly twice as large as the effect of ethnicity, with head circumference being 0.31cm smaller for Pakistani infants compared to White British infants and 0.59cm smaller for girls compared to boys.
Results: Factors that influence the size of Bradford infants

Table 8.6. Predictors of head circumference (cm) at birth (n=2586): adjusted model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1a</th>
</tr>
</thead>
<tbody>
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<td>B(SE)</td>
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<tr>
<td>Constant</td>
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<td>Ethnicity (Pakistani Vs. White British)</td>
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</tr>
<tr>
<td>Sex (female Vs. male)</td>
<td>-0.590 (0.052)</td>
</tr>
<tr>
<td>Term (preterm Vs. term)</td>
<td>-2.378 (0.138)</td>
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<tr>
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<td>0.487 (0.250)</td>
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<td>Size for gestational age (SGA Vs. AGA)</td>
<td>-1.245 (0.078)</td>
</tr>
<tr>
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<td>1.580 (0.116)</td>
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<tr>
<td>Parity (para 2 Vs. para 1)</td>
<td>0.091 (0.063)</td>
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<tr>
<td></td>
<td>0.162 (0.065)</td>
</tr>
<tr>
<td>Index of Multiple Deprivation (1st tertile Vs. 3rd tertile)</td>
<td>-0.079 (0.069)</td>
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<tr>
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<td>-0.013 (0.067)</td>
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<tr>
<td>Adjusted R²</td>
<td>0.286**</td>
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Model significance: *p<0.05 **p<0.01
Results: Factors that influence the size of Bradford infants

Table 8.7. Predictors of length (cm) at 12 days of age (n=520): unadjusted models

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B(SE)</td>
<td>P</td>
<td>B(SE)</td>
<td>P</td>
<td>B(SE)</td>
</tr>
<tr>
<td>Constant</td>
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<td>52.116</td>
<td>&lt;0.001</td>
<td>51.478</td>
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<tr>
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<td>(0.117)</td>
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<td>(0.092)</td>
<td></td>
<td>(0.075)</td>
</tr>
<tr>
<td>Ethnicity</td>
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<td></td>
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<td></td>
</tr>
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<td>(Pakistani Vs. White British)</td>
<td>-0.295</td>
<td>0.049</td>
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<tr>
<td></td>
<td>(0.149)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(female Vs. male)</td>
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<td></td>
<td>(0.132)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size for gestational age</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(SGA Vs. AGA)</td>
<td>-1.369</td>
<td>&lt;0.001</td>
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</tr>
<tr>
<td></td>
<td>(0.238)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(LGA Vs AGA)</td>
<td>1.592</td>
<td>&lt;0.001</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>(0.331)</td>
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<td></td>
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</tr>
<tr>
<td>Parity</td>
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<td></td>
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<td></td>
</tr>
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<td>(0.177)</td>
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<td></td>
</tr>
<tr>
<td>(para ≥3 Vs. para 1)</td>
<td>0.219</td>
<td>0.215</td>
<td></td>
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<tr>
<td></td>
<td>(0.177)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index of Multiple Deprivation</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1st tertile Vs. 3rd tertile)</td>
<td>-0.432</td>
<td>0.015</td>
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<tr>
<td></td>
<td>(0.177)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2nd tertile Vs. 3rd tertile)</td>
<td>-0.276</td>
<td>0.124</td>
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</tr>
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<td>(0.179)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.006*</td>
<td>0.180**</td>
<td>0.101**</td>
<td>0.000</td>
<td>0.008*</td>
</tr>
</tbody>
</table>

Model significance: *p<0.05 **p<0.01
8.1.4 **Length at 12 days**

Without adjusting for covariates, sex explained 18% of the variance in length, whereas ethnicity alone only explained 0.6% of the variance (see Table 8.7). This meant that girls were 1.42cm shorter than boys, whereas Pakistani infants were only 0.30cm shorter than White British infants. Unlike unadjusted models for other dimensions, parity was not a significant predictor of length. Also, only infants in the lowest IMD tertile were significantly shorter than infants in the highest IMD tertile. When all significant independent variables were adjusted for (see Table 8.8) 31.3% of the variance in length was explained. Adjusting the model also meant that the coefficient for ethnicity changed from -0.295cm to 0.024cm, and became insignificant. The main covariate that resulted in this attenuation was size for gestational age. IMD was also insignificant after adjusting for covariates.

*Table 8.8. Predictors of length (cm) at 12 days of age (n=520): adjusted model*
Table 8.9. Predictors of BMI (kg/m²) at 12 days of age (n=520): unadjusted models

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B(SE)</td>
<td>P</td>
<td>B(SE)</td>
<td>P</td>
<td>B(SE)</td>
</tr>
<tr>
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<td>13.814</td>
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<td>13.445</td>
<td>&lt;0.001</td>
<td>13.496</td>
</tr>
<tr>
<td></td>
<td>(0.072)</td>
<td></td>
<td>(0.065)</td>
<td></td>
<td>(0.041)</td>
</tr>
<tr>
<td>Ethnicity (Pakistani Vs. White British)</td>
<td>-0.601</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.092)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex (female Vs. male)</td>
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<td></td>
<td>0.006</td>
<td>0.948</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.093)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size for gestational age (SGA Vs. AGA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-1.453</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>(0.132)</td>
</tr>
<tr>
<td>(LGA Vs. AGA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.914</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td>(0.184)</td>
</tr>
<tr>
<td>Parity (para 2 Vs. para 1)</td>
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<td></td>
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<tr>
<td>(para ≥3 Vs. para 1)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Index of Multiple Deprivation (1st tertile Vs. 3rd tertile)</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(2nd tertile Vs. 3rd tertile)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.074**</td>
<td>-0.002</td>
<td>0.321**</td>
<td>0.022**</td>
<td>0.024**</td>
</tr>
</tbody>
</table>

Model significance: *p<0.05 **p<0.01
8.1.5 BMI at 12 days

Ethnicity was a significant predictor variable in the unadjusted model (see Table 8.9), with BMI being 0.601kg/m$^2$ lower for Pakistani infants compared to White British infants. Unlike unadjusted models for other dimensions, sex was not a significant predictor variable, and BMI was 0.006kg/m$^2$ higher for girls compared to boys. Para two was a significant predictor variable of BMI, although para three or more was not significant. Infants in the first and second IMD tertiles had BMI values that were 0.349kg/m$^2$ and 0.397kg/m$^2$ lower, respectively, than those of infants in the third IMD tertile. When all significant independent variables were adjusted for, 35.8% of the variance in BMI was explained and IMD became insignificant (see Table 8.10). Adjusting for other covariates also reduced the effect of ethnicity, with BMI being 0.359kg/m$^2$ lower for Pakistani infants compared to White British infants.

Table 8.10. Predictors of BMI (kg/m$^2$) at 12 days of age (n=520): adjusted model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>13.623 (0.082)</td>
</tr>
<tr>
<td>Ethnicity (Pakistani Vs. White British)</td>
<td>-0.359 (0.091)</td>
</tr>
<tr>
<td>Size for gestational age</td>
<td></td>
</tr>
<tr>
<td>(SGA Vs. AGA)</td>
<td>-1.330 (0.130)</td>
</tr>
<tr>
<td>(LGA Vs. AGA)</td>
<td>1.779 (0.182)</td>
</tr>
<tr>
<td>Parity (para 2 Vs. para 1)</td>
<td>0.294 (0.091)</td>
</tr>
<tr>
<td>(para ≥3 Vs. para 1)</td>
<td>0.087 (0.094)</td>
</tr>
<tr>
<td>Index of Multiple Deprivation</td>
<td></td>
</tr>
<tr>
<td>(1$^{st}$ tertile Vs. 3$^{rd}$ tertile)</td>
<td>0.011 (0.101)</td>
</tr>
<tr>
<td>(2$^{nd}$ tertile Vs. 3$^{rd}$ tertile)</td>
<td>-0.107 (0.100)</td>
</tr>
<tr>
<td>Adjusted R$^2$</td>
<td>0.358**</td>
</tr>
</tbody>
</table>

Model significance: *p<0.05 **p<0.01
8.2 Factors that influence size at nine months of age

Most of the predictor variables used in the first set of regression models were also used to investigate factors that influence size at nine months of age. The predictor variable term was not included in regression models because anthropometry at nine months of age was only available for infants with a normal gestational age, who had been included in the multilevel modelling analysis. Additional variables included: anthropometry at birth, conditional anthropometry at two months of age, and feeding status at two months. Table 8.11 shows that White British infants showed evidence of catch-up growth (i.e. change in size above that predicted by regression to the mean) for weight, abdominal circumference, and head circumference; and evidence of catch-down growth for length and BMI. Pakistani infants showed the complete opposite (i.e. catch-down growth for weight, abdominal circumference, and head circumference; and catch-up growth for length and BMI). Table 8.12 shows that there was little difference in the prevalence of exclusive breastfeeding between White British and Pakistani infants. However, more than twice as many Pakistani infants were partially breastfed at two months of age compared to White British infants. It is important to note that some infants had missing data for this variable (n=507 for White British, n=838 for Pakistani).

Table 8.11. Conditional anthropometry of term infants at two months of age, split by ethnicity and sex

<table>
<thead>
<tr>
<th></th>
<th>White British</th>
<th></th>
<th>Pakistani</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boys (n=570)</td>
<td>Girls (n=544)</td>
<td>Boys (n=688)</td>
<td>Girls (n=662)</td>
</tr>
<tr>
<td>Weight (g)</td>
<td>mean (SE)</td>
<td></td>
<td>mean (SE)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13.4 (11.9)</td>
<td>26.8 (11.8)</td>
<td>-12.3 (9.9)</td>
<td>-20.4 (9.6)</td>
</tr>
<tr>
<td>Abdominal circumference (cm)</td>
<td>mean (SE)</td>
<td></td>
<td>mean (SE)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.44 (0.03)</td>
<td>0.47 (0.04)</td>
<td>-0.34 (0.03)</td>
<td>-0.37 (0.03)</td>
</tr>
<tr>
<td>Head circumference (cm)</td>
<td>mean (SE)</td>
<td></td>
<td>mean (SE)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.17 (0.02)</td>
<td>0.18 (0.02)</td>
<td>-0.13 (0.02)</td>
<td>-0.13 (0.02)</td>
</tr>
<tr>
<td>Length (cm)</td>
<td>mean (SE)</td>
<td></td>
<td>mean (SE)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.05 (0.01)</td>
<td>-0.02 (0.01)</td>
<td>0.01 (0.01)</td>
<td>0.03 (0.01)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>mean (SE)</td>
<td></td>
<td>mean (SE)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-0.002 (0.047)</td>
<td>-0.047 (0.046)</td>
<td>0.007 (0.035)</td>
<td>0.032 (0.036)</td>
</tr>
</tbody>
</table>
Table 8.12. Infant feeding status of term infants at two months of age, split by ethnicity

<table>
<thead>
<tr>
<th>Feeding Status</th>
<th>White British n=607 (54.2%)</th>
<th>Pakistani n=512 (45.8%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exclusively breastfeeding</td>
<td>133 (21.9)</td>
<td>123 (24.0)</td>
</tr>
<tr>
<td>Partially breastfeeding</td>
<td>47 (7.7)</td>
<td>109 (21.3)</td>
</tr>
<tr>
<td>Bottle-fed</td>
<td>427 (70.4)</td>
<td>280 (54.7)</td>
</tr>
</tbody>
</table>

In the unadjusted regression models, the predictor variables that were significant or borderline significant varied depending on the outcome variable. Sex was a significant predictor of all dimensions, IMD was a significant predictor of all dimensions apart from BMI, and feeding status was only a significant predictor of weight and abdominal circumference. Ethnicity was a significant predictor of weight, abdominal circumference, and head circumference, but not of length or BMI. In general, anthropometry at birth and conditional anthropometry at two months of age explained the most variance in each dimension. For weight, abdominal circumference, and BMI, conditional anthropometry at two months explained more variance than anthropometry at birth. The opposite was found for head circumference and length, with anthropometry at birth explaining more variance than conditional anthropometry at two months.

When all significant or borderline significant variables were adjusted for in multivariable regression models, the amount of variance explained was high and ranged between 93.9% and 100.0%. Adjusting for covariates meant that weight and abdominal circumference at nine months of age were greater for Pakistani infants compared to White infants. In effect, this meant that these dimensions were larger for Pakistani infants who were male, AGA, born to a primiparous mother, in the third IMD tertile, were exclusively breastfed at two months of age, had a mean abdominal circumference at birth, and showed no evidence of catch-up or catch-down growth in the first two months of life (i.e. conditional anthropometry of zero). Sex was the only predictor variable to remain significant in all of the adjusted models, and feeding status only remained significant in the model for abdominal
circumference. IMD only remained significant in the adjusted model for length. However, because ethnicity was not included in this model, it was not refitted including the interaction variable ethnicity*IMD.
Results: Factors that influence the size of Bradford infants

Table 8.13. Predictors of weight (g) at nine months of age (n=2464): unadjusted models

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
<th>Model 6</th>
<th>Model 7</th>
<th>Model 8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B(SE)</td>
<td>P</td>
<td>B(SE)</td>
<td>P</td>
<td>B(SE)</td>
<td>P</td>
<td>B(SE)</td>
<td>P</td>
</tr>
<tr>
<td>Constant</td>
<td>8939.2 (31.6)</td>
<td>&lt;0.001</td>
<td>9101.7 (28.7)</td>
<td>&lt;0.001</td>
<td>8799.4 (23.6)</td>
<td>&lt;0.001</td>
<td>8783.6 (33.8)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>-233.1 (42.7)</td>
<td>&lt;0.001</td>
<td>-592.9 (41.0)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>(Pakistani Vs. White British)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Sex</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(female Vs. male)</td>
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<td></td>
</tr>
<tr>
<td>Size for gestational age</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(SGA Vs. AGA)</td>
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<td></td>
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</tr>
<tr>
<td>(LGA Vs. AGA)</td>
<td>55.6 (63.8)</td>
<td>0.384</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parity</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(para 2 Vs. para 1)</td>
<td>83.2 (51.7)</td>
<td>0.108</td>
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</tr>
<tr>
<td>(para ≥3 Vs. para 1)</td>
<td>10.6 (51.4)</td>
<td>0.837</td>
<td></td>
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<tr>
<td>Index of Multiple Deprivation</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>(1st tertile Vs. 3rd tertile)</td>
<td>-173.7 (52.0)</td>
<td>0.001</td>
<td></td>
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</tr>
<tr>
<td>(2nd tertile Vs. 3rd tertile)</td>
<td>-116.7 (52.5)</td>
<td>0.026</td>
<td></td>
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</tr>
<tr>
<td>Feeding status at 2 months</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(bottle Vs. exclusive)</td>
<td>153.4 (81.7)</td>
<td>0.061</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(partial Vs. exclusive)</td>
<td>107.7 (113.8)</td>
<td>0.344</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Weight (g) at birth</td>
<td>1.113 (0.040)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conditional weight (g) at 2 months</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.012**</td>
<td>0.078**</td>
<td>0.000</td>
<td>0.000</td>
<td>0.004**</td>
<td>0.001</td>
<td>0.242**</td>
<td>0.644**</td>
</tr>
</tbody>
</table>

Model significance: *p<0.05 **p<0.01
8.2.1 Weight at nine months

Table 8.13 shows the unadjusted regression models for weight at nine months of age. The difference in weight between different ethnic groups had marginally increased from birth, whereas the difference between sexes had nearly quadrupled. At nine months of age Pakistani infants were 233.1g lighter than White British infants, and girls were 592.9g lighter than boys. The effects of IMD and feeding status on weight were similar, but in different directions. Infants in the first and second IMD tertiles were 173.7g and 116.7g lighter, respectively, than infants in the third IMD tertile. Whereas, infants who were bottle-fed or partially breastfed at two months of age were 153.4g and 107.7g heavier, respectively, than infants who were exclusively breastfed. A one gram increase in conditional weight at two months of age increased weight at nine months by 3.196g. Therefore, an infant who was 100g heavier than their expected weight (calculated using a population based estimation equation) at two months of age would be 319.6g heavier at nine months of age, compared to an infant with a conditional weight of zero. When all significant or borderline significant predictor variables were adjusted for, 93.9% of the variance in weight was explained and IMD and feeding status became insignificant (see Table 8.14). Girls were still significantly lighter than boys, but Pakistani infants were now 110.6g heavier than White British infants. The differences in mean birthweight and conditional weight between ethnic groups were entered into the equation for this model to calculate that Pakistani boys were 300.1g lighter than White British boys and Pakistani girls were 238.1g lighter than White British girls.
Results: Factors that influence the size of Bradford infants

**Table 8.14. Predictors of weight (g) at nine months of age (n=2464): adjusted model**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1a</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B(SE)</td>
<td></td>
<td>P</td>
</tr>
<tr>
<td>Constant</td>
<td>8999.2</td>
<td>(22.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Ethnicity (Pakistani Vs. White British)</td>
<td>110.6</td>
<td>(18.7)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Sex (female Vs. male)</td>
<td>-496.6</td>
<td>(16.7)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Index of Multiple Deprivation (1st tertile Vs. 3rd tertile)</td>
<td>-17.1</td>
<td>(22.1)</td>
<td>0.441</td>
</tr>
<tr>
<td>(2nd tertile Vs. 3rd tertile)</td>
<td>-16.5</td>
<td>(20.7)</td>
<td>0.425</td>
</tr>
<tr>
<td>Feeding status at 2 months (bottle Vs. exclusive)</td>
<td>24.6</td>
<td>(20.5)</td>
<td>0.231</td>
</tr>
<tr>
<td>(partial Vs. exclusive)</td>
<td>46.1</td>
<td>(28.5)</td>
<td>0.106</td>
</tr>
<tr>
<td>Weight (g) birth</td>
<td>1.062</td>
<td>(0.018)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Conditional weight (g) at 2 months</td>
<td>3.177</td>
<td>(0.029)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Adjusted R²</strong></td>
<td><strong>0.939</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Model significance: *p<0.05 **p<0.01
Results: Factors that influence the size of Bradford infants

Table 8.15. Predictors of abdominal circumference (cm) at nine months of age (n=2464): unadjusted models

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
<th>Model 6</th>
<th>Model 7</th>
<th>Model 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>44.637</td>
<td>43.980</td>
<td>43.864</td>
<td>43.694</td>
<td>44.301</td>
<td>43.994</td>
<td>43.776</td>
<td>43.762</td>
</tr>
<tr>
<td></td>
<td>(0.051)</td>
<td>(0.053)</td>
<td>(0.038)</td>
<td>(0.060)</td>
<td>(0.064)</td>
<td>(0.117)</td>
<td>(0.031)</td>
<td>(0.023)</td>
</tr>
<tr>
<td>Ethnicity (Pakistani Vs. White British)</td>
<td>-1.572</td>
<td>&lt;0.001</td>
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<tr>
<td></td>
<td>(0.069)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex (female Vs. male)</td>
<td>-0.417</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>(0.075)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Size for gestational age</td>
<td></td>
<td></td>
<td>-1.599</td>
<td>&lt;0.001</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>(SGA Vs. AGA)</td>
<td></td>
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<td>(0.104)</td>
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<td></td>
</tr>
<tr>
<td>(LGA Vs. AGA)</td>
<td></td>
<td></td>
<td>2.114</td>
<td>&lt;0.001</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.152)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parity (para 2 Vs. para 1)</td>
<td>0.297</td>
<td>0.001</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.091)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(para ≥3 Vs. para 1)</td>
<td>-0.022</td>
<td>0.808</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>(0.091)</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Index of Multiple Deprivation (1st tertile Vs. 3rd tertile)</td>
<td></td>
<td></td>
<td>-0.861</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.090)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(2nd tertile Vs. 3rd tertile)</td>
<td>-0.709</td>
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<tr>
<td>Feeding status at 2 months (bottle Vs. exclusive)</td>
<td>0.030</td>
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<tr>
<td>(partial Vs. exclusive)</td>
<td>-0.359</td>
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<td></td>
</tr>
<tr>
<td>Abdominal circumference (cm) at birth</td>
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<td>0.456</td>
<td>&lt;0.001</td>
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<td>(0.013)</td>
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<tr>
<td>Conditional abdominal circumference (cm) at 2 months</td>
<td>1.613</td>
<td>&lt;0.001</td>
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<tr>
<td>Adjusted R²</td>
<td>0.174**</td>
<td>0.012**</td>
<td>0.161**</td>
<td>0.005**</td>
<td>0.039**</td>
<td>0.003*</td>
<td>0.316**</td>
<td>0.620**</td>
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Model significance: *p<0.05 **p<0.01
8.2.2 Abdominal circumference at nine months

All of the unadjusted regression models were significant or borderline significant (see Table 8.15). The effect of ethnicity was approximately three times greater than the effect of sex, with abdominal circumference being 1.57cm smaller for Pakistani infants compared to White British infants, and 0.42cm smaller for girls compared to boys. Interestingly, the extent to which being Pakistani influenced abdominal circumference was very similar to the effect of being SGA. Infants in the first and second IMD tertiles had abdominal circumferences that were 0.86cm and 0.71cm smaller, respectively, than those of infants in the third IMD tertile. Partial breastfeeding at two months of age was a significant predictor variable, however bottle feeding was not. When all significant or borderline significant predictor variables were adjusted for, 95.1% of the variance in abdominal circumference was explained and LGA, parity, IMD, and partial breast feeding became insignificant (see Table 8.16). Similarly to the results for weight, abdominal circumference was still significantly smaller for girls compared to boys, but was now 0.36cm larger for Pakistani infants compared to White British infants. The differences in mean abdominal circumference at birth and conditional abdominal circumference at two months between ethnic groups were entered into the equation for this model to calculate that abdominal circumference at nine months of age was 1.22cm smaller for Pakistani boys compared to White British boys and 1.08cm smaller for Pakistani girls compared to White British girls.
Table 8.16: Predictors of abdominal circumference (cm) at nine months of age (n=2464): adjusted model

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<th>Variable</th>
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<th></th>
</tr>
</thead>
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<td>Constant</td>
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<td>Ethnicity (Pakistani Vs. White British)</td>
<td>0.358 (0.032)</td>
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</tr>
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<td>Sex (female Vs. male)</td>
<td>-0.331 (0.025)</td>
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<tr>
<td>Size for gestational age (SGA Vs. AGA)</td>
<td>0.123 (0.043)</td>
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<tr>
<td>Size for gestational age (LGA Vs. AGA)</td>
<td>-0.080 (0.056)</td>
<td>0.152</td>
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</tr>
<tr>
<td>Parity (para 2 Vs. para 1)</td>
<td>0.040 (0.030)</td>
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<tr>
<td>Parity (para ≥3 Vs. para 1)</td>
<td>0.048 (0.032)</td>
<td>0.129</td>
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<tr>
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<td>0.007 (0.033)</td>
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<td>-0.003 (0.031)</td>
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<td>Feeding status at 2 months (partial Vs. exclusive)</td>
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<td>Abdominal circumference (cm) at birth</td>
<td>0.478 (0.006)</td>
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<td>Conditional abdominal circumference (cm) at 2 months</td>
<td>1.709 (0.015)</td>
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Adjusted R<sup>2</sup> 0.951**

Model significance: *p<0.05  **p<0.01
Table 8.17. Predictors of head circumference (cm) at nine months of age (n=2464): unadjusted models

<table>
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<tr>
<th>Variable</th>
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<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
<th>Model 6</th>
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<th>Model 8</th>
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<td>B(SE)</td>
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<td>B(SE)</td>
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<td>(0.012)</td>
<td>(0.014)</td>
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<td>&lt;0.001</td>
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<td>&lt;0.001</td>
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<td>Feeding status at 2 months</td>
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<td>Head circumference (cm) at birth</td>
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<td>&lt;0.001</td>
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<tr>
<td>Conditional head circumference (cm) at 2 months</td>
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<tr>
<td>Adjusted R²</td>
<td>0.119**</td>
<td>0.237**</td>
<td>0.111**</td>
<td>0.002**</td>
<td>0.033**</td>
<td>0.006**</td>
<td>0.521**</td>
<td>0.299**</td>
</tr>
</tbody>
</table>

Model significance: *p<0.05  **p<0.01
8.2.3 Head circumference at nine months

All unadjusted regression models were significant at alpha one percent, although the p-values for the dummy variables partially breastfed and bottle-fed were not significant or borderline significant (see Table 8.17). Head circumference was 0.59cm smaller for Pakistani infants compared to White British infants, and 0.82cm smaller for girls compared to boys. Similarly to the unadjusted models for abdominal circumference, the extent to which being Pakistani influenced head circumference was very similar to the effect of being SGA. Infants in the first and second IMD tertiles had head circumferences that were 0.36cm and 0.28cm smaller, respectively, than those of infants in the third IMD tertile. When all significant or borderline significant predictor variables were adjusted for, 95.6% of the variance in head circumference was explained and SGA, parity, and IMD became insignificant (see Table 8.18). Adjusting for covariates slightly reduced the effect of sex, but greatly reduced the effect of ethnicity, with head circumference only being 0.09cm smaller for Pakistani infants compared to White British infants. The differences in mean head circumference at birth and conditional head circumference between ethnic groups were entered into the equation for this model to calculate that head circumference at nine months of age was 0.36cm smaller for Pakistani boys compared to White British boys and 0.27cm smaller for Pakistani girls compared to White British girls.
Table 8.18. Predictors of head circumference (cm) at nine months of age (n=2464): adjusted model

<table>
<thead>
<tr>
<th>Variable</th>
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<td></td>
<td>B(SE)</td>
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<tr>
<td>Constant</td>
<td>45.665 (0.009)</td>
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<tr>
<td>Ethnicity (Pakistani Vs. White British)</td>
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<td>Sex (female Vs. male)</td>
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<td>(SGA Vs. AGA)</td>
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<td>(LGA Vs. AGA)</td>
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<td>Parity (para 2 Vs. para 1)</td>
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<td>(para ≥3 Vs. para 1)</td>
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<td>Index of Multiple Deprivation</td>
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<td>(1st tertile Vs. 3rd tertile)</td>
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<td>(2nd tertile Vs. 3rd tertile)</td>
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<td>Head circumference (cm) at birth</td>
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<td>Conditional head circumference (cm) at 2 months</td>
<td>1.029 (0.009)</td>
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Adjusted $R^2$: 0.956**

Model significance: *p<0.05 **p<0.01
Results: Factors that influence the size of Bradford infants

Table 8.19. Predictors of length (cm) at nine months of age (n=520): unadjusted models

<table>
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<th>Model 1</th>
<th>Model 2</th>
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<th>Model 4</th>
<th>Model 5</th>
<th>Model 6</th>
<th>Model 7</th>
<th>Model 8</th>
</tr>
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<td>(0.113)</td>
<td>(0.092)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Length (cm) at 12 days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.131</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.019)</td>
</tr>
<tr>
<td>Conditional length (cm) at 2 months</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.446</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>(0.607)</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>-0.001</td>
<td>0.165**</td>
<td>0.080**</td>
<td>-0.001</td>
<td>0.003</td>
<td>0.002</td>
<td>0.870**</td>
<td>0.092**</td>
</tr>
</tbody>
</table>

Model significance: *p<0.05 **p<0.01
8.2.4 Length at nine months

Table 8.19 shows the unadjusted regression models for length at nine months of age. The difference in length between ethnic groups decreased after 12 days of age, and by nine months the difference between Pakistani and White British infants was not significant. The difference in length between sexes was marginally greater at nine months of age than at birth, with girls being 1.65cm shorter than boys. There was a borderline significant difference in length between infants in the first and third IMD tertiles, but not between infants in the second and third IMD tertiles. When all significant or borderline significant predictors were adjusted for, SGA and IMD became insignificant (see Table 8.20). However, with just five predictor variables it was possible to explain 100% of the variance in length at nine months of age.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1a</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B(SE)</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>72.440 (0.003)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Sex (female Vs. male)</td>
<td>-0.224 (0.004)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Size for gestational age (SGA Vs. AGA)</td>
<td>-0.007 (0.006)</td>
<td>0.210</td>
<td></td>
</tr>
<tr>
<td>(LGA Vs. AGA)</td>
<td>-0.029 (0.008)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Index of Multiple Deprivation (1st tertile Vs. 3rd tertile)</td>
<td>0.007 (0.004)</td>
<td>0.083</td>
<td></td>
</tr>
<tr>
<td>(2nd tertile Vs. 3rd tertile)</td>
<td>-0.004 (0.004)</td>
<td>0.306</td>
<td></td>
</tr>
<tr>
<td>Length (cm) at 12 days of age</td>
<td>1.126 (0.001)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Conditional length (cm) at 2 months</td>
<td>5.255 (0.011)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

Adjusted $R^2$ 1.00**

Model significance: *p<0.05 **p<0.01
### Table 8.21. Predictors of BMI (kg/m$^2$) at nine months of age (n=520): unadjusted models

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
<th>Model 5</th>
<th>Model 6</th>
<th>Model 7</th>
<th>Model 8</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>B(SE)</td>
<td>P</td>
<td>B(SE)</td>
<td>P</td>
<td>B(SE)</td>
<td>P</td>
<td>B(SE)</td>
<td>P</td>
</tr>
<tr>
<td>Constant</td>
<td>17.097</td>
<td>&lt;0.001</td>
<td>17.321</td>
<td>&lt;0.001</td>
<td>16.960</td>
<td>&lt;0.001</td>
<td>16.933</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>(0.121)</td>
<td></td>
<td>(0.104)</td>
<td></td>
<td>(0.081)</td>
<td></td>
<td>(0.123)</td>
<td></td>
</tr>
<tr>
<td>Ethnicity (Pakistani Vs. White British)</td>
<td>-0.216</td>
<td>0.164</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.155)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td>-0.729</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(female Vs. male)</td>
<td>(0.148)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Size for gestational age</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(SGA Vs. AGA)</td>
<td>-0.397</td>
<td>0.125</td>
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</tr>
<tr>
<td>(LGA Vs. AGA)</td>
<td>0.919</td>
<td>0.011</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parity</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(para 2 Vs. para 1)</td>
<td>0.134</td>
<td>0.466</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>(para ≥3 Vs. para 1)</td>
<td>-0.032</td>
<td>0.863</td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>(para 2 Vs. para 1)</td>
<td>(0.184)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>(para ≥3 Vs. para 1)</td>
<td>(0.359)</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Index of Multiple Deprivation</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(1$^{st}$ tertile Vs. 3$^{rd}$ tertile)</td>
<td>-0.179</td>
<td>0.333</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2$^{nd}$ tertile Vs. 3$^{rd}$ tertile)</td>
<td>-0.163</td>
<td>0.384</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Feeding status at 2 months</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(bottle Vs. exclusive)</td>
<td>0.201</td>
<td>0.390</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(partial Vs. exclusive)</td>
<td>-0.190</td>
<td>0.549</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(bottle Vs. exclusive)</td>
<td>(0.233)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(partial Vs. exclusive)</td>
<td>(0.317)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m$^2$) at 12 days</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.737</td>
<td>&lt;0.001</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conditional BMI (kg/m$^2$) at 2 months</td>
<td>3.233</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted R$^2$</td>
<td>0.002</td>
<td>0.043**</td>
<td>0.014**</td>
<td>-0.002</td>
<td>-0.002</td>
<td>0.001</td>
<td>0.204**</td>
<td>0.729**</td>
</tr>
</tbody>
</table>

Model significance: *p<0.05 **p<0.01
8.2.5 BMI at nine months

The unadjusted regression models (see Table 8.21) show that there was no significant or borderline significant difference between ethnic groups, with BMI only being 0.216 kg/m² lower for Pakistani infants compared to White British infants. The difference in BMI between sexes had increased from 12 days of age, when it was insignificant, and was now 0.729 kg/m² lower for girls compared to boys. When all significant or borderline significant predictors were adjusted for, 97.9% of the variance in BMI at nine months of age was explained (see Table 8.22).

Table 8.22. Predictors of BMI (kg/m²) at nine months of age (n=520): adjusted model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B(SE) P</td>
</tr>
<tr>
<td>Constant</td>
<td>17.327 &lt;0.001</td>
</tr>
<tr>
<td></td>
<td>(0.016)</td>
</tr>
<tr>
<td>Sex (female Vs. male)</td>
<td>-0.733 &lt;0.001</td>
</tr>
<tr>
<td></td>
<td>(0.022)</td>
</tr>
<tr>
<td>Size for gestational age</td>
<td></td>
</tr>
<tr>
<td>(SGA Vs. AGA)</td>
<td>-0.165 &lt;0.001</td>
</tr>
<tr>
<td></td>
<td>(0.042)</td>
</tr>
<tr>
<td>(LGA Vs. AGA)</td>
<td>0.100 0.084</td>
</tr>
<tr>
<td></td>
<td>(0.058)</td>
</tr>
<tr>
<td>BMI (kg/m²) at 12 days</td>
<td>0.710 &lt;0.001</td>
</tr>
<tr>
<td></td>
<td>(0.013)</td>
</tr>
<tr>
<td>Conditional BMI (kg/m²) at 2 months</td>
<td>3.249 &lt;0.001</td>
</tr>
<tr>
<td></td>
<td>(0.024)</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.979**</td>
</tr>
</tbody>
</table>

Model significance: *p<0.05 **p<0.01
9 Results: Comparison to the UK90 references and WHO standards
9.1 The UK90 references

Infants demonstrated similar patterns of WFA, HCFA, and LFA growth in the first nine months of life compared to the UK90 references. In general, White British infants approximated the 50th centile of the UK90 sex specific centile charts and Pakistani infants approximated the 25th centile. At ages where there were a lot of data (i.e. birth to four months and seven to nine months) growth generally did not deviate from the growth canals detailed below by more than 0.2 Z-scores. However, at ages between prescribed measurement periods, where there were less data (i.e. four to seven months), Z-scores deviated more substantially. Between four and seven months of age, infants demonstrated accelerated WFA growth and slower HCFA growth compared to the UK90 references.

9.1.1 Weight-for-age

The WFA growth curves of White British infants tracked close to the 50th centile of the UK90 references from birth to nine months of age. Whereas, Pakistani infants tracked close to the 25th centile from birth to three months, and then demonstrated greater WFA gain, so that by nine months of age they had a mean Z-score of approximately -0.3 (see Figure 9.1). There was also some evidence that girls demonstrated relatively greater WFA gain than boys. Figure 9.2 shows that Pakistani infants consistently had lower WFA Z-scores than White British infants, and that boys generally had lower Z-scores than girls. The differences in WFA Z-scores between ethnic groups decreased after birth and by nine months of age was approximately 0.2.
Results: Comparison to the UK90 references

**Figure 9.1. Weight-for-age growth curves plotted against the UK90 references**

- White British boys (n=570)
- Pakistani boys (n=688)
- White British girls (n=544)
- Pakistani girls (n=662)

**Figure 9.2. Mean weight-for-age Z-scores relative to the UK90 references**

- White British boys (n=570)
- White British girls (n=544)
- Pakistani boys (n=688)
- Pakistani girls (n=662)
9.1.2   Head circumference-for-age
The HCFA growth curves of White British and Pakistani infants approximated the 50th and 25th centiles of the UK90 references, respectively (see Figure 9.3). Figure 9.4 shows that Pakistani infants consistently had lower HCFA Z-scores than White British infants and that this difference of approximately 0.4 Z-scores remained fairly constant between birth and nine months of age. Similarly to the results for WFA, boys had HCFA Z-scores that were generally lower than those for girls.
Results: Comparison to the UK90 references

Figure 9.3. Head circumference-for-age growth curves plotted against the UK90 references

Figure 9.4. Mean head circumference-for-age Z-scores relative to the UK90 references
9.1.3 Length-for-age

The difference between ethnicities in LFA growth was less noticeable than that in WFA and HCFA growth. The LFA growth curves for all sex and ethnic specific groups tracked close to the 50th centile of the UK90 references until six months of age, after which they demonstrated accelerated growth so that by nine months of age mean Z-scores were approximately +0.6 (see Figure 9.5). There was also some evidence that girls demonstrated relatively greater LFA gain than boys. Figure 9.6 shows that Pakistani infants had marginally lower mean LFA Z-scores than White British infants and that these difference decreased after 12 days of age and by nine months were negligible.
Results: Comparison to the UK90 references

Figure 9.5. Length-for-age growth curves plotted against the UK90 references

White British boys (n=102)

Pakistani boys (n=164)

White British girls (n=101)

Pakistani girls (n=153)

Figure 9.6. Mean length-for-age Z-scores relative to the UK90 references

*12 days
9.1.4 **BMI-for-age**

BMI growth curves were not produced, although it was possible to calculate BMI at 12 days and one, two, three….nine months of age using predictions of weight and length from the MLMs. All ethnicity and sex specific groups demonstrated similar patterns of BMIFA growth, relative to the UK90 references (see Figure 9.10). Infants demonstrated a period of slow growth from birth to two months, followed by a period of rapid growth until six months, and a final period of slow growth from six to nine months. Pakistani infants generally had lower BMIFA Z-scores than White British infants. In the first nine months of life, White British infants had BMIFA Z-scores ranging between +0.3 and -0.5, and Pakistani infants had Z-scores ranging between -0.1 and -0.9. For both ethnic groups, boys had lower BMIFA Z-scores between birth and five months, after which girls had lower Z-scores.

*Figure 9.7. Mean BMI-for-age Z-scores relative to the UK90 references*
9.2 The WHO standards

Compared to the WHO standards, infants demonstrated dissimilar WFA growth curves and reasonably similar HCFA and LFA growth curves. Even at ages where there were fewer data points (i.e. four to seven months) the HCFA and LFA growth curves of infants were similar to any given centile of the WHO standards. The growth of infants did not deviate from the growth canals detailed below by more than 0.2 Z-scores.

9.2.1 Weight-for-age

The common WFA growth pattern for all ethnic and sex specific groups was slow growth between birth and two months, followed by accelerated growth until nine months of age (see Figure 9.8). There was a difference of approximately 0.3 Z-scores between Pakistani and White British infants, with the former being born smaller (-0.2 vs. +0.2 Z-scores), achieving lower minimum Z-scores at two months (-0.7 vs. -0.3 Z-scores), crossing the 50th centile later (five vs. three months), and being smaller at nine months (+0.1 vs. +0.3 Z-scores). Therefore, the average Bradford infant lost 0.5 Z-scores between birth and two months, and then gained 0.7 Z-scores between two and nine months (see Figure 9.9). The differences in WFA Z-scores between ethnic groups decreased after birth and by nine months of age was approximately 0.2. As with the UK90 comparison, there was some evidence that girls demonstrated relatively greater WFA gain than boys, and boys generally had lower WFA Z-scores than girls.
Results: Comparison to the WHO standards

Figure 9.8. *Weight-for-age growth curves plotted against the WHO standards*

![Graph showing weight-for-age growth curves for White British boys and Pakistani boys, with standard curves and Z-scores.](image1)

Figure 9.9. *Mean weight-for-age Z-scores relative to the WHO standards*

![Graph showing mean weight-for-age Z-scores for White British boys and Pakistani boys, with standard curves and Z-scores.](image2)
9.2.2 Head circumference-for-age

Between birth and seven months of age, the HCFA growth curves of White British and Pakistani infants approximated the 75th and 50th centiles of the WHO standard centile charts, respectively (see Figure 9.10). After seven months of age, infants demonstrated greater HCFA gain, relative to the WHO standards, so that by nine months of age mean Z-scores ranged between 0.3 and 1.0 (see Figure 9.11). Pakistani infants consistently had lower Z-scores than White British infants, and this difference remained fairly constant between birth and nine months of age. As with the UK90 comparison, boys generally had lower Z-scores than boys.
Results: Comparison to the WHO standards

Figure 9.10. Head circumference-for-age growth curves plotted against the WHO standards

Figure 9.11. Mean head circumference-for-age Z-scores relative to the WHO standards
9.2.3 Length-for-age

The comparison of the LFA growth curves of infants against the WHO standards was similar to the comparison against the UK90 references (i.e. approximated the 50th centile from birth to six months and then demonstrated accelerated growth). This suggests that the WHO and UK90 LFA growth curves are similar from birth to nine months. It is, however, worthwhile noting that infants were approximately 0.2 Z-scores longer at birth based on the WHO standards compared to the UK90 references (see Figure 9.13). Similarly to the UK90 comparison, girls demonstrated relatively greater LFA gain than boys, and the differences in LFA Z-scores between ethnic groups decreased with age.
Results: Comparison to the WHO standards

Figure 9.12. Length-for-age growth curves plotted against the WHO standards

- **White British boys (n=102)**
- **Pakistani boys (n=164)**

- **White British girls (n=101)**
- **Pakistani girls (n=153)**

Figure 9.13. Mean length-for-age Z-scores relative to the WHO standards

- **White British boys (n=102)**
- **White British girls (n=101)**
- **Pakistani boys (n=164)**
- **Pakistani girls (n=153)**

*12 days
9.2.4 BMI-for-age

All ethnicity and sex specific groups demonstrated similar patterns of BMI-for-age growth, relative to WHO standards (see Figure 9.14). As with the UK90 comparison, Bradford infants demonstrated a period of slow growth from birth to two months, followed by a period of rapid growth until six months, and a final period of slow growth from six to nine months. However, the range of BMI-for-age Z-scores was larger for White British (+0.6 to -0.6) and Pakistani (+0.2 to -1.0) infants based on the WHO standards compared to external Z-scores based on the UK90 references. For both ethnic groups, boys had lower Z-scores between birth and five months, after which girls had lower Z-scores.

*Figure 9.14. Mean BMI-for-age Z-scores relative to the WHO standards*
9.3 Relative risk of underweight, poor infant weight gain, and obesity

By the WHO standards, Bradford infants were significantly less likely to be classified as underweight (weight < 2nd centile) at birth and six to nine months, compared to the UK90 references (see Table 9.1). Infants were also significantly less likely to be classified as demonstrating poor infant weight gain between birth and nine months of age according to the WHO standards. Whereas, the proportion of children classified as obese (BMI > 98th centile) between birth and nine months was not significantly higher according to the WHO standards, compared to the UK90 references. Table 9.2 shows the same results, but split by ethnic group. Risk for underweight, using the WHO standards compared to the UK90 references, was significantly greater at seven to nine months of age for White British infants, and at birth and six to nine months for Pakistani infants. There were no significant risks for poor infant weight gain and obesity.
Table 9.1. The relative risk of infants being classified as underweight, poor infant weight gain, or obese according to the WHO standards, compared to the UK90 references

<table>
<thead>
<tr>
<th>Bradford infants</th>
<th>WHO standards</th>
<th>UK90 references</th>
<th>RR (95% CI) (n=2464)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Underweight (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birth</td>
<td>2.3</td>
<td>4.7</td>
<td>0.496* (0.363 to 0.678)</td>
</tr>
<tr>
<td>1 month</td>
<td>1.7</td>
<td>2.1</td>
<td>0.808 (0.540 to 1.208)</td>
</tr>
<tr>
<td>2 months</td>
<td>2.6</td>
<td>1.7</td>
<td>1.500* (1.019 to 2.208)</td>
</tr>
<tr>
<td>3 months</td>
<td>1.6</td>
<td>1.3</td>
<td>1.219 (0.766 to 1.939)</td>
</tr>
<tr>
<td>4 months</td>
<td>0.9</td>
<td>1.1</td>
<td>0.786 (0.451 to 1.369)</td>
</tr>
<tr>
<td>5 months</td>
<td>0.6</td>
<td>1.1</td>
<td>0.615 (0.331 to 1.144)</td>
</tr>
<tr>
<td>6 months</td>
<td>0.6</td>
<td>1.3</td>
<td>0.438* (0.234 to 0.818)</td>
</tr>
<tr>
<td>7 months</td>
<td>0.6</td>
<td>1.8</td>
<td>0.333* (0.186 to 0.596)</td>
</tr>
<tr>
<td>8 months</td>
<td>1.0</td>
<td>2.8</td>
<td>0.348* (0.219 to 0.552)</td>
</tr>
<tr>
<td>9 months</td>
<td>2.2</td>
<td>5.0</td>
<td>0.431* (0.314 to 0.592)</td>
</tr>
<tr>
<td><strong>Poor infant weight gain (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birth to 9 months</td>
<td>6.7</td>
<td>8.6</td>
<td>0.783* (0.644 to 0.952)</td>
</tr>
<tr>
<td><strong>Obese (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 days</td>
<td>0.8</td>
<td>1.7</td>
<td>0.444 (0.138 to 1.434)</td>
</tr>
<tr>
<td>1 month</td>
<td>0.2</td>
<td>0.2</td>
<td>1.000 (0.063 to 15.945)</td>
</tr>
<tr>
<td>2 months</td>
<td>0.0</td>
<td>0.0</td>
<td>-</td>
</tr>
<tr>
<td>3 months</td>
<td>0.0</td>
<td>0.0</td>
<td>-</td>
</tr>
<tr>
<td>4 months</td>
<td>0.2</td>
<td>0.2</td>
<td>1.000 (0.063 to 15.945)</td>
</tr>
<tr>
<td>5 months</td>
<td>1.3</td>
<td>1.0</td>
<td>1.400 (0.447 to 4.383)</td>
</tr>
<tr>
<td>6 months</td>
<td>2.3</td>
<td>1.9</td>
<td>1.200 (0.523 to 2.753)</td>
</tr>
<tr>
<td>7 months</td>
<td>3.3</td>
<td>1.9</td>
<td>1.700 (0.786 to 3.677)</td>
</tr>
<tr>
<td>8 months</td>
<td>3.3</td>
<td>1.5</td>
<td>2.125 (0.925 to 4.881)</td>
</tr>
<tr>
<td>9 months</td>
<td>2.7</td>
<td>1.3</td>
<td>2.000 (0.814 to 4.915)</td>
</tr>
</tbody>
</table>

*significant at alpha 5% level.

RR, relative risk for each outcome using the WHO standard compared with the UK90 reference; Underweight, weight <2nd centile; Poor infant weight gain, conditional weight gain <-1.33 Z-scores, equivalent to downward crossing through two major centile lines on each growth chart; Obese, body mass index >98th centile.
Table 9.2. The relative risk of infants being classified as underweight, poor infant weight gain, or obese according to the WHO standards, compared to the UK90 references, split by ethnic group

<table>
<thead>
<tr>
<th></th>
<th>Bradford infants</th>
<th>WHO standards</th>
<th>UK90 references</th>
<th>RR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>White British</td>
<td>Pakistani</td>
<td>White British (n=1114)</td>
</tr>
<tr>
<td><strong>Underweight (%)</strong></td>
<td></td>
<td>White British</td>
<td>Pakistani</td>
<td>RR (95% CI)</td>
</tr>
<tr>
<td>Birth</td>
<td>1.5</td>
<td>3.0</td>
<td>2.5</td>
<td>6.4</td>
</tr>
<tr>
<td>1 month</td>
<td>1.2</td>
<td>2.1</td>
<td>1.5</td>
<td>2.6</td>
</tr>
<tr>
<td>2 months</td>
<td>1.7</td>
<td>3.3</td>
<td>1.3</td>
<td>2.1</td>
</tr>
<tr>
<td>3 months</td>
<td>1.2</td>
<td>1.9</td>
<td>0.9</td>
<td>1.6</td>
</tr>
<tr>
<td>4 months</td>
<td>0.9</td>
<td>0.9</td>
<td>0.6</td>
<td>1.6</td>
</tr>
<tr>
<td>5 months</td>
<td>0.7</td>
<td>0.6</td>
<td>0.7</td>
<td>1.3</td>
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<tr>
<td>6 months</td>
<td>0.6</td>
<td>0.5</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>7 months</td>
<td>0.8</td>
<td>0.4</td>
<td>1.8</td>
<td>1.9</td>
</tr>
<tr>
<td>8 months</td>
<td>1.3</td>
<td>0.7</td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td>9 months</td>
<td>2.5</td>
<td>1.9</td>
<td>4.8</td>
<td>5.2</td>
</tr>
<tr>
<td><strong>Poor infant weight gain (%)</strong></td>
<td></td>
<td>White British</td>
<td>Pakistani</td>
<td>RR (95% CI)</td>
</tr>
<tr>
<td>Birth to 9 months</td>
<td>7.3</td>
<td>6.3</td>
<td>9.5</td>
<td>7.9</td>
</tr>
<tr>
<td></td>
<td>(n=203)</td>
<td>(n=317)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Obese (%)</strong></td>
<td></td>
<td>White British</td>
<td>Pakistani</td>
<td>RR (95% CI)</td>
</tr>
<tr>
<td>12 days</td>
<td>1.5</td>
<td>0.3</td>
<td>3.4</td>
<td>0.6</td>
</tr>
<tr>
<td>1 month</td>
<td>0.5</td>
<td>0.0</td>
<td>0.5</td>
<td>0.0</td>
</tr>
<tr>
<td>2 months</td>
<td>0.0</td>
<td>0.0</td>
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<td>3 months</td>
<td>0.0</td>
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<tr>
<td>4 months</td>
<td>0.5</td>
<td>0.0</td>
<td>0.5</td>
<td>0.0</td>
</tr>
<tr>
<td>5 months</td>
<td>2.5</td>
<td>0.6</td>
<td>1.5</td>
<td>0.6</td>
</tr>
<tr>
<td>6 months</td>
<td>3.9</td>
<td>1.3</td>
<td>3.0</td>
<td>1.3</td>
</tr>
<tr>
<td>7 months</td>
<td>4.9</td>
<td>2.2</td>
<td>3.0</td>
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<td>8 months</td>
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<td>2.5</td>
<td>2.5</td>
<td>0.9</td>
</tr>
<tr>
<td>9 months</td>
<td>3.4</td>
<td>2.2</td>
<td>2.5</td>
<td>0.6</td>
</tr>
</tbody>
</table>

*significant at alpha 5% level.

RR, relative risk for each outcome using the WHO standard compared with the UK90 reference; Underweight, weight <2nd centile; Poor infant weight gain, conditional weight gain <-1.33 Z-scores, equivalent to downward crossing through two major centile lines on each growth chart; Obese, body mass index >98th centile.
10 Discussion
10.1 Integrating research with growth monitoring practice

The benefits of growth monitoring in the UK are diverse, and the NHS rightly invests extensive resources to ensure that infant growth is monitored (Department of Health and Social Security 1974). A vast repository of growth data is produced, which is largely unutilised (Patterson et al. 2006). In Bradford, a collaboration between P2PG and Bradford and Airedale tPCT has worked to improve the quality of growth monitoring, so that routinely collected growth data are developed to research calibre and are made more accessible. The purpose of this section is to describe how a major research programme on child health has been integrated into practice, and highlight the benefits and challenges of aligning research and practice.

The first change to growth monitoring practice in Bradford was the introduction of abdominal circumference as a new measurement. Lassos (Harlow Health Care, London, UK) were also provided for health workers to measure both abdominal and head circumferences. Abdominal circumference is particularly relevant considering the increasing prevalence of obesity, and in particular abdominal obesity, in children (Li et al. 2006). Similar to adults, central obesity is associated with increased risk of CVD and NIDDM in children (Freedman et al. 1999; Maffeis et al. 2001; Katzmarzyk et al. 2004). Cross-validation against magnetic resonance imaging has demonstrated that abdominal circumference is an accurate predictor of visceral adipose tissue in children (Brambilla et al. 2006). Abdominal circumference is a sensitive measure of central obesity in children (Savva et al. 2000; Taylor et al. 2000; McCarthy, Ellis & Cole 2003), whereas the more common measure of BMI has been shown to underestimate childhood obesity (McCarthy, Ellis & Cole 2003).

Health workers were asked to perform their first postnatal visits at ten to 14 days of age, instead of birth to 28 days. This age period was chosen to ensure that infants were only measured when they have regained weight that is lost in the first few days of life (Macdonald et al. 2003). The use of a narrower age period also meant that anthropometry could more easily be
compared between infants, without having to perform analyses to adjust for age. A small difference in age is less of a problem later in infancy and childhood, when growth velocity is slower (Cameron 2002). More frequent measurement in the first two weeks of life would enable researchers to investigate weight loss after birth. Unfortunately, the high work load and competing demands of health workers meant that no additional age periods could be introduced to growth monitoring practice. The addition of an additional measurement form to the PCHRs in Bradford did, however, mean that all growth data collected by health workers, not just those collected during the three prescribed age periods, were transferred to System One and made available to BiB.

The large number of health workers responsible for collecting anthropometry on BiB infants meant that measurement error posed a potential problem. Measurement training workshops were organised to help standardise measurement technique. A measurement protocol (see Appendix II), which was subsequently incorporated into a growth monitoring standard (see Appendix III), was also produced for health workers. The reliability of growth monitoring data collected by health workers was assessed (Johnson et al. 2009a) and measurement error was comparable to anthropometric literature which reports acceptable levels of reliability.

The changes that were introduced to growth monitoring practice helped develop growth monitoring data to research calibre, meaning that there was a known, well documented, and standardised measurement procedure, data were reliable, and the extractions from System One were in a format that can be used for research. However, if these data are not made accessible to future researchers, the potential benefits of growth monitoring will not be fulfilled (Hall & Voss 2000). The P2PG study worked with Child Health to set up data sharing and extraction protocols to enable growth monitoring data to be utilised, not only for this thesis, but also to be more accessible for future research. The current study was the first to use routine growth monitoring data in Bradford for research, and we are only aware of two other published studies that have used growth monitoring data from other areas in the UK.
The vast repository of data created by growth monitoring has not yet been exploited by researchers.

10.1.1 Benefits of research for growth monitoring

Changes to growth monitoring practice were introduced not only to develop the quality and accessibility of data for research, but also to improve the quality of growth monitoring, with the ultimate aim of improving the ability of growth monitoring to detect health problems. Health workers were given the tools necessary to measure and interpret infant growth. Regular feedback was provided for health workers, in the form of newsletters produced by P2PG and one day conferences organised by BiB and the tPCT. The introduction of abdominal circumference to growth monitoring practice in Bradford was successful, with 80% of infants being measured for abdominal circumference between birth and 28 days of age. These data are important to determine phenotypic differences between White British and Pakistani infants that may be used for public health surveillance and obesity research in the future. Information on the importance and interpretation of abdominal circumference was also provided with the aim to improve awareness about childhood obesity. Research is now part of everyday growth monitoring practice in Bradford. Health workers are responsible for data collection, and Child Health are responsible for data entry and audit and feedback of performance. For these reasons, we believe growth monitoring in Bradford should be recognised as a national exemplar (Johnson et al. 2009b).

10.1.2 Challenges of aligning research with practice

Over 90% of PCTs use health workers to monitor child growth (Patterson et al. 2006). Any changes to growth monitoring practice, therefore, ought to consider the competing demands on health workers and the additional work created by such changes. Aligning research with practice without increasing the workload of health workers, and therefore losing their support for the study, presented a potential problem for P2PG. With this in mind, all changes to growth monitoring practice were discussed with the tPCT before being implemented. Arguably, the largest amount of work created for health
Discussion

workers arose from the collection of data for the reliability study, and this only included taking repeat measurements on five infants. Informal discussions with a number of health visitors made it apparent that additional work was generally not considered as a problem. There was, however, some negativity about being trained in anthropometry that some health workers had been using for many years. Also, despite efforts to reassure health workers that variability is an inherent part of the measurement process, some felt that they were being tested during the reliability study.

Growth monitoring data had not been extracted from System One for research purposes before and the tPCT were very cautious about making these data available to P2PG. Ethical approval was granted, research governance was approved by two separate institutions, and honorary employment contracts were awarded at both BTHT and the tPCT. The first datasets, which were extracted to assess data collection, were not allowed to be removed from the Child Health department, which limited the number of hours that could be spent using the data. After further discussion, subsequent data sets were allowed to be removed from Child Health, under the strict condition that all files were encrypted. Unfortunately, the tPCT email system flagged encrypted files as potentially dangerous, which meant data could not be shared via email. System One was not designed for the storage of research data and extracts needed considerable coding. Additional permission was needed to access the PCHRrs for data cleaning, and a poorly organised filing system meant that only 36% of raw data could be found. A considerable amount of time was spent collaborating with the tPCT to enable the use of growth monitoring data for this thesis. Even after resolving these challenges there were disputes regarding what the data were being used for and who should be co-authors on publications.

It also important to briefly note that P2PG also worked with various members of the BiB team and Information Services personnel at BRI to enable the use of data collected at birth. Access to these data was less restricted, although technical problems with eClipse meant that the date of extraction of data for P2PG was delayed. Gaining information about the data
trail for each variable (i.e. when it was collected, by who and how, and where was it recorded and stored) was the greatest challenge associated with using these data.

10.1.3 Growth monitoring data collection Vs. use
Throughout the current study there has been a conflict between the collection of growth monitoring data and its use, be it for research, feedback to practitioners, audit of performance, or public health surveillance. Growth monitoring data are routinely collected throughout the UK and the processes that allow the collection of these data, at least in Bradford, are well established. All parents receive PCHR S, health workers are employed to measure infants and children, and these data are sent to Child Health where personnel input them into System One. This is a process that operates continuously without any apparent problems. The NHS invest extensive resources in the process of growth monitoring (Department of Health and Social Security 1974), although the information rich data that result from this process are, for most part, not used. Prior to P2PG, growth monitoring data in Bradford had not been used for any purpose other than to identify poor growth. The P2PG has shown that growth monitoring data can be successfully used for research purposes, and to provide audit of performance and feedback to practitioners. It is important that commissioners of health policy fully understand the potential benefits of growth monitoring and invest not only in the collection of data but also in its use. The production of national standard protocol for the extraction of growth monitoring data would allow access to an invaluable source of data for research, and guidance to PCTs on the use of data would ultimately improve health care for the consumer. This is a fundamental argument that can be applied to all processes within the NHS, not just growth monitoring.

10.2 The growth of White British and Pakistani infants
Routine data collected at BRI provided details about the birth characteristics of our sample and the differences in size at birth between White British and Pakistani infants. When combined with growth monitoring data, MLMs were
applied to explain the differences in growth, from birth to nine months, between ethnic groups.

10.2.1 Birth characteristics and size at birth
There were marginally more boys than girls in the core analysis sample, with a male: female sex ratio of 1.05. This is the opposite to what was found in the 2001 UK census, which reported a ratio of 0.95 (Office for National Statistics 2009). When split by ethnicity, the sex ratios were approximately the same for both groups. The larger number of boys than girls in our sample was not because of a son preference among Pakistani parents, as has been reported in Pakistan (Khan & Sirageldin 1977; Winkvist & Akhtar 2000). More than half of our core sample consisted of Pakistani infants, and before this sample had been selected 45.1% of all infants in the extract from eClipse were Pakistani. This percentage is more than three times greater than the percentage (14.54%) of Bradford’s population who classified themselves as Pakistani in the 2001 UK census (Office for National Statistics 2008a). It is also nearly two times greater than the 2007 estimate of the percentage (24.1%) of Bradford’s Pakistani population that is less than 15 years old. Bradford’s Pakistani population are disproportionately contributing to the number of births at BRI; a quarter of the population are responsible for nearly half of the births. It is known that total fertility rates (TFR) for Pakistani populations are higher than those for western populations (Aziz 1994), and this phenomenon may contribute to the large proportion of infants in Bradford that are born to Pakistani parents. This is supported by the fact that the majority of White British infants in our core sample were born to first time mothers, whereas the majority of Pakistani infants were born to mothers with a parity of three or greater. The large number of Pakistani infants in Bradford will subsequently form a large proportion of the adult population, who are likely to have more offspring than the White British population. For these reasons, it is expected that Bradford’s Pakistani population will continue to grow.

The use of cut-off points recommended by the WHO (Williams et al. 1982), which were based on a source sample of largely White Californians, were
used to classify infants into size for gestational age categories. By definition ten percent of the sample should have been classified as SGA and ten percent should have been classified as LGA. Frequencies for the White British group were slightly smaller than the expected ten percent, whereas 17.3% of Pakistani infants were classified as SGA and only 3.2% were classified as LGA. Even more extreme percentages have been reported in an Indian population (Muthayya et al. 2006). There are no published data on the foetal growth of Pakistanis. There are some boundaries based on an Indian population (Ghosh et al. 1971), although known differences between the growth of Pakistani and Indian foetuses meant they were not used (Janjua et al. 2009; Yajnik et al. 2003). Stratifying the classification of birthweight by gestational age essentially controls for the effects of gestational age on birthweight. Our results suggest that the lower birthweight of Pakistani infants persists across the full range of gestational ages. Pakistani infants are not lighter than White British infants because of a shorter gestational period. This is supported by the fact that mean gestational age was approximately the same for both ethnic groups.

Kierans et al (2008) have argued the case for ethnic specific boundaries to classify size for gestational age, because when used there is a concordance between perinatal mortality and SGA which is not present when a single standard is used. Similarly, there is an ongoing discussion about whether ethnic specific growth references should be preferred over a single international growth standard (Cameron & Hawley 2009). Individuals grow very similarly in healthy environments (Graitcer & Gentry 1981; Habicht et al. 1974; Martorell 1985; WHO 1995) and inter-ethnic variability can thus be seen as a result of environmental assaults. Understanding this, if a researcher is using a growth chart or a set of boundaries to assess some aspect of health he/she could argue that they should not be ethnic specific. In practice, however, the use of single standard or set of boundaries may result in the percentage of individuals identified as SGA (or obese or underweight etc) to vary between ethnic groups and uneven sample sizes may become a statistical problem in some analyses.
The English IMD for 2007 (Noble et al. 2008) was used to quantify differences in SES between ethnic groups and to determine the effect it has on infant growth. Other publications have used the IMD in various areas of research, including demography and epidemiology (Gartner et al. 2008; Woods et al. 2005; Woolley et al. 2006). The IMD provides a relative ranking of LSOAs from one to 32,482, according to their level of deprivation. It, therefore, only provides information for an area and does not account for individual differences in deprivation within LSOAs. IMD is calculated using seven domain indices, which include income deprivation; employment deprivation; health deprivation and disability; education, skills, and training deprivation; barriers to housing and services; crime; and living environment deprivation. Ranks for each of these domains were not used as SES is not the main focus of this thesis. Sheppard et al (2009) have argued that indices of SES can be used to explain similar levels of variance in childhood anthropometry compared to multiple individual measures of SES. In Bradford, almost 30% of the LSOAs are among the 10% most deprived in England and out of 354 local authority districts Bradford is the 52nd most deprived (Noble et al. 2008). The average IMD for individuals in Bradford is 21029.26, which is considerably higher than the mean for our core sample which was 6786.43. The core sample of infants in this analysis were represented in 296 of the 307 LSOAs in Bradford, meaning that the sample did not under represent LSOAs with high IMD scores. It is, however, uncertain that the frequency of infants from high IMD scoring LSOAs was the same as that found in the general population. IMD, for our core sample, was positively skewed, and a median value for Bradford would allow a better comparison with our data. There were clear socio-economic inequalities between ethnic groups. Others have reported differences in SES between ethnic groups in England (Saxena et al. 2004; Saxena, Eliahoo & Majeed 2002), but no publications have demonstrated that Pakistani individuals are more socio-economically disadvantaged than White British individuals in the same city.

At birth, Pakistanis were consistently smaller than White British infants. The differences in mean birthweight between ethnic groups, for boys (236.2g)
Discussion

and girls (162.3g), were smaller than the expected 300g difference that has recently been reported in the MCS (Kelly et al. 2009). White British infants in our core sample were marginally lighter those in the MCS, whilst Pakistani infants were marginally heavier. The prevalence of LBW for each ethnic group were also smaller than those reported by the MCS. However, similarly to the MCS, the prevalence of LBW in Pakistani infants was approximately double that found in White British infants. The majority of Pakistani individuals in the MCS are second generation migrants (i.e. mother migrated to the UK) (Jayaweera et al. 2007), whereas the majority of Pakistani infants in BiB are third generation migrants (i.e. grandmother migrated to the UK) (Raynor & Born in Bradford Collaborative Group 2008). There may be a generational effect on birthweight, with third generation Pakistani infants in Bradford being heavier than second generation infants. A detailed comparison of the BiB cohort to the MCS cohort would enable researchers to understand the reasons for differences in birthweight and other variables, between the two cohorts.

Abdominal circumference (sexes combined) at birth was 1.12cm smaller for Pakistani infants compared to White British infants, whereas head circumference was only 0.49cm smaller. There are no comparable data for Pakistani infants in the UK. However, others have found larger differences in abdominal than head circumference between Indian and White British infants (Yajnik et al. 2003; Krishnaveni et al. 2005). The developmental origins of adult disease paradigm (Solomons 2009), which, among other things, proposes that constraint on foetal growth results in the preferential use of glucose for brain growth, provides an explanation for the relatively large head circumference and relatively small abdominal circumference of Pakistani infants in Bradford.

10.2.2 Growth from birth to nine months

Multilevel modelling analysis was limited to infants with a normal gestational age. The inclusion of infants who were either pre-term or post-term, and were therefore likely to demonstrate specific patterns of postnatal growth (Lejarraga 2002), would have made the results difficult to interpret and
generalise to the population. Larger numbers of preterm and post-term infants would have allowed the growth of these groups to be modelled separately (Fenton 2003; Rao, Tompkins & World Health Organization 2007). Term infants were significantly heavier at birth and had significantly larger head circumferences compared to the core analysis sample. Similarly, birthweight was significantly greater for the 520 infants included in the MLMs for length compared to the core analysis sample. The higher prevalence of preterm (3.6%, n=94) than post-term (1.1%, n=28) infants in the core analysis sample provides a likely explanation for these findings. Mongelli and Gardosi (1997) have also reported a greater prevalence of preterm than post-term in a sample of 34,249 infants in the UK.

The multilevel modelling approach allows random variation to occur between clusters (Goldstein 1989), which in this case were individuals. The process uses a probability function to essentially predict a regression equation and, therefore, a growth curve for each individual (Rabe-Hesketh & Skrondal 2008). This approach allowed us to investigate differences in growth between ethnic groups whilst controlling for individual differences. It also meant that growth curves could be produced using routine data, where infants had variable numbers of observations at different ages. The benefits of multilevel modelling have been well documented (Baxter-Jones & Mirwald 2004), and this approach is popular not only for growth modelling but also in other areas of research, including demography and more recently in the investigation of factors influencing physical activity level and nutrition (Besson et al. 2009; Gray & Leyland 2009; King 2008; Owen et al. 2009; Snelgrove, Pikhart & Stafford 2009).

Other techniques, including the LMS method and quantile regression have been used to model growth (Cole & Green 1992; Green & Silverman 1994; Koenker 2005; Wei et al. 2006). The LMS method imposes a structure to the growth curve and should be used with cross-sectional data, whereas quantile regression is a non-structural method which should be used with longitudinal data (Wei et al. 2006). Both approaches can be used to estimate selected quantiles of a distribution of any given dimension as a
function of age. Rather than only being able to describe the mean or median constant growth of a source sample, as is with multilevel modelling, these techniques allow the description of any chosen centile. They have been used in the production of growth reference and standard charts (Cole, Freeman & Preece 1998; WHO Multicentre Growth Reference Study Group 2006a), and BiB will ultimately use them to produce growth references. To address the aims of this thesis, these approaches are, however, unnecessary.

A preliminary analysis showed that, in general, the Reed 1st order MLM most accurately described the growth of White British girls. Simondon et al. (1992) have also reported that the Reed 1st order model provides the best fit for weight data during infancy. There were, however, some problems associated with the use of this model, because it is not defined at age zero. A transformation had to be used to shift the age scale. Too small of a transformation (age+0.001) meant that growth during the first few weeks was inaccurately modelled, whilst a transformation large enough to resolve this problem (age+1), as recommended by others (Simondon et al. 1992; Hauspie & Molinari 2004), increased the collinearity between covariates and risked model stability. In this case, Stata was actually unable to fit the models. Berkey et al (1989) have also found problems with collinearity using the Reed 1st order model when modelling adolescent height growth. A different age transformation of ‘age (in months) + nine/ nine’ has been recommended by Berkey and Reed (1987). However, Simondon et al (1992) have reported that this does not significantly alter the correlation between covariates. A procedure developed by Bock et al (1973), which corrects the between individual correlations with within individual error correlations, has been successfully used by Kouchi et al (1985) to resolve the collinearity problems associated with the Reed 1st order model. However, this procedure is complex, and increasing the amount of data available for modelling provides an easier solution (Simondon et al. 1992).

Stata was able to fit Reed 1st order models using the transformation ‘age+1’ to growth data for all infants, as opposed to data for sex and ethnic specific
groups. Final MLMs were used to produce sex and ethnic specific mean constant growth curves and to predict anthropometry for each individual at specified ages. The differences in size between ethnic groups as explained by the MLMs were similar to the differences in size between ethnic groups as explained using the predicted anthropometry. For example, the final MLM for weight explained that Pakistani infants were 232.7g lighter than White British infants at nine months of age, and using the predicted anthropometry the difference in mean weight between ethnic groups, at nine months of age, was 233.1g. This finding suggested that the random-effect parameters of the MLM were normally distributed, and this was confirmed with histograms (see Appendix V). If this were not the case, data could have been converted to Z-scores prior to modelling. MLMs were not applied to Z-scores, in the first instance, because data would have had to have been normalised using an external reference. This would have made the interpretation of the growth curves difficult, especially in the subsequent analysis where they were plotted against the UK90 references and WHO standards.

The final MLMs provided a good fit for the data. Mean monthly residuals were generally not more than the precision of the instrument for length (i.e. 0.5cm), two times the precision of the instrument for abdominal circumference and head circumference, and three times for weight. There are no published data to provide a comparison for these results. A paucity of data at ages between prescribed measurement periods meant that MLMs provided the worst fit for the data between three and seven months of age. More data within these months would have improved the fit of the growth models at all ages (Rabe-Hesketh & Skrondal 2008; Cole 2002). The BiB project is augmenting routine growth data with anthropometry at more frequent ages on a sample of 1000 infants. Unfortunately, these data were not available for this thesis.

The use of dummy variables in the MLMs made it possible to produce ethnic and sex specific growth curves. The intercepts of the mean constant growth curves varied by ethnic group and sex, whereas the coefficients only varied
by ethnic group and only for the WFA and ACFA growth curves. Weight and abdominal circumference can fluctuate due to minor changes in body composition and are more sensitive than skeletal dimensions such as length and head circumference (Lejarraga 2002). It is, therefore, possible for the socio-cultural, geographical, and nutritional factors common to Pakistanis, that are known to influence growth, to have a greater influence on WFA and ACFA growth compared to HCFA and LFA growth. It is also important to remember that South Asian infants are relatively long (Yajnik et al. 2003; Krishnaveni et al. 2005), which may explain why they do not demonstrate a different pattern of LFA growth compared to White British infants. Two publications (Bansal et al. 2008; Tate et al. 2006) have used Z-scores to demonstrate that South Asian infants in the UK demonstrate a different pattern of WFA growth compared to the UK90 references. We are not, however, aware of any publications that have demonstrated that the pattern of WFA and ACFA growth is different for Pakistani infants compared to White British infants in the same city.

The MLMs explained that Pakistani infants were consistently smaller than White British infants and that girls were consistently smaller than boys. Girls were 161.4g lighter and 1.42cm shorter than boys, and had abdominal and head circumferences that were 0.32cm and 0.78cm smaller, respectively. These figures are similar to the differences between the 50th centiles of the UK90 growth references for boys and girls, in the first nine months of life, which range from 151g to 618g for weight, 0.82cm to 1.66cm for length, and 0.66cm to 1.18cm for head circumference (Cole, Freeman & Preece 1998). There are no comparable data for abdominal circumference. The gender differences in size of the UK90 references increase throughout infancy. The dummy variables in our MLMs that would have allowed this to be the case for Bradford infants were not significant. Some publications have advocated controlling for the effects of sex because the literature suggests there should be a gender difference, even when it is not known whether sex is significantly associated with the outcome in the sample being studied (Griffiths et al. 2008; Jones et al. 2008). In this analysis, it was decided not to include the dummy coefficients for girl in the final MLMs, even when they
were insignificant, because their inclusion also made other covariates insignificant.

The differences in size between ethnic groups were larger than those found between sexes for weight and abdominal circumference, but not for head circumference and length. Again, this may be because weight and abdominal circumference are sensitive dimensions (Lejarraga 2002), which are likely to be more easily affected by environmental factors common to a particular ethnic group. We are unaware of any other publications that have reported that the difference in size between Pakistani and White British infants is larger than the differences between sexes. The MLMs explained that Pakistani infants were 0.32cm shorter than White British infants and had head circumferences that were 0.59cm smaller. Since the coefficients in the MLMs for weight and abdominal circumference varied for each ethnic group, the differences in size between White British and Pakistani infants were not consistent. Pakistani infants were anywhere between 210.3g and 321.7g lighter than White British infants, and had abdominal circumferences that were anywhere between 0.39cm and 1.15cm smaller than those for White British infants.

Tate et al (2006) have used data from the MCS to compare the size of White and Asian infants at nine months of age to the UK90 references. There was a 0.66 Z-score difference between these two ethnic groups, which equates to approximately 600g. This is more than double the difference of 232.7g which we found between White British and Pakistani infants at nine months of age. The MCS Asian sample will have included infants with origins in India, an ethnic group who are known to be small even compared to Pakistanis (Krishnaveni et al. 2005). This may partially explain the larger differences in weight, at nine months of age, between ethnic groups found by the MCS compared to this research.
10.3 Factors influencing infant growth

Multivariable linear regression models were built to investigate the factors that influence size at birth and at nine months of age. All outcome and predictor variables in these models were either routinely collected data or were derived from routine data. We were unable to adjust the models for other factors that are known to influence foetal and infant growth, but for which data is not routinely collected. For example, maternal size has long been known to be an important determinant of size at birth (Walton & Hammond 1938). Paternal size and maternal weight gain during pregnancy are also associated with size at birth (Hulsey et al. 2005; Miletic et al. 2007; Nahar, Mascie-Taylor & Begum 2007), following which the size of both parents contribute equally to infant weight gain (Griffiths, Dezateux & Cole 2007). Parental smoking status and nutrition, consanguinity, and other factors, including season and altitude have also been shown to influence growth (Gloria-Bottini et al. 2009; Ong et al. 2002; Pawson & Huicho 2009; Rao et al. 2001; Shami et al. 1991).

Without parental anthropometry it was not possible to determine whether Pakistani infants are small because their parents are small. Kelly et al (2009) have demonstrated that after adjusting for infant and maternal factors, including maternal height and pre-pregnancy weight, the difference in birthweight between White and Pakistani infants in the MCS decreased by approximately 50g. They do not, however, report the effect sizes of each predictor variable, making it impossible to understand their contribution to birthweight. The inclusion of parental anthropometry is likely to have improved the amount of variance that our regression models explained, therefore improving our understanding of the factors that influence size. Even without this information all adjusted regression models had medium to large effect sizes (Cohen 1992).

Sample sizes for the weight, abdominal circumference, and head circumference multivariable regression models were large enough to detect small effect sizes. The smallest adjusted R-squared value for these models
was 0.193, which indicates a medium effect size (Cohen 1992). Whereas, samples sizes for the length and BMI regression models only had sample sizes sufficient to detect medium effect sizes. The smallest adjusted R-squared value for these models was 0.313, which indicates a large effect size. Sample sizes were, therefore, large enough to detect the effect sizes that were found, at the specified level of power and significance.

10.3.1 Factors that influence size at birth
Adjusting for covariates in multivariable regression models meant that the differences in size at birth between ethnic groups increased for weight, but decreased for all other dimensions, relative to differences between ethnic groups found in univariable regression models. The difference in weight between White British and Pakistani infants increased from 200.5g in the unadjusted model to 301.3g in the adjusted model. Data from the MCS have been used to demonstrate that after adjusting for maternal and infant factors, including gender, gestational age, parity, and maternal anthropometry, Pakistani infants were 257g lighter than White infants (Kelly et al. 2009). Similarly, after adjusting for socio-economic factors, including annual household income, housing tenure, and highest educational qualification, the difference in birthweight between ethnic groups in the MCS was 234g. Even though predictor variables differed slightly, the adjusted regression models of both Kelly et al (2009) and ourselves explain similar differences in birthweight between White British and Pakistani infants. The most noticeable difference between the two studies is that adjusting for covariates in the MCS analysis decreased the difference in birthweight between ethnic groups by 41 or 72g, depending on what group of covariates were included in the model, whereas adjusting for covariates in our analysis increased the difference.

It was only when the interaction term ethnicity*IMD was added to the adjusted model that the difference in birthweight between ethnicities become approximately 100g larger than the difference that was found in the unadjusted model. White British infants in the first and second IMD tertiles were significantly lighter than White British infants in the third IMD tertile.
Whereas there were no significant differences between the mean birthweights of Pakistani infants in different IMD tertiles. It was White British infants in the third IMD tertile who had a noticeably different mean birthweight compared to the other groups (see Figure 8.1). Including the interaction term in the adjusted model accounted for the difference in weight between White British and Pakistani infants in the same IMD tertiles, which increased the ethnicity coefficient relative to that found in the unadjusted model. Kelly et al (2009) did not test for interactions between socio-economic factors and ethnicity, which explains the discrepancy between the results of the MCS and this study. It is generally accepted that birthweight is positively correlated with SES (Brooks-Gunn & Duncan 1997; Hirve & Ganatra 1994; O'Campo et al. 1997). We are unaware of any data that have shown that this association is present in White British infants but not in Pakistani infants. It is possible that this could be a chance finding because interactions, which are sub-group analyses, frequently fail to replicate in epidemiological studies. It is also possible that this interaction reflects the possibility that the major cause of lower birth weight is maternal smoking (Kramer 1998; Kramer et al. 1999) and smoking prevalence among Pakistani women in Bradford is low compared to White British women (Director of public health 2008). Therefore, one might not expect a SES-birthweight association in the Pakistani group but would expect an association in the White British group if mothers with low SES are more likely to smoke than those with higher SES.

The effects of ethnicity were larger than the effects of sex in the adjusted models for weight and abdominal circumference, but not in the models for head circumference and length. The MLMs demonstrated the same trend. After adjusting for covariates, the difference in length between ethnic groups was not significant and Pakistani infants were, in fact, 0.02cm longer than White British infants. It is generally accepted that South Asian infants are relatively long. Krishnaveni et al (2005) have demonstrated that there is no significant difference in crown-heel length between infant born in Mysore, India and infants born in Southampton, UK, after adjusting for gestational age. At three and 12 months of age, there is no significant difference in
length between South Asian and European infants (Bansal et al. 2008). We are, however, unaware of any publications that have shown that there is no significant difference in length, at birth or during infancy, between White British and Pakistani infants in the same city.

Sex was not included in the adjusted model for BMI at 12 days of age, because it was not a significant or borderline significant predictor variable in the unadjusted model. The rationale for BMI is that it is an index of weight that is uncorrelated with height or length. Researchers have used the same principle to calculate fat mass and abdominal circumference indices (Cameron et al. 2009; Wells et al. 2002). Understanding that sex was not a significant predictor of BMI, the difference in birthweight between sexes in our sample was a result of the difference in length (i.e. boys were only heavier than girls because they were longer). Similarly, the UK90 references explain that there is only a small sex difference in BMI at birth (Cole, Freeman & Preece 1998). The adjusted model explains that BMI was 0.359 kg/m² less for Pakistani infants compared to White British infants. Understanding that Pakistani infants were approximately 50 cm long at 12 days of age, it can be calculated that, after controlling for length, they are only approximately 100 g lighter than White British infants. The true difference in weight between ethnic groups is masked because Pakistani infants are long relative to other body dimensions.

10.3.2 Factors that influence size at nine months
Additional covariates in the multivariable regression models that investigated size at nine months of age included conditional anthropometry and feeding status at two months of age. White British infants demonstrated catch-up growth in weight, abdominal circumference, and head circumference, and catch-down growth in length and BMI. Interestingly, Pakistani infants demonstrated the opposite trend. The insult that causes poor foetal growth in Pakistanis is not removed with birth and/ or additional insults in the postnatal environment cause poor growth during infancy. Tate et al (2006) have used conditional weight gain between birth and nine months of age to show that Asian infants enrolled in the MCS demonstrated
catch-down growth (mean Z-score -0.25, SD 1.3), whereas White infants demonstrated catch-up growth (mean Z-score 0.26, SD 1.2). We are not unaware of any other studies that have reported similar findings in a Pakistani population and for other dimensions.

The majority of infants, for whom we had breastfeeding data, were being bottle-fed at two months of age. The prevalence of bottle feeding (63.2%) in our sample was approximately ten percent more than that reported by the nationally representative Infant Feeding Survey 2005 (IFS) at six weeks of age (Bolling et al. 2005). The prevalence of exclusive breastfeeding in our sample (22.9%) was similar to that reported in the IFS (21%), whereas the prevalence of partial breastfeeding was considerably less (13.9% and 27%, respectively). When split by ethnic group, twice as many Pakistani infants than White British infants were partially breastfed at two months of age. The IFS reported that all minority ethnic groups were more likely to breastfeed compared with white mothers (Bolling et al. 2005), however they did not report ethnic specific prevalence rates of exclusive and partial breastfeeding. Another national survey of infant feeding in Asian families reported that, although the prevalence of breastfeeding is initially high among Pakistani mothers, they stop breastfeeding sooner than White mothers (Thomas 1997). At four months of age, of those who started to breastfeed, 39% of White and 21% of Pakistani mothers were still at least partially breastfeeding (Thomas 1997). Our results provide novel information that Pakistani mothers are more likely to partially breastfeed than White British mothers at two months of age.

The amount of variance explained by multivariable regression models ranged from 93.9% in the model weight and 100.0% in the model for length. It is very rare to be able to explain these levels of variance. Cohen (1992) states that R-squared values above 0.259 indicate large effect sizes. The small age difference between the anthropometric predictor variables (i.e. size at birth and conditional anthropometry at two months) and the outcome variables (i.e. size at nine months) provides an explanation for the high levels of variance we were able to explain. Nevertheless, the models were
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double checked adding one covariate at a time. In the models for weight, abdominal circumference, and BMI it was the addition of conditional anthropology that contributed to the largest increase in the R-squared value, followed by the addition of anthropology at birth. Whereas, in the models for head circumference and length the opposite was found. It was the addition of anthropology at birth that contributed to the largest increase in the R-squared value, followed by the addition of conditional anthropology. Length and head circumference are more stable dimensions than weight, abdominal circumference, and BMI and exhibit less variance at all ages (Lejarraga 2002; Cole, Freeman & Preece 1998). Growth in length and head circumference is, therefore, likely to be more similar between infants than growth in any of the other dimensions. This may explain why a measure of size rather than growth explained the most variance in the models for length and head circumference, and a measure of growth rather than size explained the most variance in the models for weight and abdominal circumference.

The unadjusted regression models showed that, at nine months of age, Pakistani infants were smaller than White British infants for all dimensions and approximately to the same extent as the differences that were found at birth. This finding was consistent with the growth curves. Ethnicity was not a significant or borderline significant predictor variable in the unadjusted models for length and BMI. It was expected that Pakistani infants would be relatively long at nine months (Yajnik et al. 2003). We did not, however, expect there to be no significant difference in BMI between the two ethnic groups, especially considering that the unadjusted models showed significant differences in weight but not length between ethnic groups. After controlling for the confounding effects of length, there was no significant difference in weight between Pakistani and White British infants at nine months of age. We are unaware of any studies with similar findings. A larger sample size would have increased the power to detect statistically significant differences in BMI (Cohen 1992).
Adjusting for covariates in multivariable regression models meant that weight and abdominal circumference were actually larger for Pakistani infants than for White British infants (110.6g and 0.36cm, respectively), and that mean head circumference was approximately the same for both ethnic groups. The models adjusted for the fact that, for these dimensions, Pakistani infants were small at birth and demonstrated catch-down growth in the first two months of life, compared to White British infants who were larger at birth and demonstrated catch-up growth. Considering this, a Pakistani infant who is born smaller than a White British infant, and who demonstrates less growth in the first two months of life, may grow to be the same size as the White British infant at nine months of age. This finding is important in understanding the timing of the insult that is responsible for poor growth in Pakistani infants in the UK. The differences in mean birthweight and conditional weight at two months of age between ethnic groups were entered back into the appropriate regression equation to calculate the difference in weight between White British and Pakistani infants at nine months of age. This was also done for abdominal circumference and head circumference. As expected, the resulting figures were similar to the differences found between ethnic groups in the adjusted models at birth. The effects of ethnicity were only larger than the effects of sex in the model for abdominal circumference. It appears that the abdominal circumference growth of Pakistani infants suffers more than that of other dimensions. This has been previously been reported in a sample of infants in India (Yajnik et al. 2003; Krishnaveni et al. 2005), but not in Pakistani infants.

Various publications have demonstrated that infants and children grow very similarly when their environments support healthy development and provide appropriate nutrition (Graitcer & Gentry 1981; Habicht et al. 1974; Martorell 1985; WHO 1995). Inter-ethnic variability in growth can, therefore, be seen as a result of environmental assaults. This is demonstrated in the WHO standards, where the source sample of infants from six widely different ethnic and cultural countries, who were raised in healthy environments and followed a recommended feeding practice, demonstrated strikingly similar
patterns of growth (WHO Multicentre Growth Reference Study Group 2006c). Is was not until prior size and growth were adjusted for in our multivariable regression models that the inequalities in weight, abdominal circumference, and head circumference between Pakistani and White British infants were largely removed. We were unable to demonstrate that infants from both ethnic groups were of similar sizes at nine months of age after controlling for only birth characteristics and environmental factors. The incorporation of more environmental factors into our models, such as individual level measures of SES and parental smoking status, may have made this possible. Of the environmental factors we had, feeding status was only significant in the adjusted model for abdominal circumference and IMD was only borderline significant in the adjusted model for length.

The inclusion of anthropometry at birth and conditional anthropometry at two months of age in regression models made the interpretation of differences in size between ethnic groups slightly complicated, but did mean that we were able to explain very large levels of variance. It is possible to use routine data collected in the first two months of life to predict size at nine months. These models could be developed and extended into childhood, at ages where the early onset of obesity begins, to produce estimation equations to identify infants who are at risk of developing obesity. De Onis et al (2004, pp.25) have similarly proposed that “velocity references will enable the early identification of children in the process of becoming under- or overnourished”. The development of a tool for practitioners to screen for infants who are at risk of obesity could be developed with the use of routine data.

10.4 Implications of adopting the WHO standards in the UK

Growth in weight of infants differed significantly from that represented by the WHO standards. White British infants had birthweights that were approximately 0.2 Z-scores greater than the WHO standards median, and Pakistani infants had birthweights that were approximately 0.2 Z-scores smaller. Intrauterine growth of infants from India and Oman in the MGRS
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was constrained (WHO Multicentre Growth Reference Study Group 2006d), which may have resulted in a lower mean birthweight of the MGRS cohort compared to that for White British infants in the current study. Both White British and Pakistani infants lost approximately 0.5 Z-scores between birth and two months, and then gained 0.7 Z-scores between two and nine months. It is highly unlikely that both the White British and Pakistani infants are actually demonstrating growth faltering during the first two months or catch-up growth during the next seven months (Ong et al. 2000), but the WHO standards imply that this is the case, making interpretation of the actual growth patterns problematical for both researchers and practitioners. The reason for this pattern is to be found in the differences between the WHO source sample and ‘normal’ Bradford infants who have not been selected on the basis of high SES and adherence to the WHO feeding regime (Cameron & Hawley 2009). The WHO standards allow for normal neonatal weight loss (WHO Multicentre Growth Reference Study Group 2006d), and the apparent failure to thrive of infants in the first two months of life is not simply a transient physiological weight loss. Wright et al (2008) have reported that this weight loss of UK infants, relative to the WHO standards, suggests that LBW babies in the MGRS showed rapid growth in the first two months of life. The catch-up growth from two months onwards in BiB infants is most likely to be due to the fact that the WHO infants are on a feeding regime that does not promote rapid weight gain and thus risk of overweight and obesity (Garza & de Onis 2004). So whilst the WHO standards do not represent the ‘normal’ WFA growth of Bradford infants they do represent ‘optimum’ growth, which indeed is what they were designed to do.

Only one study, other than the current one, has used quantitative analyses to address the implications of adopting the WHO standards for growth monitoring practice in the UK, although various publications have debated whether their use is appropriate (Cameron & Hawley 2009; Cameron 2009; Cole 2008). Wright et al (2008) compared the growth of infants in the ALSPAC and the Gateshead Millennium Baby Study (GMBS) to the UK90 references and WHO standards. The pattern of WFA growth demonstrated
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by the ALSPAC and GMBS infants, relative to the WHO standards, was similar to the pattern demonstrated by Bradford infants. Both cohorts had higher birthweights compared to the WHO median (mean Z-scores: ALSPAC 0.34, GMBS 0.17), similar weights at four months of age (mean Z-scores: ALSPAC -0.07, GMBS 0.01), and larger weights thereafter (mean Z-scores at eight months: ALSPAC 0.46, GMBS 0.49). The figures for White British infants (sexes combined) in our sample, at the same ages, were very similar (mean Z-scores: 0.21, 0.07, and 0.45). Our results showed a lower minimum Z-score for White British infants at two months of age (-0.35) compared to the figure for GMBS infants at the same age (-0.17); there were no data for ALSPAC infants at this age. Our results suggest a greater degree of failure to thrive in the first two months of life, and therefore a greater degree of catch-up growth compared to the results reported by Wright et al (2008).

Wright et al (2008) also reported that risk for being classified as underweight was significantly lower according to the WHO standards than the UK90 references at eight, 12, and 18 months of age. Risk for poor infant weight gain between birth and 12 months of age was also significantly lower, whereas risk for obesity was significantly higher at various ages during infancy and early childhood. Most noticeably, at one year of age infants were approximately three times more likely to be classified as obese according to the WHO standards than the UK90 references. For reasons not known to us, Wright et al (2008) chose to report the RR for obesity at four to five years of age in the text of their paper, which was only marginally higher according to the WHO standards than the UK90 references. Our results showed a similar trend although RRs were generally not as extreme. For example, the risk of poor infant weight gain, from birth to 12 months, for ALSPAC and GMBS infants was 0.24 (95% CI 0.16 to 0.36), whereas the risk for Bradford infants was 0.783 (95% CI 0.644 to 0.952). Our RRs for obesity were also not significant. Between birth and 24 months of age the WHO standards are based on longitudinal data. Our analysis correctly compared like with like, whereas Wright et al (2008) compared cross-sectional data with the longitudinal standards. Longitudinal data tends to
exhibit less variation than cross-sectional data (Cameron & Hawley 2009). Cross-sectional data for ALSAC and GMBS infants were, therefore, more likely to be extreme in comparison to longitudinal data for Bradford infants when compared to the WHO standards. The RRs for underweight, poor infant weight gain, and obesity given in this thesis are likely to be more accurate than those reported by Wright et al (2008).

The WHO standards were constructed using data from a source sample of infants who were exclusively or predominately breastfed for the first four months of life. Infant feeding data were not available for all term infants in our analysis sample, and infants with data had a variable number of recordings at variable ages. We were only able to identify 214 term infants who were exclusively or partially breastfed for more than four months. Given the problems we experienced of not being able to fit Reed 1st order MLMs in Stata for small sample sizes, it would not have been possible to produce growth curves for the 214 infants who followed a similar feeding regime to those in the WHO source sample. Appendix VII provides figures of the mean Z-scores, relative to the UK90 references and WHO standards, for the 1119 infants with infant feeding data at two months of age, split into exclusively breastfed, partially breastfed, and bottle-fed groups. The patterns of growth were similar to those found in the main analysis. There was a clear pattern of slower growth among exclusively breastfed infants and more rapid growth among bottle-fed infants. One way ANOVAs with Bonferroni post hoc multiple comparisons showed no significant differences between the Z-scores for different feeding status groups. The pattern of growth of breastfed, and even partially breast-fed, infants differs from that of bottle-fed infants, and this phenomenon is well established (Gunnarsdottir et al. 2009; Hindmarsh et al. 2008; Kramer et al. 2002; Ong et al. 2002). No study has investigated whether the WHO standards accurately represent the growth of infants and children in the UK, who have the same defining characteristics as the WHO source sample (i.e. exclusively or predominately breastfed and living in an unconstrained environment). This information is necessary to determine whether their use as a standard in the UK is appropriate.
Given the short time since publication of the WHO standards, it is not surprising that few studies have used them to assess growth. Published comparisons are only available from studies in four countries, consisting of the UK (Wright et al. 2008), Belgium (Roelants, Hauspie & Hoppenbrouwers 2009), South Africa (Norris et al. 2009), and India (Prinja, Thakur & Bhatia 2009). Belgian infants were born 0.25 Z-scores above the WHO standards median, but were then below the median between four weeks and 18 months of age. South African infants demonstrated the same rapid growth in the first year of life as seen in White British infants, but after one year of age had mean WFA Z-scores that were consistently below the WHO median. The Indian study reported a significantly greater prevalence of underweight using the WHO standards compared to the currently recommended Indian national references (Nutrition Sub-Committee of the Indian Academy of Paediatrics 1972). Health policy commissioners for most countries do not have adequate information to assess the implication of adopting the WHO standards to assess the growth of infants and children within their country. The UK is the only country that had adopted the standards for routine practice, and is therefore at the forefront of the campaign to establish the breastfed infant as the normative feeding model. There has, however, been some concern that the WHO standards were adopted for use in the UK without being piloted and without sufficient training of practitioners (Fry 2009), which were two recommendations of the SACN and the RCPCH (2007).

Our results showed that the WFA growth differed significantly from that represented by the WHO standards. ‘Normal’ infants demonstrated a complex pattern of growth, characterised by failure to thrive in the first few months of life, followed by catch-up growth. This finding is particularly important because the new UK-WHO charts will be used by practitioners to assess the growth of all infants in the UK, the majority of which, like Bradford infants, will not be exclusively breastfed and may have health, environmental, and economic constraints on growth. For example, unlike the MGRS infants, an infant in the UK may live in an area characterised by high levels of morbidity, have a mother who smokes, and have parents with
relatively little education and income. The new charts in the UK also combine references with standards as if they both respond to the same question (Cameron & Hawley 2009). The preterm element should be used to determine whether growth is normal compared to a reference population, whereas between two weeks and four years of age the charts should be used to determine whether growth is optimal compared to that of infants and children living in an unconstrained environment. These complexities mean that practitioners may incorrectly interpret infant and child growth if they do not receive adequate training, which will necessarily limit the DoH aspirations for the charts.

10.5 Future research

During the process of completing this PhD a number of further research questions were raised, but were not explored due to the nature of the data and/ or time restrictions. Therefore, the following comments relate to potential future research projects.

- We are unaware of any studies that have used abdominal circumference and head circumference indices to investigate differences in size between South Asian and White British infants. The use of indices would allow for the difference in size between ethnic groups to be determined, after controlling for the confounding effects of length. This is particularly important considering that South Asian infants are relatively long.

- The current study only produced growth distance curves from birth to nine months of age. These growth curves need to be extended to describe the growth of Pakistanis later in infancy and in childhood. A natural extension would also be to produce growth velocity curves, thus identifying the pattern of changing rates of growth.

- There are no growth charts of Pakistani infants in the UK. There is potential to apply LMS and quantile regression analyses to BiB data
to model selected quantiles of a distribution of any given dimension as a function of age.

- Research has demonstrated that other covariates, that were not available for this thesis (i.e. parental size), are important determinants of growth. Multivariable regression models that control for more covariates that are known to influence growth would improve our understanding of why Pakistani infants are small compared to White British infants and inform interventions to reduce growth and health inequalities in this ethnic group.

- There is a need to develop multivariable regression models to investigate the factors that influence size during childhood, at ages where the early onset of obesity begins. There is an opportunity to use routine data to develop estimation equations, which could be incorporated into a simple tool for practitioners to use to screen for children who are at risk of obesity.

- No study has investigated whether the WHO standards accurately represent the growth of infants and children in the UK, who have the same defining characteristics as the WHO source sample (i.e. exclusively or predominately breastfed infants living in an unconstrained environment). This information is necessary to determine whether their use as a standard for growth monitoring practice in the UK is appropriate.

- Growth monitoring is a well established process within the NHS, although the information rich data that result from this process are largely unutilised. The production of national standard protocol for the extraction of growth monitoring data would allow access to an invaluable source of data for research.
11 Conclusions
11.1 Key findings

This thesis developed and utilised routine infant growth monitoring data. Many of the key findings, which are listed below, are novel and add to the literature regarding the growth of Pakistani and White British infants in the UK.

- The majority of infant growth monitoring data were not collected at prescribed age periods. In general, only 30% of eligible infants were measured for any given dimension within any one routinely prescribed age period. Child Health could regularly produce performance related information to provide audit and quality assurance for the tPCT.

- Growth monitoring data were found to be reliable after an anthropometric training intervention, with mean TEMs that were comparable to published results from research studies and coefficients of reliability that ranged from 0.96 to 1.00. The commissioning of routine reliability assessments has been recommended to the tPCT to provide regular anthropometric training for health workers.

- Pakistani infants were consistently smaller than White British infants between birth and nine months of age. MLMs explained that Pakistani infants were between 210.3g and 321.7g lighter than White British, had abdominal circumferences that were between 0.39cm and 1.15cm smaller, had head circumferences that were 0.59cm smaller, and were 0.32cm shorter.

- The shape of the growth curves did not vary between sexes for any of the dimensions, but did vary between White British and Pakistani infants for weight and abdominal circumference. The difference in size between ethnic groups was also larger than the differences between sexes for these dimensions. For example, girls were 161.4g lighter than boys between birth and nine months, but Pakistani infants were always more than 210.3g lighter than White British infants.
• Adjusting for covariates in multivariable regression models meant that the differences in birthweight between White British and Pakistani infants increased from 200.5g to 301.3g. An interaction between ethnicity and IMD also showed that the lower birthweight of Pakistani infants persisted across the full range of SES.

• Pakistani infants were not significantly shorter than White British infants at birth (adjusted model) or at nine months of age (unadjusted model). This finding that Pakistani infants were relatively long is consistent with the thin-fat phenotype that had been reported in Indian infants.

• Multivariable regression models explained between 93.9% and 100.0% of the variance in weight, abdominal circumference, head circumference, length, and BMI at nine months of age. There is an opportunity to extend these models into childhood and develop predictions equations to identify infants who are at risk of developing obesity.

• Growth in weight of infants differed significantly from that represented by the WHO standards. Both White British and Pakistani infants lost approximately 0.5 Z-scores between birth and two months and then gained 0.7 Z-scores between two and nine months. This, and other complexities of the UK-WHO charts, means that practitioners may incorrectly interpret infant growth if they do not receive adequate training.

• By the WHO standards, infants were significantly less likely to be classified as underweight at birth (RR 0.496; 95% CI 0.363 to 0.678) and six to nine months, compared with the UK90 references. Infants were also significantly less likely to be classified as demonstrating poor infant weight gain between birth and nine months of age according to the WHO standards (RR 0.783; 95% CI 0.644 to 0.952).
11.2 Concluding remarks

The aims of this thesis were related to the utilisation of routine growth monitoring data to investigate the growth of White British and Pakistani infants. Various changes have been introduced to growth monitoring practice, which have helped develop routinely collected data to research calibre. Growth monitoring practice in Bradford has been aligned with research and, we believe, should be recognised as a national exemplar. The P2PG study has shown that growth monitoring data can be extracted from NHS databases and used to answer important questions about infant growth. Despite efforts, the determinants of the small size of Pakistani infants have not yet been fully elucidated, and it is questionable whether boundaries based on western populations are appropriate to assess their growth; identify underweight, poor infant weight gain, and obesity; and categorise them into size for gestational age groups. More research is needed to determine whether the same degree of growth constraint results in the same disease risk for both White British and Pakistani infants. Infant growth in weight differed significantly from that represented by the WHO standards. The low rates of exclusive breastfeeding in the UK and perhaps the variation in socio-economic conditions within which infants live may lead to the wrong interpretation of the growth of ‘normal’ infants unless practitioners receive adequate training. The UK-WHO growth charts are, however, an important vehicle for the public health message of the benefits of exclusive breastfeeding. The alliances made between P2PG, the tPCT, and practitioners across the city means there is scope not only to continue research into the implications and impact of adopting the WHO standards, but also to address other unanswered questions about infant growth and health.
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Appendix I: Mother’s consent form

MOTHER’S CONSENT FORM
A copy of this consent form will be retained in your hospital case notes

Please initial box
I confirm I have read and understood the information sheet dated 25th July 2006 and have had the opportunity to ask questions

I understand that my participation and that of my child is voluntary and that we are free to withdraw at any time, without giving any reason, without our medical care or legal rights being affected

I agree to take part in the above study

I understand that sections of any of my medical records may be looked at by researchers working for the Born in Bradford project, researchers working on ethically approved linked studies or from appropriate authorities where their involvement is relevant to my taking part in research. I give permission for these individuals to have access to my notes

I understand that my child’s details may be passed onto the ethically approved NHS central register and that this will require the permission of the local Data Advisory Group

I agree to give a blood sample for use in the above study. I understand this sample will be used by the Born in Bradford team and their research partners both in the UK and overseas. I understand I will not be given the results on the blood samples

I agree to a blood sample being taken from my baby’s umbilical cord after delivery. I understand this sample will be used by the Born in Bradford team and their research partners both in the UK and overseas. I understand I will not be given the results on the blood samples

I understand this blood sample will be stored indefinitely and may be used by the Born in Bradford team and their research partners in the UK and overseas in the future.

Name of participant date signature

Name of person taking consent date signature
(if different from researcher)

Researcher date signature
Appendix II: Measurement protocol

Measurement Protocol

*What measurement technique allows you to produce exactly the same result time and time again?*

This document provides clear guidance on how to collect anthropometric measurements on infants, children, and mothers. It is important that you follow the same procedures each time you take a measurement, and that all health visitors use the same techniques. By following these guidelines, and through practice, errors will be dramatically reduced and the results will be more accurate.

6 Key points

- Be confident when taking measurements as the subject will tend to pull away and be more apprehensive if you appear hesitant.
- When measuring children it is important to familiarise the mothers with the instrumentation and to talk them through the procedure to make them feel at ease.
- The participant should be wearing a minimum of clothing or clothing that does not prevent accurate measurement. Where possible suggest that infants (0-2 years old) are measured naked.
- All measurement should be taken on the left hand side of the body.
- Record each measurement to the last completed unit.
- If you are unhappy with the measurement take it again. The acceptable differences between repeat recordings are given for each measurement.

Weight

*Acceptable difference between repeat measurements: 0.2kg*

Infants should be weighed naked, and children and mothers in a minimum of clothing (i.e. no outdoor coats, heavy jumpers, shoes etc). Whether recording the weight of a one week old baby or a 40 year old women it is
important to wait until the participant is still so an accurate measurement can be recorded.

**Supine length**

*Acceptable difference between repeat measurements: 1.0cm*

This measurement requires two people.

- Firstly lay the infant down in his/her back on the neonatometer.
- Ask the mother to hold the infants head against the fixed head board so the infant is looking directly upwards at the mothers face.
- Hold the ankles at right angles, so the toes are pointing directly upwards.
- Then straighten the legs by pressing down gently on the knees with your forearms.
- Bring the moveable foot board up to the heels.
- Apply slight pressure to the ankle to straighten the legs even more.
- Check the mother still has the head in the right position. It may also be necessary for the mother to hold down the shoulders.
- Record the measurement.

Notes: If you have problems keeping the infant still concentrate on straightening just one leg to take the measurement.

**Standing height**

*Acceptable difference between repeat measurements: 1.5cm*

Height should be measured using a Leicester heightometer.

- The participant should remove shoes and socks and heavy outdoor clothing.
- Ask the participant to stand upright such that the buttocks and shoulders are touching the backboard.
- Next make sure the participant is looking directly forwards so that you could draw an imaginary horizontal line from the centre of the ear through the lower boarder of the eye socket.
- Bring the head board down to rest on the head, compressing the hair.
- Record the measurement.

**Head circumference**

*Acceptable difference between repeat measurements: 0.5cm*

When recording this measurement on infants you will need them to sit on their mothers lap facing to the right hand side of the mother (i.e. so their left hand side is closest to you). It may also be necessary to kneel down so you
are at a similar height to the infant. Also ask the mother to talk to the child and distract them if they attempt to remove the tape.

- First, place the tape around the head.
- Using the index fingers on each hand position the tape so that it crosses the most anterior part of the head (midway between the eyebrows and the hair line) and the most posterior part of head (occipital prominence).
- Pull the tape tight to compress hair and record the measurement.

**Abdominal circumference**

*Acceptable difference between repeat measurements: 1.0cm*

When recording this measurement on infants you will need them to be lying down with their hands away from their body. You may also need the mother to lift the infant so you can slip the tape measure underneath them.

- First, pass the tape around the body.
- Ensure that the measurement is taken at the level of the umbilicus (belly button).
- Make sure the tape is horizontal and not compressing soft tissue.
- Finally, record the measurement.

**Skinfold measurements**

Skinfold callipers record a measure of subcutaneous fat. The thumb and middle finger on the left hand are used to sweep together the fold, whilst the right hand is used to operate the callipers. The aim is to apply the callipers to the ‘neck’ of the fold just below your thumb and middle finger. After applying the callipers count to three and then record the measurement. It is important to ensure the participant (and in the case of infants the mother) that the skinfold will not cause any pain and. Also make sure that participant are not wearing any clothes that may interfere with the measurement.
Triceps skinfold

*Acceptable difference between repeat measurements: 2mm*

- With the arm bent at right angles locate the midpoint between the elbow and the shoulder and make a mark with a washable pen.
- Sweep together the fold of fat at the back of the arm.
- Still holding the fold, straighten the arm and take the measurement.

Subscapular skinfold

*Acceptable difference between repeat measurements: 3mm*

- Locate the lowest part of the shoulder blade (i.e. inferior angle of the scapular).
- You will notice that the fold of fat runs diagonally downwards and outwards, in line with the ribs.
- Sweep weep together the fold, apply the callipers, and record the measurement.
GROWTH MONITORING STANDARD

The growth rate of an individual is an important indicator of general health. Growth monitoring is therefore an important tool to screen for diseases and health related problems. Routine growth monitoring is a standard component of community and child health services in the United Kingdom. Growth monitoring involves individuals being regularly measured, these data being plotted on growth reference charts, and where growth is unfavourable, the health worker referring the individual to an appropriate specialist. Growth monitoring can identify individuals who demonstrate unfavourable growth and in extreme cases individuals with growth disorders, such as:

- Hypothyroidism
- Microcephaly
- Turner’s syndrome
- Growth hormone insufficiency
- Marfan’s syndrome
- Thyrotoxicosis
- Dysmorphic syndrome

FOR BORN IN BRADFORD
Any measurements taken in addition to routine data needs to be documented on the carbon copy sheets, which are attached to the centile charts in the Personal Child Health Records (PCHR). These additional measurements make an important contribution to the Born in Bradford project, and we would be grateful if they were returned to Child Health at 6 months, 18 months, and 3 years of age.

KEY POINTS
To maximise the potential for growth monitoring, and to ensure measurements are accurate, the following should be adhered to:

- It is imperative the same procedure is followed every time a measurement is taken.
- Be confident when taking measurements as the child will tend to pull away and be more apprehensive if you appear hesitant.
- When measuring children it is important to familiarise the mothers with the procedure and talk them through what is going to happen to make them feel at ease.
The participant should be wearing a minimum of clothing or clothing that does not prevent accurate measurement.

Record each measurement to the last completed unit. For example, neonatometers measure to the precision of 0.5cm. If a child’s length was between 50cm and 50.5cm, but closer to 50.5cm, the last completed unit would be 50cm.

If you are unhappy with the measurements take it again.

Always complete the relevant review form in the PCHR and return to Child Health as soon as possible.

RECORDING AND PLOTTING DATA ON GROWTH REFERENCE CHARTS

It is essential health visiting team members record and plot data they collect accurately. If this is not achieved the growth of an individual may be misreported on the growth reference charts, and then misinterpreted by the team member. To ensure all data is recorded and plotted accurately team members should:

- After completing a measurement record the result in the PCHR straight away.
- Plot the result on the appropriate growth reference chart with a well defined dot.
- If you want to join dots together to produce a growth curve, make sure to leave the dots clearly visible. This may be useful to demonstrate a child who is dropping through the centile lines.
- Where there are vulnerable children, children on the child protection register, or parental/professional concerns regarding a child an additional centile chart should be maintained within the health visiting records.
- If an infant was born pre-term remember to adjust for this on the growth reference charts. When the infant is one year old there is no longer the need to adjust for gestational age.

WHEN TO SEEK GUIDANCE OR REFER

Normal variation within a population is expected. An individual who is below the 0.4th, or above the 99.6th, centile for any given measurement is not necessarily demonstrating unfavourable growth. An individual with weight measurements that approximate the 0.4th centile may be growing along the correct, genetically predetermined growth canal. There is only cause for worry when infants, and children are not growing i.e. they decline through the centiles on a growth chart. Using your professional judgement, it is then appropriate to either give advice, seek advice, or refer to an appropriate specialist.

WEIGHT

Rationale

An individuals weight is an indicator of total body growth i.e. growth of lean body mass and fat. A change in weight does not tell us what tissue is being infected, but it does inform us that a health problem is present. Weight is a very sensitive measure, in the sense that it can change from one day to
another due to very minor alterations of body composition. For example, the changes seen in infants due to a common cold. An infant's weight may, therefore, be the first measure to stop increasing, or decline, as the result of a health problem. When paired with length, weight measurements can also be used to screen for wasting (low weight for height).

Opportunities may arise to weigh infants at every contact. Weighing too regularly (once a week) can cause increased parental anxiety and should therefore be discouraged. Your professional judgement can be used to determine if parents are anxious because of weighing too regularly.

**Best practice indicators**
- Make sure the scale is calibrated. This should be done at least once a year.
- Place scales on a firm, flat surface in a warm room.
- Infants must be weighed naked.
- Wait until the infant is still before the weight is recorded.
- Those infants who do not lie still in a basin scale can be weighed in the arms of an adult and the adult's weight then deducted.

**Evidence of best practice**
- If weight is recorded twice on an infant the difference between the two weights should not be more than 200g.
- All measurements are obtained at prescribed ages and documented appropriately.
- Review sheets are submitted to Child Health immediately.

**Measurement frequency for Born in Bradford babies**
10 to 14 days, 6 to 8 weeks, and 7 to 9 months.

**Equipment**
Use EU approved – 90/384/EEC – Class III or IIII scales. Ensure all scales are regularly calibrated (If scales were purchased prior to December 31st 2002 and are still regularly calibrated, the European Union Directive 90/384/EEC allows its continued use).

**SUPINE LENGTH**

**Rationale**
Length is an important indicator of total body mass, and accurately indicates the length of long bones of the lower limbs and the irregular bones of the vertebral column. When growth in length is impaired, it can be assumed that an important health problem is present. When paired with weight, length can be used to screen for wasting (low weight for height).

**Best practice indicators**
If the child can stand independently then follow the standing height protocol.
- Ensure the neonatometer is on a firm flat surface, and place a piece of paper towel down before measuring each infant.
Appendix III: Growth monitoring standard

- Lay the infant down on his/her back on the neonatometer.
- Ask the parent to hold the infant’s head against the fixed head board so the infant is looking directly upwards into the mother’s face.
- Straighten the legs by pressing down on the knees with your forearm.
- Hold the ankles at right angles so the toes are pointing directly upwards.
- The footboard can now be brought into contact with both heels.
- Apply slight pressure to the ankles to straighten the legs even more.
- Check the mother still has the infant’s head in the correct position, and record the measurement.
- It may be necessary for the parent to hold down the shoulders.
- If the infant becomes restless ask the parent to distract the child’s attention from the measurement procedure by talking to them.

**Evidence of best practice**

- Correct neonatometers are used and cleaned after use.
- If length is recorded twice on one infant the difference between the two lengths should not be more than 1.0 cm.
- All measurements are obtained at prescribed ages and documented appropriately.
- Review sheets are submitted to Child Health immediately.

**Measurement frequency for Born in Bradford babies**

10 to 14 days, 6 to 8 weeks, and 7 to 9 months.

**Equipment**

- Pedobaby (Incubator), Rollameter, Measure Mat. Kiddimeter, Dunmow (for disabled children over 1m).

**ABDOMINAL CIRCUMFERENCE**

**Rationale**

Waist circumference is recommended as an independent measure of central fat. Abdominal fat is more labile than fat found elsewhere, which increases risk for various diseases including type 2 diabetes and cardiovascular disease. Abdominal circumference has consistently been shown to be the better of the hip and waist circumference pairing and is easier to measure.

**Best practice indicators**

- When recording this measurement on infants you will need them to be lying down with their hands away from their body.
- Clothing around the abdomen needs to be removed.
- Pass the tape around the body.
- Make sure the tape is horizontal and not compressing soft tissue.
- Finally, record the measurement at the level of the umbilicus.
- If possible, take the measurement midway between inspiration and expiration.
- If an infant presents with a umbilical hernia record the measurement above or below the hernia, and document appropriately.
Evidence of best practice
- The tape measures provided by Born in Bradford are best for this measurement and should be used, and cleaned regularly.
- If abdominal circumference is recorded twice on one child the difference between measurements should not be more than 1.0cm.
- All measurements are obtained immediately at prescribed ages and documented appropriately.
- Review sheets are submitted to Child Health immediately.

Measurement frequency for Born in Bradford babies
10 to 14 days, 6 to 8 weeks, and 7 to 9 months.

Equipment
Tape measures (Harlow Health Care, London, UK).

HEAD CIRCUMFERENCE
Rationale
Head growth is the expression of the growth of the brain, and its measurement is very important. Head circumference increase relatively faster than weight and height in early years. Because of this early rapid growth, head circumference is more likely to be affected by malnutrition or disease. During the first months of life it can be used to detect congenital microcephaly, and excess growth due to hydrocephaly.

Best practice indicators
- First, place the lasso around the head
- Using the index fingers on each hand position the tape so that it crosses the most anterior part of the head (midway between the eyebrows and the hair line) and the most posterior part of head (occipital prominence)
- Pull the tape tight to compress hair and record the measurement

Evidence of best practice
- Head lassos provided by Born in Bradford are best for this measurement and, should be used and cleaned regularly.
- The measurement protocol is followed consistently.
- If head circumference is recorded twice on one child the difference between measurements should not be more than 0.5cm.
- All measurements are obtained at prescribed ages and documented appropriately.
- Review sheets are submitted to Child Health immediately.

Measurement frequency for Born in Bradford babies
10 to 14 days, 6 to 8 weeks, and 7 to 9 months.

Equipment
Lassos (Harlow Health Care, London, UK).
Appendix IV: Data cleaning report

Birth Data

± two standard deviation check

Baby NHS number 64******98
Birthweight changed from 272g to 2720g.

Baby NHS number 64******29
Abdominal circumference changed from 10.0cm to 28.2cm
Baby NHS number 64******60
Abdominal circumference changed from 11.0cm to 31.0cm
Baby NHS number 64******95
Abdominal circumference changed from 39.0cm to 41.0cm
Baby NHS number 64******28
Abdominal circumference changed from 5.2cm to 35.5cm
Baby NHS number 64******34
Abdominal circumference changed from 13.2cm to 26.4cm
Baby NHS number 70******23
Abdominal circumference changed from 23.5cm to 26.5cm
Baby NHS number 70******40
Abdominal circumference changed from 23.2cm to 28.2cm
Baby NHS number 70******17
Abdominal circumference changed from 10.2cm to 26.5cm
Baby NHS number 70******28
Abdominal circumference changed from 37.4cm to 37.2cm

Baby NHS number 64******29
Head circumference changed from 29.3cm to 33.3cm
Baby NHS number 64******72
Head circumference changed from 37.8cm to 34.8cm
Baby NHS number 70******89
Head circumference changed from 30.0cm to 30.8cm
Baby NHS number 70******87
Head circumference changed from 30.5cm to 31.5cm
Baby NHS number 70******28
Head circumference changed from 12.0cm to 34.2cm
Baby NHS number 70******23
Head circumference changed from 27.5cm to 32.5cm
Baby NHS number 70******40
Head circumference changed from 28.8cm to 30.3cm
Baby NHS number 70******65
Head circumference changed from 30.0cm to 29.5cm
Baby NHS number 70******00
Head circumference changed from 5.5cm to 35.5cm
Appendix IV: Data cleaning report

Frequency distributions

Baby NHS number 70******42
Birthweight changed from 2722g to 2720g.
Baby NHS number 64******01
Birthweight changed from 4004g to 4000g.
Baby NHS number 64******75
Birthweight changed from 3062g to 3060g.
Baby NHS number 70******34
Birthweight changed from 3043g to 3040g.
Baby NHS number 70******08
Birthweight changed from 3374g to 3370g.
Baby NHS number 64******22
Birthweight changed from 3456g to 3460g.
Baby NHS number 64******05
Birthweight changed from 3032g to 3030g.

Random 5% sample check

Baby NHS number 70******93
Gestational age changed from 41 to 40 weeks.
Baby NHS number 70******25
Gestational age changed from 44 to 41 weeks.

Baby NHS number 64******49
Abdominal circumference changed from 32.5cm to 32.3cm
Baby NHS number 64******86
Abdominal circumference changed from 29.3cm to 28.3cm
Baby NHS number 70******96
Abdominal circumference changed from 35.0cm to 34.0cm

Baby NHS number 70******76
Head circumference changed from 39.8cm to 37.8cm
Baby NHS number 70******27
Head circumference changed from 33.0cm to 35.0cm

Postnatal anthropometry

± three standard deviation check

Baby NHS number 64******32
Weight changed from 9380g to 3980g.

Baby NHS number 64******99
Abdominal circumference changed from 25.0cm to 31.3cm
Baby NHS number 64******09
Abdominal circumference changed from 27.7cm to 29.9cm

Baby NHS number 70******85
Head circumference changed from 27.5cm to 37.5cm
Appendix IV: Data cleaning report

Baby NHS number 70******74
Head circumference changed from 30.0cm to 36.0cm
Baby NHS number 70******03
Head circumference changed from 4.3cm to 36.5cm
Baby NHS number 70******09
Head circumference changed from 78.5cm to 38.5cm

Baby NHS number 70******28
Length changed from 46.5cm to 41.5cm.
Baby NHS number 70******40
Length changed from 45.0cm to 48.0cm.
Baby NHS number 70******03
Length changed from 43.0cm to 43.0cm.

Frequency distributions

Baby NHS number 64******30
Weight changed from 10745g to 10750g.
Baby NHS number 64******06
Weight changed from 9375g to 9380g.
Baby NHS number 70******43
Weight changed from 9245g to 9250g.
Baby NHS number 64******95
Weight changed from 9205g to 9210g.
Baby NHS number 64******42
Weight changed from 8955g to 8960g.
Baby NHS number 70******55
Weight changed from 8335g to 8340g.
Baby NHS number 64******43
Weight changed from 8278g to 8280g.
Baby NHS number 64******95
Weight changed from 7654g to 7650g.
Baby NHS number 70******76
Weight changed from 7625g to 7630g.
Baby NHS number 70******80
Weight changed from 7541g to 7540g.
Baby NHS number 70******15
Weight changed from 7395g to 7400g.
Baby NHS number 64******95
Weight changed from 7059g to 7060g.
Baby NHS number 70******53
Weight changed from 6725g to 6730g.
Baby NHS number 70******76
Weight changed from 6535g to 6540g.
Baby NHS number 70******54
Weight changed from 6025g to 6030g.
Baby NHS number 70******64
Weight changed from 5525g to 5530g.
Baby NHS number 70******64
Weight changed from 5515g to 5520g.
Appendix IV: Data cleaning report

Baby NHS number 70******64
Weight changed from 5385g to 5390g.
Baby NHS number 70******03
Weight changed from 4775g to 4780g.
Baby NHS number 64******21
Weight changed from 4435g to 4440g.
Baby NHS number 70******91
Weight changed from 4421g to 4420g.
Baby NHS number 70******08
Weight changed from 4185g to 4190g.
Baby NHS number 64******13
Weight changed from 4175g to 4180g.
Baby NHS number 70******01
Weight changed from 3905g to 3910g.
Baby NHS number 70******56
Weight changed from 3895g to 3900g.
Baby NHS number 64******45
Weight changed from 3765g to 3770g.
Baby NHS number 70******81
Weight changed from 3685g to 3690g.
Baby NHS number 70******51
Weight changed from 2365g to 2370g.

Baby NHS number 70******37
Abdominal circumference changed from 36.75cm to 36.8cm
Baby NHS number 70******21
Abdominal circumference changed from 36.54cm to 36.5cm
Baby NHS number 70******54
Abdominal circumference changed from 36.25cm to 36.3cm
Baby NHS number 64******15
Abdominal circumference changed from 34.25cm to 34.3cm
Baby NHS number 70******23
Abdominal circumference changed from 34.25cm to 34.3cm
Baby NHS number 64******99
Abdominal circumference changed from 31.15cm to 31.2cm
Baby NHS number 64******49
Abdominal circumference changed from 31.05cm to 31.1cm

Baby NHS number 70******10
Head circumference changed from 44.75cm to 44.8cm
Baby NHS number 70******85
Head circumference changed from 44.45cm to 44.5cm
Baby NHS number 70******61
Head circumference changed from 40.25cm to 40.3cm
Baby NHS number 70******68
Head circumference changed from 40.02cm to 40.0cm
Baby NHS number 70******22
Head circumference changed from 38.75cm to 38.8cm
Baby NHS number 70******89
Head circumference changed from 37.25cm to 37.3cm
Appendix IV: Data cleaning report

Baby NHS number 70******54
Head circumference changed from 36.75cm to 36.8cm
Baby NHS number 64******07
Head circumference changed from 36.75cm to 36.8cm
Baby NHS number 64******41
Head circumference changed from 35.75cm to 35.8cm
Baby NHS number 70******55
Head circumference changed from 34.75cm to 34.8cm

Baby NHS number 70******12
Length changed from 72.2cm to 72.0cm.
Baby NHS number 70******99
Length changed from 67.6cm to 67.5cm.
Baby NHS number 70******53
Length changed from 67.4cm to 67.5cm.
Baby NHS number 70******96
Length changed from 66.3cm to 66.5cm.
Baby NHS number 70******11
Length changed from 59.2cm to 59.0cm.
Baby NHS number 64******86
Length changed from 58.9cm to 59.0cm.
Baby NHS number 64******81
Length changed from 58.7cm to 58.5cm.
Baby NHS number 70******52
Length changed from 58.6cm to 58.5cm.
Baby NHS number 70******26
Length changed from 58.4cm to 58.5cm.
Baby NHS number 70******97
Length changed from 58.1cm to 58.0cm.
Baby NHS number 70******81
Length changed from 56.4cm to 56.5cm.
Baby NHS number 64******12
Length changed from 55.8cm to 56.0cm.
Baby NHS number 70******26
Length changed from 55.6cm to 55.5cm.
Baby NHS number 64******66
Length changed from 55.4cm to 55.5cm.
Baby NHS number 64******38
Length changed from 55.2cm to 55.0cm.
Baby NHS number 64******16
Length changed from 53.6cm to 53.5cm.
Baby NHS number 64******16
Length changed from 53.4cm to 53.5cm.
Baby NHS number 70******76
Length changed from 53.2cm to 53.0cm.
Baby NHS number 70******07
Length changed from 52.3cm to 52.5cm.
Baby NHS number 64******96
Length changed from 50.2cm to 50.0cm.
Baby NHS number 64******22
Length changed from 49.3cm to 49.5cm.
Baby NHS number 70******76
Length changed from 46.1cm to 46.0cm.
Baby NHS number 70******05
Length changed from 45.2cm to 45.0cm.
Baby NHS number 64******24
Length changed from 34.6cm to 34.5cm.
Appendix V: Histograms of multilevel model residuals and random effect parameters

Weight

- Residuals (grams)
- Random constant
- Random coefficient
Appendix V: Histograms of multilevel model residuals and random effect parameters

Abdominal circumference

![Histograms of multilevel model residuals and random effect parameters](image-url)
Appendix V: Histograms of multilevel model residuals and random effect parameters

Head circumference
Appendix V: Histograms of multilevel model residuals and random effect parameters

Length

![Histograms of multilevel model residuals and random effect parameters](image)
Appendix VI: Birth characteristics and anthropometry at birth of term infants

Appendix VI: Birth characteristics and anthropometry at birth of term infants

Birth characteristics of term infants

<table>
<thead>
<tr>
<th></th>
<th>White British</th>
<th>Pakistani</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n=1114 (45.2%)</td>
<td>n=1350 (54.8%)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>n(%) 570 (51.2)</td>
<td>688 (51.0)</td>
</tr>
<tr>
<td>Female</td>
<td>n(%) 544 (48.8)</td>
<td>662 (49.0)</td>
</tr>
<tr>
<td>Gestational age in weeks</td>
<td>mean(SE) 39.69 (0.033)</td>
<td>39.39 (0.030)</td>
</tr>
<tr>
<td>Size for gestational age</td>
<td>n(%)</td>
<td></td>
</tr>
<tr>
<td>SGA</td>
<td>88 (7.9)</td>
<td>228 (16.9)</td>
</tr>
<tr>
<td>AGA</td>
<td>934 (83.8)</td>
<td>1078 (79.9)</td>
</tr>
<tr>
<td>LGA</td>
<td>92 (8.3)</td>
<td>44 (3.3)</td>
</tr>
<tr>
<td>Registerable parity</td>
<td>median(range) 1.5 (7)</td>
<td>2 (9)</td>
</tr>
<tr>
<td>Para 1</td>
<td>n(%) 557 (50.0)</td>
<td>428 (31.7)</td>
</tr>
<tr>
<td>Para 2</td>
<td>n(%) 351 (31.5)</td>
<td>381 (28.2)</td>
</tr>
<tr>
<td>Para ≥3</td>
<td>n(%) 206 (18.5)</td>
<td>541 (40.1)</td>
</tr>
<tr>
<td>Index of Multiple Deprivation</td>
<td>median(range) 9648 (32222)</td>
<td>2058 (29597)</td>
</tr>
<tr>
<td>1st tertile</td>
<td>n(%) 217 (19.5)</td>
<td>621 (46.0)</td>
</tr>
<tr>
<td>2nd tertile</td>
<td>n(%) 303 (27.2)</td>
<td>503 (37.3)</td>
</tr>
<tr>
<td>3rd tertile</td>
<td>n(%) 594 (53.3)</td>
<td>226 (16.7)</td>
</tr>
<tr>
<td>Low Birth Weight (&lt;2500g)</td>
<td>n(%) 23 (2.1)</td>
<td>65 (4.8)</td>
</tr>
</tbody>
</table>

Anthropometry at birth of term infants

<table>
<thead>
<tr>
<th></th>
<th>White British</th>
<th>Pakistani</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boys (n=570)</td>
<td>Girls (n=554)</td>
</tr>
<tr>
<td>Weight (g)</td>
<td>mean 3487.4 (SE 19.3)</td>
<td>3331.8 (SE 19.6)</td>
</tr>
<tr>
<td>Abdominal circumference (cm)</td>
<td>mean 32.55 (SE 0.10)</td>
<td>32.15 (SE 0.10)</td>
</tr>
<tr>
<td>Head</td>
<td>mean 34.90 (SE 0.06)</td>
<td>34.22 (SE 0.06)</td>
</tr>
<tr>
<td>Circumference (cm)</td>
<td>mean (SE)</td>
<td></td>
</tr>
</tbody>
</table>
Birth characteristics of term infants, included in MLMs for length

<table>
<thead>
<tr>
<th></th>
<th>White British</th>
<th></th>
<th>Pakistani</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n=203 (39.0%)</td>
<td>n=317 (61.0%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>n(%)</td>
<td>102 (50.2)</td>
<td>164 (51.7)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>n(%)</td>
<td>101 (49.8)</td>
<td>153 (48.3)</td>
<td></td>
</tr>
<tr>
<td>Gestational age in weeks</td>
<td>mean(SE)</td>
<td>39.67 (0.079)</td>
<td>39.50 (0.061)</td>
<td></td>
</tr>
<tr>
<td>Size for gestational age</td>
<td>n(%)</td>
<td>8 (3.9)</td>
<td>41 (12.9)</td>
<td></td>
</tr>
<tr>
<td>SGA</td>
<td>n(%)</td>
<td>178 (87.7)</td>
<td>269 (84.9)</td>
<td></td>
</tr>
<tr>
<td>AGA</td>
<td>n(%)</td>
<td>17 (8.4)</td>
<td>7 (2.2)</td>
<td></td>
</tr>
<tr>
<td>LGA</td>
<td>n(%)</td>
<td>100 (49.2)</td>
<td>99 (31.2)</td>
<td></td>
</tr>
<tr>
<td>Registerable parity</td>
<td>median(range)</td>
<td>2 (5)</td>
<td>2 (8)</td>
<td></td>
</tr>
<tr>
<td>Para 1</td>
<td>n(%)</td>
<td>70 (34.5)</td>
<td>90 (28.4)</td>
<td></td>
</tr>
<tr>
<td>Para ≥3</td>
<td>n(%)</td>
<td>33 (16.3)</td>
<td>128 (40.4)</td>
<td></td>
</tr>
<tr>
<td>Index of Multiple Deprivation</td>
<td>median(range)</td>
<td>11651 (29728)</td>
<td>2084 (23003)</td>
<td></td>
</tr>
<tr>
<td>1st tertile</td>
<td>n(%)</td>
<td>35 (17.2)</td>
<td>143 (45.1)</td>
<td></td>
</tr>
<tr>
<td>2nd tertile</td>
<td>n(%)</td>
<td>44 (21.7)</td>
<td>124 (39.1)</td>
<td></td>
</tr>
<tr>
<td>3rd tertile</td>
<td>n(%)</td>
<td>124 (61.1)</td>
<td>50 (15.8)</td>
<td></td>
</tr>
<tr>
<td>Low Birth Weight (&lt;2500g)</td>
<td>n(%)</td>
<td>0 (0.0)</td>
<td>12 (3.8)</td>
<td></td>
</tr>
</tbody>
</table>

Anthropometry at birth of term infants, included in MLMs for length

<table>
<thead>
<tr>
<th></th>
<th>White British</th>
<th></th>
<th>Pakistani</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boys (n=102)</td>
<td>Girls (n=101)</td>
<td>Boys (n=164)</td>
<td>Girls (n=153)</td>
</tr>
<tr>
<td>Weight (g)</td>
<td>mean (SE)</td>
<td>3491.1 (45.8)</td>
<td>3415.7 (41.2)</td>
<td>3277.7 (30.6)</td>
</tr>
<tr>
<td>Abdominal Circumference (cm)</td>
<td>mean (SE)</td>
<td>32.51 (0.25)</td>
<td>32.28 (0.28)</td>
<td>31.48 (0.17)</td>
</tr>
<tr>
<td>Head Circumference (cm)</td>
<td>mean (SE)</td>
<td>34.92 (0.14)</td>
<td>34.37 (0.13)</td>
<td>34.37 (0.10)</td>
</tr>
</tbody>
</table>
Appendix VII: Weight-for-age Z-scores split by infant feeding status

The mean weight-for-age Z-scores of infants born in Bradford relative to the UK90 reference, split by infant feeding status at two months of age

The mean weight-for-age Z-scores of infants born in Bradford relative to the WHO standards, split by infant feeding status at two months of age