Body-composition Assessment using Air Displacement Plethysmography in Healthy Term infants: An Observational Study

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Bani Ichhpuniani

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Abstract

Background:

Infant body weight and composition at birth have been recognised to be important indicators of fetal growth, maternal and offspring health, and later health outcomes. While it is well documented that average birth weight varies significantly between New Zealand-born infants of different ethnicities, there is limited evidence on body composition in new-born infants. Ethnic differences in body composition have been reported in New Zealand adults and children and it is currently unknown whether these differences are evident shortly after birth. The aim of this study was to examine the differences in fat mass (FM) and fat free mass (FFM) using Air Displacement Plethysmography (ADP) between NZ European (reference group), Māori, Pacific, Asian and South Asian healthy term infants.

Method:

Healthy term infants (37 to 42 weeks' gestation) were recruited from Auckland City Hospital (ACH). Birth parameters were recorded and weight, length, and head circumference and waist circumference were measured using standardised techniques. Air Displacement Plethysmography (ADP) was used to measure fat mass (FM) and fat free mass (FFM) of the infants. Ethnicity of all infants and their mothers was classified using standard ethnicity data protocols. Dummy variable multiple linear regression analysis and t-tests were used to compare FM and FFM of Māori, Pacific, Asian, and South Asian infants with New Zealand European (NZE) infants.

Results:

Body composition was assessed in 214 healthy term infants at a mean age of 1.7±0.85 days, while adjusting for gender and postnatal age. South Asian infants had significantly lower FFM (2691.7±389.7g vs 2938.6±364.0g, P= 0.006) and weight than NZE infants (3045.5±535.2g vs 3352.3±575.8g, P= 0.014). They also had the smallest head (34.2±1.7cm vs 35.4±1.7cm, P= 0.002) and waist circumference (31.5±3.0cm vs 33.2±2.1cm, P= 0.003). Waist circumference of Asian infants was also significantly smaller than NZ European infants (32.3±2.1cm vs 33.2±2.1cm, P= 0.044). When categorised by gender, males had significantly greater FFM, weight, length and head circumference (P< 0.05). No gender or ethnic difference was noted in FM (g) or %FM.

Conclusion:

This is the first study in New Zealand to report body composition in healthy term infants using ADP. While no differences in FM were seen between NZE and each of the other ethnicities, the differences noted in FFM and weight between NZE and South Asian infants were comparable to other studies. Longitudinal assessment of changes in FM and FFM is needed to establish the significance of ethnic differences.

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Abbreviations

ACH	Auckland City Hospital
ADHB	Auckland District Health Board
ADP	Air displacement plethysmography
AGA	Appropriate for gestational age
LBW	Low birth weight
LGA	Large for gestational age
BF	Body fat
BIA	Bioelectrical impedance analysis
BMI	Body mass index
BW	Body weight
CT Scan	Computerized tomography scan
DXA	Dual-energy X-ray absorptiometry
FM	Fat mass
FFM	Fat free mass
GA	Gestational age
GDM	Gestational diabetes mellitus
GWG	Gestational weight gain
HDEC	Health and Disability Ethics Committee
LGA	Large for gestational age
MRI	Magnetic resonance imaging
NZE	New Zealand European
SGA	Small for gestational age
SAA	Surface area artifact
TBW	Total body water
UWW	Underwater weighing

Chapter 1 Introduction

1.1 Background and justification

It is well established that growth and development during early life are strongly associated with health outcomes later in life (Barker, 2004; Wells et al., 2007; IAEA, 2013). The period from birth to two years of age in particular represents a "critical window", during which the body is malleable in nature and undergoes rapid growth and development (Barker, 2004; Wells et al., 2007; IAEA, 2013). This critical period is often seen as an opportunity to closely monitor postnatal growth and understand the association between early development and later health outcomes. However, standardised methods used to measure postnatal growth are largely based on anthropometric measurements (birth weight, length, head circumference) and fail to assess the quality of growth and the compositional nature of growth (Lee et al., 2009). In addition, maternal and infant weight gain in particular are often used as proxies for infant growth, with insufficient attention given to the components which contribute to body weight and early-life nutrition as the underlying mechanism (IAEA, 2013). For example, the substantial changes in hydration, tissue development, bone mineralisation, fat and fat free mass deposition between birth and six weeks of age may significantly impact body mass (Wrottesley et al., 2016). Hence, using techniques that are able to distinguish between the different components of body mass during infancy is needed.

Body weight is an anthropometric measure which is easy to conduct and non-invasive to the infant. It is a routinely available technique often used in conjunction with length to assess infant growth by comparison with the World Health Organization (WHO) Child Growth Standards (World Health Organization, 2006). The classic Barker's hypothesis also uses birth weight as the key outcome for fetal growth and relates it to diseases in later life (Barker & Osmond, 1986; Barker et al., 1989). Since then, the majority of studies associating early development with later health outcomes have used birth weight as the primary marker for fetal growth (Frankel et al., 1996; Vestbo et al., 1996; Parsons et al., 1999; Stern et al., 2000). Birth weight has been associated with a range of health risks such as cardiovascular disease, obesity, metabolic syndrome, and hypertension (Godfrey & Barker, 2000; Wilcox, 2001; Barker et al., 2002). Although, it is clear that good measurements of body weight and length provide useful information, these measures do not always reflect the long term risks associated with poor growth (IAEA, 2013). Neonates within the healthy weight range of 2500-3000g can have significantly different body composition and be

susceptible to later health risks (IAEA, 2013). Furthermore, it is hypothesised that if birth weight is associated with adiposity and body composition in adult life, which in turn has been shown to be related to the distribution of fat, then simply using birth weight to estimate body composition may provide an incomplete picture and potentially inaccurate conclusions (Kensara et al., 2005).

There is emerging evidence that indicates infant body composition may be an important factor in "programming" of later diseases (Wells et al., 2007). Catalano and colleagues (2009) have shown high body fat during infancy to be significantly associated with increased body fat during childhood. Moreover, evidence from longitudinal cohort studies suggest that body composition during infancy and childhood carries forward to adulthood (Fields et al., 2011). Accurate measurement of infant body composition also has the potential to enhance clinical assessment of overall nutrition status, the quality of growth, efficacy of diet and medical interventions, progression of chronic disease, and recovery from malnutrition (Butte et al., 2000b; Ma et al., 2004; Wells et al., 2007; IAEA, 2013). In addition, body composition measurements at birth provide key information about factors that can influence intrauterine growth such as gestational weight gain. Hence, the relationship between growth during early life and body composition is of considerable relevance to human health and it is essential to explore the dynamic nature of neonatal growth using body composition techniques.

The ability to measure body composition during infancy has evolved immensely since the classic body composition model by Fomon et al. in 1982, which provided age and gender specific reference values for children from birth to ten years of age (Fomon et al., 1982). Recent advances in technology offer great opportunity to safely assess infant body composition and further increase our understanding of the correlation between early growth and subsequent disease risk. Methods such as Isotope Dilution, Bioelectric Impedance Analysis (BIA), Dual-Energy X-Ray Absorptiometry, and Air Displacement Plethysmography (ADP), have been adapted to suit this population group. All the methods differ in terms of the body component (body water, fat mass, lean body mass) being measured, techniques used, complexity, training requirements, availability, cost, accuracy, and safety (Lee & Gallagher, 2008; IAEA, 2013; Demerath & Fields, 2014). But it is important to note that all the methods are indirect measures of body composition and based on several assumptions that are technique specific. One of the more recent methods used to measure infant body composition is ADP, which simply partitions the body compositions into two compartments to estimate fat mass (FM) and fat free mass (FFM) (Wrottesley et al., 2016). The

ADP system is a densitometric technique which is rapidly replacing other body composition methods because of the ease and efficiency of use, low operator skill requirements and the non-invasive nature of the technique (Ma et al., 2004).

The introduction of methods such as ADP, has made it possible to safely measure body composition in infants and estimate FM and FFM at different stages of growth (Carberry et al., 2010). As a result, there is emerging evidence that provides insight into factors that may affect infant body composition and its impact on generalised nutritional state of neonates. Gender, ethnicity, maternal body composition, maternal diet are some of the common factors that have been investigated in relation to infant body composition (Sewell et al., 2006; Hull et al., 2008; Singh & Huston-Presley, 2010; Gale et al., 2012; Simon et al., 2013; Sletner et al., 2013; Broere-Brown et al., 2016). Of particular interest is the influence of ethnicity, as it is well established that the prevalence of obesity and related co-morbidities is significantly higher in certain ethnic groups. For example, evidence indicates that relative to most other ethnic groups, South Asians have an increased risk of type 2 diabetes and cardiovascular disease (McKeigue et al., 1991; Yajnik et al., 2003; Stanfield et al., 2012). It is speculated that this disparity is related to South Asians being centrally obese and having greater FM and lower FFM (Shelgikar et al., 1991). Likewise, Pacific Island populations in New Zealand have 2.5 times higher obesity rates than New Zealand European and have been shown to have lower body fat percentage (%BF) than Europeans at equivalent BMI levels (Swinburn et al., 1996; Rush et al., 1997; Swinburn et al., 1999; Duncan et al., 2004). Although these findings need to be confirmed by other methods for measuring body composition, it is speculated that higher bone density in Pacific Island population may impact the overall density of FFM and result in underestimation of body fat (Rush et al., 1997; Duncan et al., 2004).

There is a paucity of data on ethnic differences and body composition in infants. Stanfield et al. (2012) was the first UK based study to report that South Asian infants have reduced FFM as compared to white European infants. However, as the methodology to measure body composition is becoming widely available, there are some interesting findings emerging from low-income countries. A series of studies conducted by Anderson et al. (2011; 2012; 2013) measured and compared full-term new-born from Ethiopia to similar reference data from the United States. The findings suggested that Ethiopian infants had an increased ratio of FM to FFM as well as a deficit in birth weight (Andersen et al., 2011; Andersen, 2012; Andersen et al., 2013). Although, these findings may have limited applicability to populations in high income countries such as New

Zealand, the authors report that this early recognition of body compositional differences can lead to timely nutrition interventions and subsequently yield better health outcomes for certain ethnic groups (Andersen et al., 2013).

In relation to New Zealand, the data from the Report on Maternity (2004) by Ministry of Health shows significant differences in average birth weights between New Zealand's main ethnic groups. McCowan and Stewart (2004) have also acknowledged these ethnic differences and developed ethnicity specific term birth weight percentile charts for New Zealand infants. The Early Life Factors (EFL) study based in New Zealand also reported ethnic inequalities in infant body weight at 3 months of age (Howe et al., 2015). Hence, ethnic differences in weight trajectories in New Zealand are well documented and shown to begin in very early life. Ethnic differences using other body composition techniques have majorly only been explored in New Zealand adults and children. A series of studies conducted on New Zealand children (5 to 14 years of age) using a range of body composition techniques (such as: deuterium dilution and bioelectric impedance analysis) suggests that Pacific Island and Māori girls have lower percentage body fat (% BF) compared to European, but no ethnic differences were noted for boys (Rush et al., 2003a; Rush et al., 2003b; Rush et al., 2009). A recent study by Rush et al. (2015) also found gender and ethnicity to be important determinants of body composition in 1-3 year-old children. To our knowledge, no previous studies in New Zealand have explored ethnic differences in body composition of European, South Asian, Māori and Pacific Island infants at birth using measures other than body weight. Thus, evidence that explores body composition using measures other than body weight in early life is needed.

1.2 Purpose of the study

The assessment of infant body composition and related factors has the potential to become an important research and diagnostic tool (Ahmad et al., 2010). Wells et al. (2007) also states that using the latest body composition assessment techniques to measure body composition at birth and during infancy has immense potential to increase our understanding of ethnic disparities in disease risk. In addition, there is a need for studies that investigate ethnic differences in body composition in New Zealand infants. In this cross-sectional observational study, we present the results of our study which used ADP to examine FM and FFM in New Zealand-born full term infants. The study also investigated whether ethnic differences in body composition are present at birth, as previously reported in other population groups.

1.3 Aim and objectives

1.3.1 Aim

To explore the relationship between ethnicity and body composition of healthy term New Zealand infants shortly after birth.

1.3.2 Objectives

1. To measure fat mass (FM) and fat free mass (FFM) using air displacement plethysmography in healthy term infants shortly after birth.
2. To compare FM and FFM of Māori, Pacific, Asian, and South Asian infants with New Zealand European infants.
3. To compare FM and FFM between males and females.

1.4 Thesis structure

Following this introduction, Chapter 2 reviews current and past literature to critically discuss suitable models, techniques and factors related to infant body composition. The evidence regarding the use of ADP and ethnic differences in body composition are discussed in more detail. Chapter 3 is presented in the form of a manuscript for submission to a peer-reviewed journal. It examines the relationship between ethnicity and infant body composition, and gives details of the study design and protocols used to recruit and measure healthy term infants. Followed by results and a thorough discussion of these findings. Finally, Chapter 4 summarises the research study and reflects on its strengths and limitations and makes recommendations for future research.

1.5 Researcher's contribution

Table 1.1 *Researcher's contributions to this study*

Bani Ichhpuniani	Main Researcher and author of thesis; involved in participant recruitment and measurements; collected and collated most of the medical data; analysed data and performed statistical analysis; interpreted and discussed the results.
Dr Cath Conlon	Main academic supervisor; development of study design; attained ethic approval; supervision of statistical analysis and interpretation of results; thesis revision and approval.
Dr Pamela von Hurst	Academic supervisor; supervision of statistical analysis and interpretation of results; thesis revision and approval.

Louise van Dorp	Applied for ethics; designed participant information sheet and data collection forms; assisted with recruitment and measurement of participants.
Owen Mugridge	Assisted with recruitment and measurement of participants.

Chapter 2 Literature review

2.1 Background

The purpose of this review is to describe several concepts related to infant body composition; summarise existing evidence for factors that may influence body composition of infants; and cover unresolved challenges in latest body composition research. It covers firstly the different models used to describe body composition, followed by methods for estimating body composition, and finally factors that have been shown to influence body composition in neonates. The body composition assessment techniques included in this literature review are Isotope Dilution, Bioelectric Impedance Analysis (BIA), Dual-Energy X-ray Absorptiometry (DXA), Skinfold Thickness, and Air Displacement Plethysmography (ADP). It should be noted that there are several other different models and methodologies available for measuring body composition in infants, however this review only discusses some of the most widely used methods in research settings. The use of ADP to measure infant fat mass (FM) and fat free mass (FFM) is emphasised, as it was the method used in the present study.

Also explored in this chapter is the role of anthropometric measures to estimate infant growth, as birth weight, supine length, and head circumference are known to be principle indicators of pregnancy outcome and are also important for accurately estimating body composition. Despite the shortcomings, anthropometric measures remain the core data source for researchers and clinicians around the world. While the main focus in this review is on New Zealand, we provide some comparisons with the experience of other countries.

2.2 Search strategy and study selection

Electronic databases: PubMed, Google Scholar, and Web of Science were searched for relevant articles using the following key words: body composition; term infant; air displacement plethysmography; fat mass; fat free mass; body fat; lean body mass; ethnicity; birth weight; maternal body composition; maternal body mass index (BMI); health outcomes; New Zealand. No limits were imposed as to the date of publication. Reference lists to identified articles were also hand-searched for related studies. Any unpublished reports and those available only in an abstract form were excluded from the review.

2.3 Anthropometry

Anthropometry is a simple, inexpensive, and non-invasive method for assessing infant growth (de Onis & Habicht, 1996). At attended delivery, body weight, supine length, and head circumference are the most commonly used anthropometric measures (de Onis & Habicht, 1996). They are known to be quick indicators of fetal growth and reflect intrauterine environment, overall health, and nutrition status (de Onis & Habicht, 1996). In practice, the World Health Organization (WHO) Child Growth Standards are most commonly used by clinicians and researchers, as they provide detailed instructions for measurements of body weight, length or height, and head circumference for infants (World Health Organization, 2006). Once the anthropometric values are known, they are generally compared to a population-specific set of reference values for screening and monitoring of adequate growth (World Health Organization, 2006).

2.3.1 Body weight

It is universally acknowledged that body weight is an important measure of neonatal health (World Health Organization, 2006, 2008). Body weight comprises of lean body mass, fat mass, extracellular and intracellular fluid compartments, and during infancy it is affected by daily fluid fluctuations (Moyer-Mileur, 2007). Hence, birth weight offers the earliest opportunity to assess fetal growth. It is recommended that the infant is weighed unclothed (with the exception of necessary medical equipment), preferably at the same time each day, on a regularly calibrated electronic scale, and recorded to the nearest 0.1 kg (World Health Organization, 2008). Body weight is a relatively simple technique to use on healthy infants, and therefore routinely used in practice and research settings.

There is a large volume of evidence using birth weight as an index of fetal growth and also a predictor of subsequent disease risks. For example, Barker et al. (2000) reported that infants who are low birth weight or small at birth have higher rates of adulthood diseases such cardiovascular diseases, high cholesterol, insulin resistance and hypertension. Furthermore, there are a wide range of studies suggesting that birth weight is a strong predictor of lean body mass during child and adulthood (Okosun et al., 2000; Weyer et al., 2000; Garnett et al., 2001; Singhal et al., 2003; Sachdev et al., 2005; Reilly et al., 2006). In a longitudinal birth cohort study, Richards et al. (2001) has also reported positive association between birth weight and cognitive function in childhood. However, Wilcox (2001) questions the association between birth weight and vast spectrum of later health outcomes. According to the author, even though birth weight is one of the most

accessible measures, the evidence linking birth weight and later health outcomes should be approached with caution as the outcome may be influenced by other factors such as genetic mechanisms, and ethnicity. Wells et al. (2007) support the argument made by Wilcox (2001) and emphasise the need to use newer body composition techniques to understand the link between infancy and programming of later health risks.

2.3.2 Length

Length measurement is known to reflect lean body mass and unlike body weight it is not affected by changes in hydration status (Moyer-Mileur, 2007). Birth length is also an indicator of infant size, which reflects the average growth rate for the infant from conception to birth (World Health Organization, 1995). For accurate values, two people are needed to perform the measurement. It is advised to record the length to nearest 0.1 cm using a recumbent length board, with the infant placed in a supine and fully extended position (Moyer-Mileur, 2007; World Health Organization, 2008; IAEA, 2013). Length measurements can vary considerably due to variation in posture and muscle tone among newborn infants (World Health Organization, 1995).

2.3.3 Head circumference

Head circumference is reflective of overall fetal growth and brain volume (World Health Organization, 1995). It is measured at the largest plane of the head using a measurement tape to the nearest 0.1 cm. This measurement is easy to repeat and may slightly decrease due to fluid changes during the first week of life (World Health Organization, 1995; Moyer-Mileur, 2007).

2.4 Infant body composition

The study of body composition has been an active area of research for over a century and the procedures for estimating fat mass from fluid spaces and fat free mass have been well established in principle for a number of years (Siri, 1961). With the emergence of a number of techniques, different aspects of body composition can

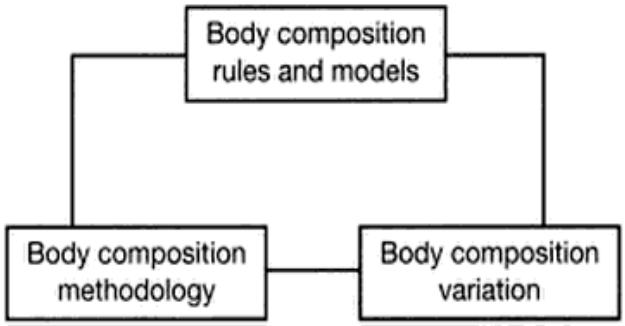

Figure 2.1 *Three main domains of body composition research (Heymsfield et al., 1997). Reprinted with permission.*

be assessed. A number methods and concepts have evolved in the investigation of body composition (Heymsfield et al., 1997; Heymsfield, 2005; Lee & Gallagher, 2008). Body composition can be summarised into three interrelated domains: establishing fundamental models related to body composition, designing and validating methods for measuring body composition and finally studying factors that can directly and indirectly impact body composition (See Figure 2.1) (Wang et al., 1992; Heymsfield, 2005).

2.4.1 Body composition models

For analysis purposes, human body composition can be simplified by using the five-level model. As illustrated in Figure 2.2, this model categorises body composition into five distinct levels: atomic, molecular, cellular, tissue system, and whole body (Wang et al., 1992; Heymsfield et al., 1997). Each level is composed of unique components and can be measured using a number of techniques. The most relevant to infant body composition are the tissue system and molecular levels.

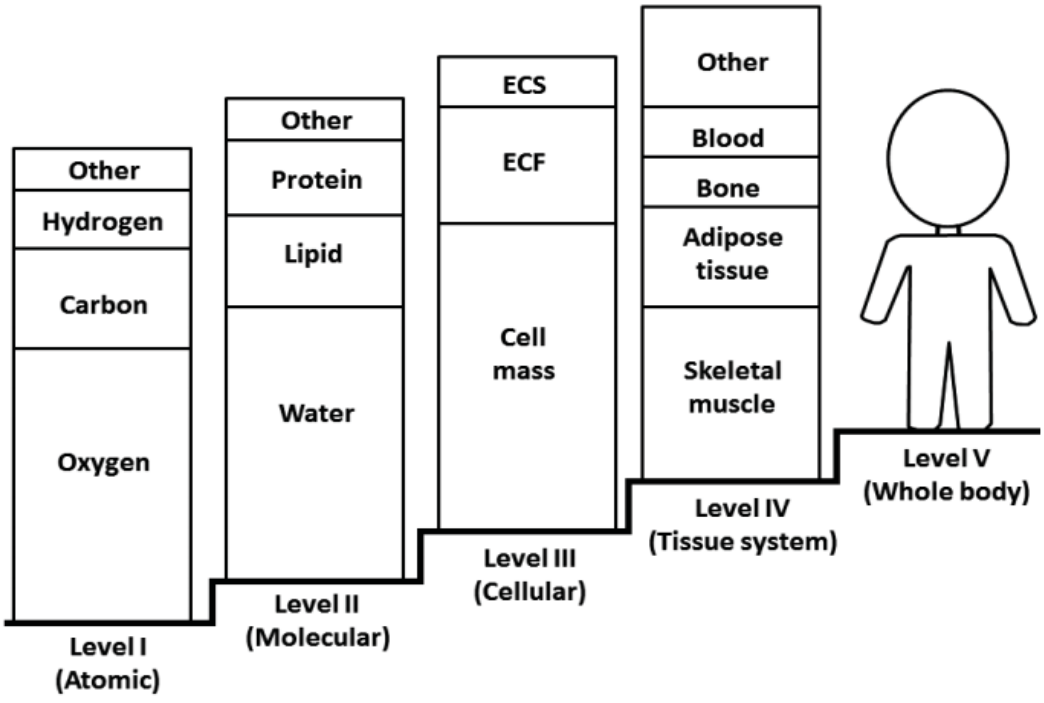

Figure 2.2 *The five-level model of body composition and its components (Ellis, 2000). Reprinted with permission.*

Abbreviations: ECS, Extracellular solids; ECF, Extracellular fluids.

The tissue system includes the adipose tissue (subcutaneous, visceral, yellow marrow, and interstitial subcomponents), skeletal muscle, bone, visceral organs, and brain. These components can be measured using anthropometric techniques, magnetic resonance imaging (MRI), and computerised tomography (CT) scanning. Although MRI and CT scan provide the most accurate measure of the components, these methods are often difficult to use on infants and children, as the procedures require them to remain still (Heymsfield et al., 1997; Demerath & Fields, 2014). Using these methods may particularly be difficult in large research settings due to radiation exposure, high costs and practicality issues.

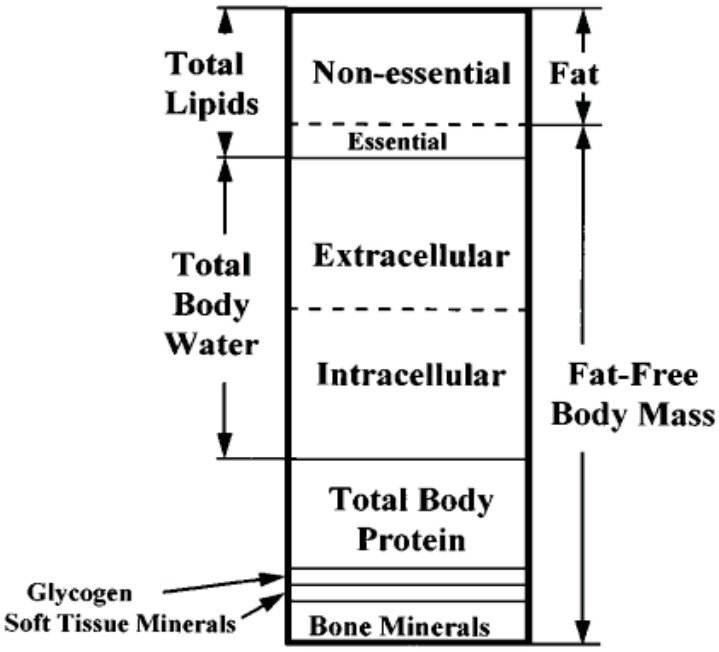

Figure 2.3 *Classification of fat mass and fat free mass based on molecular level components (Heymsfield et al., 1997). Reprinted with permission.*

As shown in Figure 2.3, the molecular level of body composition further divides the human body into five key components: lipids, water, proteins, carbohydrates, and minerals (Heymsfield et al., 1997). Total body water (TBW) being the largest component of fat free body mass, approximately 80% at birth and gradually decreasing to approximately 73% in adolescence (IAEA, 2013). These components can be combined together to estimate fat mass (FM) and fat free mass (FFM), using various compartment models (Heymsfield et al., 1997; Ellis, 2000).

A range of compartment models have been designed and validated to measure body composition in infants. These models can be categorised as two-compartment (2-C), three-compartment (3-C), four-compartment, and multicompartment (Heymsfield et al., 1997). The number of compartments vary depending on the number of body components being measured. For example, the 2-C model partitions body weight (BW) into two compartments to estimate fat mass (FM) and fat free mass (FFM); the 4-C model involves the measurement of body weight, total body volume, total body water (TBW), and bone minerals (Ellis, 2000; Heymsfield et al., 2015). The 4-C model is considered to be the gold standard for measuring body composition, as it controls for biological

variability in TBW and bone minerals (Withers et al., 1998; Demerath & Fields, 2014). But, the 4-C model is a combination of numerous tests (Isotope Dilution, Air Displacement Plethysmography, Dual-Energy X-Ray Absorptiometry) which is time consuming and potentially invasive for the infant and often impractical in the paediatric population (Butte et al., 2000a; Demerath & Fields, 2014). However, 4-C models have been shown be to ideal for deriving reference data and validating new techniques for measuring body composition. The 2-C model is considered to be a more applicable approach, as methods based on 2-C models (such as Bioelectric Impedance Analysis or Air Displacement Plethysmography) are more readily available to many clinicians/researchers, easily used by the operators, and non-invasive for subjects (Urlando et al., 2003; Lee & Gallagher, 2008; Heymsfield et al., 2015). Even though the 2-C model is influenced by age and maturation, it is most commonly used to measure body composition in infants and children (Butte et al., 2000a; IAEA, 2013).

2.4.2 Body composition methodology

A variety of methods are available to measure body composition in infants. Each method varying in technique, complexity, and assumptions that may be suitable to measure certain components of the body. It is important to note that all the available methods do not directly measure body composition, but in fact estimate it based on measurements of body properties and suitable assumptions. Hence, all methods are susceptible to methodological errors by the researcher(s) and errors associated with the technique-based assumptions used to derive body composition values. The majority of methods adapted to measure body composition in infants have been validated against the ideal 4-C models or cross validated against each other to assess interchangeability and allow comparison of results obtained using different methods.

2.4.2.1 Isotope dilution

Isotope dilution is a well-established technique that can be used to measure total body water (TBW) in the body. Total body water occupies a large proportion of FFM and is an important index of human body composition (Lukaski, 1987). Moreover, rapid changes in TBW that occur during infancy and childhood can significantly impact body composition (Lee & Gallagher, 2008). This technique involves using a tracer dose of non-radioactive isotopes of hydrogen (deuterium) or oxygen-18 to label water and determine TBW by dilution (Lukaski, 1987; Lee & Gallagher, 2008; IAEA, 2013). The type of isotope or tracer used depends on the availability of the instrumentation (isotope ratio mass spectrometry or Fourier transform infrared spectrometry) and choice of

biological tissue (blood, urine, or saliva) being used for the measurement of TBW (Ellis, 2000; IAEA, 2013). Some general assumptions associated with this technique are that the body distributes, exchanges, and metabolises the labelled water molecules in a manner similar to body water; there is no metabolism of body water and the labelled water molecules during the equilibration period; and hydration of FFM is stable (Lukaski, 1987; Demerath & Fields, 2014). Isotope dilution has been validated for use in infants and is considered to be a valuable tool for measuring body composition (Demerath & Fields, 2014). This method requires low compliance, can be easily used in large field studies, and has been shown to produce accurate and precise results (Wells & Fewtrell, 2006; Demerath & Fields, 2014).

To quantitate TBW in infants, a safe dose of tracer is administered orally or intravenously and samples of chosen biological tissue are collected, one sample prior to administration of the dose and multiple samples over the first 20 hours (Ellis, 2000; IAEA, 2013). The trace dose is based on infant's weight and generally an equilibrium time of 2-5 hours is allowed post dosage (IAEA, 2013). To calculate TBW, the amount of trace dose given to the infant is simply divided by its concentration in the analysed biological sample after the equilibrium period (Demerath & Fields, 2014). The value for TBW can then be used to estimate both FFM and FM; FFM by using the relatively consistent reference values for FFM hydration in healthy infants and FM by calculating the difference between body mass and FFM (Lee & Gallagher, 2008; Eriksson et al., 2011; Demerath & Fields, 2014). The fundamental work that provides TBW estimates for infants using isotope dilution as part of 4-C model was performed by Fomon et al. (1982). Another very similar study by Wang et al. (1992) reported longitudinal TBW data for infants up to 24 months of age and the values were comparable to the Fomon et al. (1982) study, as they were within the ±2 standard deviation range. However, it is suggested by Demerath and Fields (2014) that total body volume is measured alongside isotope dilution for infants to avoid the assumption of standard hydration of FFM in infancy.

2.4.2.2 Bioelectric impedance analysis (BIA)

A widely used method for body composition assessment is bioelectrical impedance analysis (BIA). BIA is based on the 2-C body composition model and is known to be safe, non-invasive, portable and inexpensive (Lee & Gallagher, 2008; IAEA, 2013; Lingwood, 2013). The method measures the resistance (impedance) of body tissues to a weak electric current that is passed through the body from electrodes placed on infant's wrists and ankles (Demerath & Fields, 2014). BIA is also based

on several assumptions, including stable tissue hydration levels, homogenous distribution of the electric current through cylindrical shape of human body, and a constant relationship between TBW and FFM (Lingwood, 2013; Demerath & Fields, 2014). It calculates body composition values based on infant prediction equations derived by Fjeld et al. (1990) and Kushner et al. (1992), relating impedance index to TBW and FFM.

Very few studies have explored the application of BIA in neonates to estimate TBW values, but all of these studies reported a positive association between impedance index and TBW measured using isotope dilution methods (Mayfield et al., 1991; Wilson et al., 1993; Tang et al., 1997; Raghavan et al., 1998). When compared to other body composition methods like dual-energy X-ray absorptiometry (DXA) and air displacement plethysmography (ADP), birth weight was found to be a more robust indicator of FFM than impedance index (Dung et al., 2007; Lingwood et al., 2012). Moreover, Lingwood (2013) states that BIA is comparatively an inaccurate method for measuring body composition in infants, as there is rapid turnover of body water during infancy and this technique is easily influenced by age, and ethnicity.

2.4.2.3 Dual-energy X-ray absorptiometry

While Dual-energy X-ray absorptiometry (DXA) is most commonly used in adults to measure body mineral density, it can also accurately measure body composition. This method is based on the 3-C body composition model and uses low dose X ray beams to estimate bone mineral, bone-free FFM (soft tissue) and FM (Lee & Gallagher, 2008). The radiation dose for an infant scan is very low and there are standardised dosage guidelines available according to the type of instrument and subject characteristics (IAEA, 2013).

Similar to other body composition methods, this technique is also based on some key assumptions. The most fundamental one being that bone, fat, and soft tissue have unique densities and chemical composition, thus each component absorbs X ray beams differently and can be easily distinguished from one another (Demerath & Fields, 2014). Hence, unlike many other methods, DXA is able to show whole body as well as regional distribution of body components (IAEA, 2013).

Despite the technique being widely available, safe and accurate, there is limited body composition data using DXA in infants (IAEA, 2013; Demerath & Fields, 2014). The accuracy of DXA for measuring infant body composition is predominately based on direct carcass analysis of piglets and DXA has been shown to overestimate FM and underestimate bone mass in infants (Picaud et al., 1996; Rigo et al., 1998; Koo et al., 2004a). Hence, so far no studies have reported reference body composition values in infants just by solely using this technique. The lack of evidence may partially be attributed to radiation dose, the requirement from the infant to be remain still for extended period of time, which may be difficult to achieve without sedation (Lingwood, 2013). In addition, this technique limits repeat measurements that can often be used to monitor the changing growth patterns in infants (Demerath & Fields, 2014).

2.4.2.4 Skinfold thickness

Skinfold thickness is an anthropometric measurement that is widely used to measure body composition. This is an inexpensive, non-invasive, and portable method that involves using special callipers to measure thickness of different areas of the body, such as biceps, triceps, subscapular, quadriceps femoris, and suprailiac (Demerath & Fields, 2014). Using standardised techniques allows to distinguish variation in fat, lean tissue, and subcutaneous fat distribution in a sample size (Wells & Fewtrell, 2006). It has been shown that skinfold thickness is more reliable when used in a sample of similarly aged individuals and raw skinfold data is directly used to compare individuals (Wells & Fewtrell, 2006; Demerath & Fields, 2014). However, the raw values can be easily converted into regional or whole body fat values using prediction equations for infant body composition analysis (Demerath & Fields, 2014).

Numerous studies have evaluated and questioned the validity of this method for measuring adiposity in infant (Deans et al., 1989; Kabir & Forsum, 1993; Hammami et al., 2003; Koo et al., 2004b; Lingwood et al., 2012). Lingwood et al (2012) found that skinfold thickness estimates for infant body fat percentage correlate poorly with the values determined using BIA and ADP. The authors also reported weight, gender, length to be better predictors of body composition than skinfold thickness, as using only skinfold measurements underestimated body fat by 2-9%, especially in infants with greater birth weight and adiposity (Lingwood et al., 2012). These findings are also supported by other studies, as the estimation of percentage body fat obtained from skinfold thickness measurements varied significantly to the values obtained using the ADP and isotope dilution technique (Demerath & Fields, 2014).

2.4.2.5 Air displacement plethysmography

Air displacement plethysmography (ADP) is a relatively new method for measuring infant body composition. This technique is based on the 2-C model and grounding principles of densitometry (IAEA, 2013; Demerath & Fields, 2014). Densitometry is a well-known technique that was initially applied in underwater weighing (UWW) and has evolved to be the basis of ADP (Urlando et al., 2003; IAEA, 2013; Demerath & Fields, 2014). This method uses body mass (M_b) and body volume (V_b) to derive total body density (d_{TB}), which is then inserted into a standard equation to estimate FM and FFM (Urlando et al., 2003; IAEA, 2013).

Figure 2.4 *The PeaPod (COSMED, 2004)*

The only commercially available ADP system for infants is the PeaPod Infant Body Composition System (COSMED, 2004) (See Figure 2.4), which can safely estimate FM and FFM in infants (Demerath & Fields, 2014). The basic design of the infant ADP system comprises of two chambers, a test chamber and a reference chamber, connected by a volume perturbing diaphragm (Sainz & Urlando, 2003; Urlando et al., 2003). The system also houses a calibration volume container, calibration valve, electronic scale, monitor, electronic components, printer, computer, and air circulation and heating systems (Sainz & Urlando, 2003; Urlando et al., 2003). The test chamber contains a plastic tray that is designed to safely position the infant being tested. The measurement process takes approximately two minutes, during which the air circulation system continuously circulates air from the outside environment to the test chamber (Sainz & Urlando, 2003; Urlando et al., 2003; Ma et al., 2004). The air circulated within the test chamber is maintained at a constant temperature of 31^{o}C by the air heating system. The measurements are not affected by the infant crying, moving, or urinating, thus subject compliance is not needed in this method (Ma et al., 2004; Ellis et al., 2007; Wrottesley et al., 2016).

The first paper examining the accuracy and reliability of the ADP system for body composition assessment in infants was published by Urlando et al. (2003). The ADP system is designed to estimate fat mass and fat free mass based on the application of two fundamental gas laws: Boyle's law and Poisson's Law, which describe the relation between pressure and volume of a gas under isothermal (constant temperature) and adiabatic conditions (varied temperature), respectively (Urlando et al., 2003). These conditions relate to the assumption that air inside the test chamber behaves adiabatically, whereas the air close to infant's surface and in infant's lungs behaves isothermally (Sainz & Urlando, 2003; Ma et al., 2004). The ADP system has been designed to automatically correct for these assumptions through a number of different ways. Firstly, it accurately estimates V_b through two volume calibrations, one before and one after the measurement of subject's volume (Sainz & Urlando, 2003; Ma et al., 2004). Secondly, it applies the surface area artifact (SAA) equation, which takes into account infant's weight and length, and further corrects volume measurements (Urlando et al., 2003). Lastly, when adiabatic conditions are assumed, V_b is overestimated by 40% to overcome any discrepancies between isothermal and adiabatic conditions (Sainz & Urlando, 2003; Urlando et al., 2003; Ma et al., 2004; IAEA, 2013).

Once V_b has been computed after all the adjustments, it is then used in conjunction with body mass to compute whole body density using the following equation:

$$Body\ Density\ (D_B) = \frac{Body\ Mass\ (M_B)}{Body\ Volume\ (V_B)}$$

Body volume is measured by the amount of air displaced once the infant is inside the testing chamber and body mass is measured using the electronic scales integrated within the ADP system. Body density is then converted to percentage fat mass (%FM) using the following equation:

$$\%\ Fat = \left[\frac{D_F D_{FFM}}{D_B\ (D_{FFM} - D_F)} - \frac{D_F}{D_{FFM} - D_F} \right] * 100\%$$

Where D_F is the density of fat, D_{FFM} is the density of fat free mass and D_B is the body density (Sainz & Urlando, 2003). The density of fat mass (D_F) is assumed to be constant throughout life and is equal to 0.9007 kg/L (Fomon et al., 1982; Butte et al., 2000a). The density of fat free mass (D_{FFM})

has been shown to change, thus validated sex and age specific constants by Fomon et al. (1982) and Butte et al. (2000) are applied by the ADP system. Furthermore, fluctuations in hydration level in the first six days of life in full term infants are also taken into account by this system when determining the density of fat free mass (FFM) (Rodríguez et al., 1999). Once %FM is calculated by the computer programme within the ADP system, percentage fat free mass (%FFM), fat mass (FM) and fat free mass (FFM) are determined using the following equations:

$$\% \text{ Fat free mass (FFM)} = 100 - \% \text{ fat}$$

$$\text{Fat mass (FM)} = (\% \text{ fat}) (\text{Body mass } M_B) / 100 \%$$

$$\text{Fat free mass (FFM)} = \text{Body mass } (M_B) - \text{Fat mass (FM)}$$

This method has been validated against the 4-C model, other body composition methods, and biological and physical phantoms. Sainz and Urlando (2003) compared ADP values for %FM to the cadaver analysis of bovine tissue phantoms and found ADP values to be highly precise and accurate. Ellis et al. (2007) found that the mean %FM obtained using the ADP system was not statistically different from the %FM obtained using the 4-C reference model. The study concluded that the ADP system provided reliable, and accurate assessments of %FM in infants (Ellis et al., 2007). Furthermore, Ma et al. (2004) compared the body composition estimates by ADP and isotope dilution in full term infants and found no significant difference in %BF between the two methods. Similar conclusions were drawn in this study, that ADP is a reliable method for assessing infant body composition and it is not affected by infant behaviour during the measurement (Ma et al., 2004). The easy to perform and non-invasive nature of this method has been noted by several studies and it is well documented that ADP is suitable for assessing body composition both in the clinical and research setting (Sainz & Urlando, 2003; Urlando et al., 2003; Ma et al., 2004; Wrottesley et al., 2016).

Table 2.1 identifies all the studies which have used ADP to measure body composition in full term babies and which studies have reported ethnicity as either the primary outcome or as a variable. It is also of interest to note the differences according to gender. The studies by Ma et al. (2004), Ellis et al. (2007), and Wrottesley et al. (2016) are validation studies that have compared ADP to other models or methodologies. The study by Ma et al. (2004) evaluated the accuracy and reliability of the ADP system by comparing the mean %BF from the two ADP tests with the %BF calculated from the total-body water value determined by using stable isotope dilution. While all the tests were

performed on the same day for consistency, the study population was relatively small (n =53) and varied considerably in age (0.4–24.4 weeks), body mass (2.7–7.4 kg), and %BF (5.8–36.7%BF) (Ma et al., 2004). Hence, it is possible that individual differences in FFM hydration, FFM density or water turnover rate may have impacted their values for %BF (Ma et al., 2004). Another validation study was conducted on South African neonates and estimates for FM, FFM and %BF were compared between ADP and DXA (Wrottesley et al., 2016). While there were significant correlations between values obtained from both techniques, the ADP estimates of FM and % BF were higher and FFM lower in comparison to DXA (Wrottesley et al., 2016). These differences may simply be due to the fact that ADP is limited to partitioning the body into two compartments (FM and FFM) and is not designed to distinguish between lean mass and bone constituents that contribute to FFM (Wrottesley et al., 2016). Hence, all body composition methods have certain limitations and these should be considered while developing the study design. Nonetheless, all the studies reported ADP as a reliable and feasible method for assessing body composition in infants.

While a number of studies have reported ethnic differences in body composition of infants, Stanfield et al. (2012) and Paley et al. (2015) have applied ADP to investigate these differences. Paley et al. (2015) used ADP and skinfold thickness to determine if any body composition differences were present between Asian, Caucasian, African-American, and Hispanic infants shortly after birth. The authors found a strong association between ethnicity, gender and FM; at birth males from African-American, Asian, and Hispanic descent and females from African-American descent had significantly higher FM than Caucasians (Paley et al., 2015). As identified by the authors, ethnicities were self-reported by the parents and ethnic transference was not considered during this process; hence there is a high possibility that the data might not be a true reflection of the population (Paley et al., 2015). Their study also did not collect information on any pregravid maternal characteristic (maternal diet, physical activity), which have been shown to influence infant body composition (Paley et al., 2015; Crume et al., 2016).

The cross-sectional observational study by Stanfield et al. (2012) compared FM and FFM in UK-born South Asian and White European infants using ADP. The authors found that South Asians had significantly less FFM than White Europeans (Stanfield et al., 2012). As a result, South Asian infants had greater FM than White European infants, despite their small body stature (Stanfield et al., 2012). Since the study population was measured at 6 to 12 weeks of age, adjustments for post-natal weight gain had no effect on FFM and minimal effect on FM. This may either be because

post-natal weight gain has a greater effect on FM or because fat, lean mass deposition and bone mineralisation is rapid between birth and 6 weeks of age (Stanfield et al., 2012; Paley et al., 2015). It should also be noted that only infants with mother and father from the same ethnicity ("Asian" or "White") were eligible to participate in their study (Stanfield et al., 2012). Although, applying these restrictions would have minimised the potential impact of mixed ethnic background on infant body composition, the sample size may not be representative of the population being measured (Stanfield et al., 2012). It also suggests that the methodology used for collecting ethnic data can differ significantly between studies depending on their study design, but this does not necessarily imply that one method is better than the other.

Differences in body composition between genders have been noted by a number of studies (Fields et al., 2009; Carberry et al., 2010; Simon et al., 2013; Paley et al., 2015). All the studies reviewed found females to have higher adiposity and lower lean body mass than males (Fields et al., 2009; Carberry et al., 2010; Simon et al., 2013; Paley et al., 2015). Andersen et al. (2013) reported the lowest values of % FM in Ethiopian male (7.3%) and female (7.8%) infants. This authors suggest that this difference may is due to the lower birth weights of infants in low income countries (Andersen et al., 2011; Andersen et al., 2013).

Table 2.1 *Summary of studies using Air Displacement Plethysmography for measuring body composition in full term infants*

Author (s), (year), (country)	Sample size and participant characteristics	Time of measurement	%FM	FM (g)	FFM (g)	Comments
Eriksson et al. (2010) (Sweden)	n = 108 GA: ≥ 37 weeks	1 week after birth	Males: 12.5% Females: 13.4%	Males: 484 Females: 484	Males: 3285 Females: 3036	
Lingwood et al. (2011) (Australia)	n = 77 GA: 37-42 weeks	Within 0-4 days of birth	10.0 %	350	3045	
Simon et al. (2013) (France)	n = 46 GA: 40 weeks	Within 3 days of birth	Males: 11.1% Females: 13.4%	335	2937	Gender: %FM was higher in females than in males.
Ma et al. (2004) (China and United States of America)	n = 36 GA: 37-42 weeks	Within 0.4-24.4 weeks after birth	20.32%	-	-	
Stanfield et al. (2012) (United Kingdom)	n = 60 GA: 37-42 weeks	Within 6-12 weeks after birth	-	South Asian: 1030 White British: 980	South Asian: 3850 White British: 4120	Ethnicity: South Asians had less FFM and more adipose body composition than White British infants (after adjusting for small body size and gestational age)
Fields et al. (2009) (United States of America)	n = 117 GA: ≥ 37 weeks	1 month after birth	Males: 12.7% Females: 15.1%	Males: 516 Females: 588	Males: 3454 Females: 3182	Gender: Females had significantly greater % FM and less FFM than males.

Carberry et al. (2010) (Australia)	n = 77 GA: ≥ 37 weeks	Within 4 days of birth	Males: 9.4%	Males: 341	Males: 3197	Gender: FFM was significantly higher in males than females. Gestational age (GA): Positive association between % BF and GA.
			Females: 10.1%	Females: 331	Females: 2865	
Carberry et al. (2013) (Australia)	n = 581 GA: ≥ 37 weeks	Within 2 days of birth	9.2%	-	-	
Au et al. (2013) (Australia)	n = 599 GA: 37-42 weeks	Within 0-2 days of birth	GDM: 7.9%	GDM: 425	GDM: 2846	
			NGT: 9.3%	NGT: 477	NGT: 2959	
Wrottesley et al. (2016) (South Africa)	n = 88 GA: 37-42 weeks	Within 2 weeks of birth	12.9%	408	2681	
Paley et al. (2015) (United States of America)	n = 332 GA: ≥ 37 weeks	1-3 days after birth	Males: African-American: 11.6% Asian: 12.2% Caucasian: 12.7% Hispanic: 14.5%	-	-	Ethnicity: Caucasian males had less %FM than Asian and Hispanic males. Gender: Caucasian females had higher %FM than Caucasian males and African-American females had higher %FM than African-American males.
			Females: African-American: 15.4% Asian: 11.7% Caucasian: 14.9% Hispanic: 14.0%			

Ellis et al. (2007) (United States of America)	n = 31 GA: 37-42 weeks	6-9 weeks after birth	16.9%	-	-	
Starling et al. (2015) (United States of America)	n = 856 GA: ≥ 37 weeks	Within 3 days of birth	9.1%	294	2851	Maternal pre-pregnancy Body mass index (BMI) and Gestational weight gain (GWG): positively associated with infant adiposity.
Andersen et al. (2013) (Ethiopia)	n = 348 GA: ≥ 37 weeks	Within 2 days of birth	Males: 7.3% Females: 7.8%	-	-	
Lee et al. (2009) (United States of America)	n = 87 GA: 37-42 weeks	Within 2 days of birth	10.6%	-	-	Fetal high volume: Positive association with % BF.

Abbreviations: GA, Gestational age; GDM, Gestational Diabetes Mellitus; NGT, Normal glucose tolerance; BMI, Body mass index; GWG, Gestational weight gain; FM, Fat mass; FFM, Fat free mass; BF, Body fat.

2.4.2.6 Considerations in selecting a body composition assessment method

As described above, there are several body composition methods available, each one unique to its technique and body compartment(s) being measured. When selecting an assessment method, a number of considerations must be made, including body component(s) being measured; validation of the method in an appropriate population; availability of reference data and prediction equations; strengths and weaknesses of each method (assumptions, cost, feasibility, accuracy, skills required, subject cooperation); and prospect of repeated measurements in the planned investigation (Demerath & Fields, 2014). Hence, one single technique is often not suitable for all research questions and settings. Often a combination of the techniques may be used, which helps reduce discrepancies between methods and attain accurate data (Demerath & Fields, 2014). Due to the limitations of the techniques which can be used to measure body composition in early life it has been necessary to use a combination of different approaches including anthropometry, dilution techniques and DXA to obtain accurate reference data from birth to 2 years of age (Butte, 2000).

2.4.3 Body composition variation

Evidence suggests that a number of factors may play a role in programming infant body composition (Lee et al., 2009). Maternal diet, maternal body composition, insulin sensitivity, gender, and ethnicity, are some of the factors that have been investigated to be related to body composition and influence FM and FFM during infancy. All of the studies exploring this relationship have applied either one or a combination of body composition methods described above. Additionally, while most of the emerging evidence has been around the application of body composition methods to determine differences in FM and FFM, very few prospective studies have evaluated the significance of these differences. Furthermore, there is limited evidence regarding the implications of these differences in the amount of FM and FFM on later risk of chronic diseases.

2.4.3.1 Gender

Gender is one of the key factors that has been long recognised to impact body composition in infants. Some of the initial studies on the subject have found that full-term female infants were shorter, had higher fat mass and smaller head circumference than male infants (Vincent & Hugon, 1962; Gampel, 1965; Fomon, 1967). In addition, Farr (1996) used skinfold thickness to assess

gender differences in new-born infants and found that skinfold thickness values were significantly higher in females than in males at all sites measured. These findings maintained even after birth weight and length of gestation were held constant (Farr, 1966).

More recently, Paley et al. (2015) investigated whether gender differences in FM are present at birth or manifest later in life. A total of 332 infants were assessed for FM and FFM using ADP, and the findings of the study showed that males had significantly less FM than females at birth, however the mean difference varied according to the ethnicity (Paley et al., 2015). These findings were also supported by Simon et al. (2013), as the amount of FM was found to be greater in female term infants. Similarly, a study conducted on healthy new-born Indian infants assessed body composition using isotope dilution and reported birth weight and FFM to be higher in males as compared to females, but no gender difference was noted in FM (Jain et al., 2016). There is some emerging evidence suggesting that gender differences in neonatal body composition may be associated with the risk of chronic diseases and health outcomes in later life (Geer & Shen, 2009; Simon et al., 2013). However, links between specific conditions and gender differences in infant body composition are yet to be researched.

Previously there was little research regarding the differences in growth patterns between males and females. But a recent cohort study by Broere-Brown et al. (2016) assessed the effects of fetal sex on infant growth by using fetal biometry and anthropometric measurements post-delivery. The authors assessed a total of 8556 infants, and found that while males had a larger body length and were heavier in comparison to females, they had significantly smaller HC (Broere-Brown et al., 2016). Moreover, the differences in growth pattern between genders were greater with age (Broere-Brown et al., 2016). In addition, Carberry et al. (2010) also noted that gender differences in FM were greater at 4.5 months of age. Hence, It has been suggested that males have a very different growth pattern to females, and these differences are present during the fetal period as well as infancy (Carberry et al., 2010; Broere-Brown et al., 2016).

2.4.3.2 Ethnicity

Ethnicity is one of the non-nutritional, complex, and multidimensional concept that has been associated with differences in body composition. Statistics New Zealand defines ethnicity as "'A social group whose members have one or more of the following four characteristics: they share a sense of common origins; they claim a common and distinctive history and destiny; they possess

one or more dimensions of collective cultural individuality; they feel a sense of unique collective solidarity" (Statistics, 1988). As reflected in the definition, ethnicity is a self-perceived concept and hence it can often be difficult to collect accurate ethnic data, especially since many New Zealanders now identify with multiple ethnic groups (Callister, 2004; Callister et al., 2007). It is well documented that New Zealand population has changed due to high rates of migration and ethnic intermarriage, so too have the ways to classify and record ethnicity (Callister et al., 2007). For example, the introduction of "self-defined ethnic group" and increase in mutually exclusive ethnic groups.

Ethnic differences in FM and FFM have been reported in adults as well as children (Shaw et al., 2007; Paley et al., 2015). However, the recent focus has been on understanding the timings of when these differences begin to manifest and also the magnitude of difference between various ethnicities. There is growing evidence looking at ethnic differences in body composition at birth, using a number of different ethnicities and body composition methods (Shaw et al., 2007; Singh & Huston-Presley, 2010; Stanfield et al., 2012; Sletner et al., 2013; Paley et al., 2015; Jain et al., 2016). Paley et al. (2015) used ADP and skinfold thickness to determine if any body composition differences were present between Asian, Caucasian, African-American, and Hispanic infants shortly after birth. Interestingly, the authors found a strong association between ethnicity, gender and FM; at birth males from African-American, Asian, and Hispanic descent and females from African-American descent had significantly higher FM than Caucasians (Paley et al., 2015). The study also used the skinfold data to determine the location of fat deposits and found that African-Americans, Hispanic, and Asian infants had more amount of central fat deposition as compared to Caucasian infants (Paley et al., 2015). In addition, Singh et al. (2010) found that infants born to African-American mothers were lower in birth weight and FFM than infants born to Caucasian mothers. It is important to note that both the studies used the skinfold thickness method, which has been shown to be inaccurate for measuring adiposity in infants (Lingwood, 2013; Demerath & Fields, 2014). Longitudinal studies are required to better understand the implications of varying whole body and regional adiposity levels amongst these ethnic groups.

As there is a lack of understanding of the ethnic-specific nature of the association between infant body composition and various co-morbidities, ethnicities that are predisposed to certain health conditions are often included in these studies. Evidence shows that South Asians in particular have a high prevalence of metabolic disorders and Type 2 diabetes, which may be associated with their

body composition (Wulan et al., 2010; Stanfield et al., 2012; Jain et al., 2016). The London Mother and Baby Study by Stanfield et al. (2012) is a cross-sectional observational study that compared FM and FFM in UK-born South Asian and White European infants. The authors used ADP to attain FM and FFM values and found that South Asians had significantly less FFM than White Europeans (Stanfield et al., 2012). As a result, South Asian infants had greater FM and subscapular skinfold thickness than White European infants, despite their small body stature (Stanfield et al., 2012). These results were consistent with another UK based study that reported Asian Indian infants to be lighter and smaller than European infants, but with larger subscapular skinfold thickness (Wulan et al., 2010). In addition, when compared to Caucasian term infants from the UK, Indian neonates from Pune were found to have severe deficits in weight and waist circumference, but relatively modest deficits in skinfold thickness, especially on the trunk (Yajnik et al., 2003). The authors of the study have suggested that the Indian neonates are characterised by a 'thin–fat' phenotype, having reduced lean mass but preserved truncal fat, and hence a disproportionately high fat mass (Yajnik et al., 2003). Longitudinal evidence shows that these trends carry forward to childhood and adolescence, as South Asians continue to have lower FFM and higher percentage of FM, skinfold thickness, and wait to hip ratio as compared to Caucasians (Yajnik et al., 2003; Wulan et al., 2010; Jain et al., 2016). However, it remains unclear whether these ethnic differences in physique and body composition, represent the "thrifty gene" effect or "thrifty phenotype" effect that has been associated with low birth weight infants (Yajnik et al., 2003).

In New Zealand, adults and children from Māori or Pacific descent are represented at disproportionately high levels in the prevalence statistics for obesity and the associated health consequences (Ministry of Health, 2016a). To understand the determinants behind these ethnic inequalities in health status, New Zealand population has been subject to considerable research. According to the data from Report on Maternity (2004) by Ministry of Health, Asian infants had the lowest mean birth weight (3.24kg), while Pacific infants had the highest (3.56kg). In addition, Pacific infants were reported more likely to be heavier than infants from NZ European, Asian and Māori ethnicity (Ministry of Health, 2010). Sundborn et al. (2011) have gone one step further and reported significant differences in birth weight within the Pacific population in New Zealand. The study cohort included infants from Samoan, Tongan, Cook Island Māori, and Niuean ethnicity (Sundborn et al., 2011). The results showed that Cook Island Māori and Niuean infants were significantly lighter than Samoan infants (Sundborn et al., 2011). Interestingly, the infants of Pacific born mothers had higher birth weight than infants of New Zealand born mothers

(Sundborn et al., 2011). McCowan and Stewart (2004) have also reported significant ethnic differences in birth weight among New Zealand born infants and discussed the importance of ethnicity specific birth percentile charts. Based on the data from this study, Chinese infants were significantly heavier than Indian infants but smaller than European infants; Indian infants were significantly smaller, whereas Tongan and Samoan infants were significantly heavier from all other New Zealand ethnic groups included in the study (McCowan & Stewart, 2004). Furthermore, an internet-based birth cohort study conducted in New Zealand, also reported ethnic inequalities in infant body weight, with Pacific and Māori infants having higher values of weights in first week of life and at 3 months (Howe et al., 2015). These findings were also found to be independent of measured risk factors for obesity such as maternal age, pre-pregnancy physical status, maternal education, and socio-demographic variables (Howe et al., 2015). Thus, ethnic differences in weight trajectories in New Zealand are well documented and shown to begin in very early life. There is however limited data in New Zealand infants using other body composition techniques. Ethnic differences using techniques such as DXA, BIA, ADP and stable isotope dilution, have majorly only been explored in New Zealand adults and children. A series of studies conducted on New Zealand Māori, Pacific and European children (5 to 14 years of age) using BIA and isotope dilution found that Pacific Island and Māori girls had lower percentage body fat (% BF) compared to European, but no ethnic differences were noted for boys (Rush et al., 2003a; Rush et al., 2003b; Rush et al., 2009). In a recent study, Rush et al. (2015) used DXA to explore gender and ethnic differences in body composition of 1-3 year old children born to women on Metformin treatment during pregnancy. While no significant difference in body fat was noted between the ethnicities included (European, Indian, and Polynesian), Indian girls were found to be lighter and Polynesian heavier than European children (Rush et al., 2015). This study also states that no other studies in New Zealand have explored ethnic differences in body composition of very young European, Indian and Polynesian children (Rush et al., 2015). Hence, this highlights a need for evidence in New Zealand population that will help to better understand ethnic differences in infant body composition, obesity and related comorbidities.

2.4.3.3 Maternal characteristics

There are multiple maternal factors shown to be associated with infant growth and body composition. It is well known among practitioners that maternal obesity is a significant risk factor for macrosomic new-borns. In addition, obese or overweight women are also at risk for a multitude of potential medical conditions during gestation, which may directly impact infant's

health. Hull et al. (2008) reported a strong correlation between maternal BMI and infant birth weight and body composition. The findings showed that infants born to overweight/obese women (BMI ≥25 Kg/m^2) were heavier, had greater FM and FFM than infants born to lean women (BMI < 25 Kg/m^2) (Hull et al., 2008). Similar data were reported by Sewell et al. (2006) as the infants born to overweight/obese women with normal glucose tolerance levels had greater birth weight and increased FM.

Maternal anthropometric variables are also important factors that have shown to influence fetal growth parameters and birth weight. Evidence indicates that both maternal pregravid weights as well as gestational weight gain (GWG) are positively correlated to birth weight, especially in the case of nulliparous women (Catalano & Ehrenberg, 2006; Starling et al., 2015). Very few studies have investigated the correlation between infant body composition and GWG in specific stages of pregnancy (Whitaker & Dietz, 1998; Fraser et al., 2010; Starling et al., 2015). However, it has been proposed that gain in maternal fat stores during early and mid-pregnancy may be linked to offspring adiposity (Fraser et al., 2010; Starling et al., 2015). Also, unless adjusted for weight, maternal height has also been associated with an increase in birth weight (Catalano & Ehrenberg, 2006).

There is strong evidence suggesting a correlation between insulin sensitivity, birth weight and body composition (Catalano et al., 2003; Catalano & Ehrenberg, 2006; Sewell et al., 2006; Hull et al., 2008; Singh & Huston-Presley, 2010). Catalano et al. (1995) suggests that maternal insulin sensitivity during pregnancy has a much stronger correlation to birth weight than gestational weight gain. Furthermore, there is consensus that diabetes during pregnancy and increased pregravid body mass index (BMI) are associated with significant risk of larger birth weights. In 51 infants of mothers with gestational diabetes (GDM), Nasrat et al. (1997) found the birth weight and skinfold thickness to be significantly greater as compared to infants of non-diabetic mothers. The authors also reported that while the findings suggest a disproportionate pattern of growth in infants of diabetic mothers, these results may be influenced by variables other than maternal diabetes such as mother's ethnicity, pregravid weight, and genes (Nasrat et al., 1997). Another study that evaluated the body composition of infants born to women with normal glucose tolerance and GDM is by Catalano et al. (2003). On adjustment for factors such as maternal pregravid weight, ethnicity, smoking status, and maternal and paternal height, there was no significant difference in birth weight or FFM; however, infants of GDM mothers had significantly

greater FM (Catalano et al., 2003). In addition, evidence also indicates that level of insulin sensitivity pre-pregnancy may be related to the amount of FM at birth (Catalano & Ehrenberg, 2006).

Maternal diet during pregnancy has been shown to influence fetal growth and body composition. Animal models have consistently demonstrated a relationship between maternal high fat diet and higher offspring adiposity and birth size (McCurdy et al., 2009; Krasnow et al., 2011; Ashino et al., 2012; Franco et al., 2012; Parlee & MacDougald, 2014). However, the evidence supporting this relationship in human population is only recently emerging. The Healthy Start study is a large cohort study that assessed the influence of maternal macronutrient intake during pregnancy on infant body size and body composition (Crume et al., 2016). Among 1410 mother-infant pairs in Colorado, Crume et al. (2016) found increased maternal dietary intake of all macronutrients except protein (total fat, saturated fat, unsaturated fat, and total carbohydrates) to be significantly associated with increased infant FM. However, after adjustment for maternal pregravid BMI these differences were no longer statistically significant; hence the authors suggest maternal obesity to be more strongly associated to infant body composition than maternal diet. In addition, there was no association reported between maternal macronutrient intake and birth weight or infant FFM (Crume et al., 2016). The same cohort was used by Shapiro et al. (2017) to investigate the association between infant body composition and maternal diet high in dietary niacin and fat. While niacin or vitamin B3 has been found to influence adipose tissue growth in animal models, no significant association was noted in this study (Shapiro et al., 2017). The findings also showed that maternal high fat diet during pregnancy was significantly related to infant FM, but not with FFM or birth weight. The results from these studies may relate to the speculation that FM is a more sensitive indicator of the maternal in-utero environment and of nutritional status, whereas FFM may have a greater genetic influence (Sparks, 1984; Catalano et al., 2003; Knight et al., 2005).

There is some evidence that infant body composition may be affected by physical activity during pregnancy, particularly in the later stages of pregnancy (Clapp et al., 2000; Clapp et al., 2002; Hopkins et al., 2010). Using the cohort from the Healthy Start study, Harrod et al. (2014) found an inverse association between total energy expenditure during late stages of pregnancy and infant FM. There were no significant relationship found between energy expenditure and infant FFM or birth weight (Harrod et al., 2014). A recent study by Bisson et al. (2016), also supported these

findings and reported that intensity of physical activity may also influence infant body composition, with vigorous intensity related to reduced birth weight and FM.

Other maternal factors such as age, parity and education have not been shown to influence infant body composition (Stanfield et al., 2012; Baidal et al., 2016).

2.5 Summary

It is well established that birth weight, head circumference, and length are important indicators of pregnancy outcomes. Early studies have used birth weight as an index of fetal growth and also a predictor of subsequent disease risks. However, studies that have associated birth weight with health risks in adulthood remain controversial, and require confirmation using more sophisticated methodologies. Recent advances in the ability to measure body composition in infants offer a major opportunity to improve the understanding of fetal growth, intrauterine environment, overall health, and nutrition status. A variety of methods are available to measure body composition in infants, each method varying in technique, complexity, assumptions, and limitations. Air displacement plethysmography (ADP) has been found to be a feasible and accurate method to measure FM and FFM in infants.

Recently, there is accumulating evidence showing a correlation between the ethnicity and infant body composition. Comparative studies in both high and low income countries have reported ethnic differences in birth weight, FM and FFM values. While ethnic differences in weight trajectories in New Zealand infants are well documented, there is limited evidence using other body composition methods. To date, no studies in New Zealand have measured FM and FFM in new-born infants using ADP. Hence, further studies are needed exploring the use of different body composition methods in New Zealand infants.

Chapter 3 Research manuscript

3.1 Abstract

Background:

Ethnic differences in fat mass (FM) have been reported in adults and children but it is currently unknown whether these differences are evident shortly after birth. Significant differences in birth weight, which comprises FM and fat free mass (FFM), have been observed in different ethnic groups in New Zealand (NZ). The aim of this study was to examine the differences in FM and FFM using air displacement plethysmography (ADP) between NZ European (reference group), Māori, Pacific, Asian and South Asian healthy term infants.

Method:

Body composition, including FM and FFM, weight, length, head circumference (HC) and waist circumference (WC), was measured in a convenience sample of healthy term infants (n=214) shortly after birth. Ethnicity was classified using standard ethnicity data protocols. Statistical analysis included t-tests and multiple linear regression analysis.

Results:

Body composition was assessed at a mean age of 1.7±0.85 days, while adjusting for gender and postnatal age. South Asian infants had significantly lower FFM (2691.7±389.7g vs 2938.6±364.0g, *P*= 0.006) and weight than NZ European infants (3045.5±535.2g vs 3352.3±575.8g, *P*= 0.014). They also had the smallest HC (34.2±1.7cm vs 35.4±1.7cm, *P*=0.002) and WC (31.5±3.0cm vs 33.2±2.1cm, *P*= 0.003). The WC of Asian infants was also significantly smaller than NZ European infants (32.3±2.1cm vs 33.2±2.1cm, *P*=0.044). When categorised by gender, males had significantly greater FFM, weight, length and HC ($p< 0.05$). No gender or ethnic difference was noted in FM (g) or %FM.

Conclusion:

This is the first study in New Zealand to report body composition in healthy term infants using ADP and the findings justify further prospective investigation in a representative sample size to investigate the significance of the differences identified.

3.2 Background

In New Zealand, there is considerable interest in measuring disparities across different ethnicities and also within a particular ethnic group. Ethnic inequalities in health status of New Zealand population are well established (Ministry of Health, 2016a). In comparison to New Zealand European, Māori and Pacific populations are represented at disproportionately high levels in the prevalence statistics for obesity and associated health risks (Ministry of Health, 2016a). To understand the determinants behind these ethnic discrepancies in health status, the New Zealand population has been subject to considerable research. Yet, it needs to be recognised that ethnicity is a complex concept that cannot be easily identified or measured (Callister, 2004; Callister et al., 2007; Bisley, 2008). With many New Zealanders reporting mixed ethnicities or reporting only one ethnicity despite their mixed heritage, this can make ethnic data collection a very challenging process (Callister et al., 2007). The methods for collection and reportage of ethnicity data in New Zealand are regularly adapted to take into account the continuous transformation and increasing heterogeneity of our population (Callister, 2004; Callister et al., 2007; Bisley, 2008). Nonetheless, there are various factors (such as: ethnic affiliation, ethnic intermarriage, migration) that must be considered when analyzing ethnic data (Kukutai, 2004; Howard & Didham, 2007; Bisley, 2008).

Existing research in New Zealand adults and children shows a strong correlation between body composition and ethnicities (Rush et al., 1997; Rush et al., 2003b; Duncan et al., 2004; Howe et al., 2015). Evidence also suggests that these differences can start during early years of life and can carry forward to adulthood (Fields et al., 2011). While, significant differences in mean body weights have been noted in New Zealand born infants of different ethnic groups, there is limited body composition research in new-borns using techniques other than body weight (McCowan & Stewart, 2004; Howe et al., 2015). The paucity of literature assessing body composition in New Zealand infants may partly be due to the absence of safe, reliable, and accurate techniques that can be routinely used in the clinical setting. Techniques such as bioelectrical impedance analysis (BIA), isotope dilution, and dual-energy X-ray absorptiometry (DXA) are potentially invasive for the infant and often impractical for clinical use in the paediatric population (Rigo et al., 1998; Wrottesley et al., 2016).

The introduction of newer methods such as Air Displacement Plethysmography (ADP), has now made it possible to safely measure body composition in infants and estimate fat mass (FM) and fat

free mass (FFM) at different stages of growth (Carberry et al., 2010). Hence, it provides a major opportunity to investigate the body composition of New Zealand infants and study factors (such as ethnicity) that may affect infant FM and FFM. In this cross-sectional observational study, we used ADP to examine FM and FFM in New Zealand-born full term infants. The study also investigated whether ethnic differences in body composition are present at birth.

3.3 Methods

3.3.1 Study design

This was a cross-sectional observational study designed to explore the relationship between ethnicity and fat mass and fat free mass in healthy term infants.

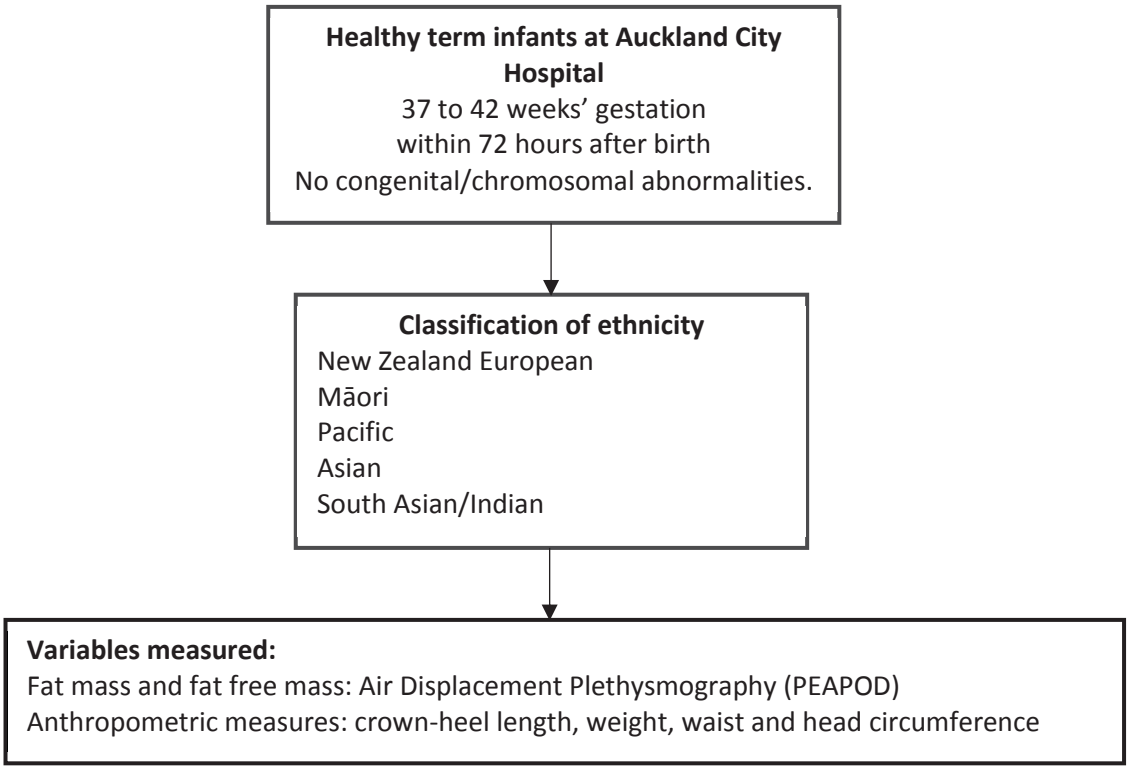

Figure 3.1 *Flow diagram detailing the study design*

3.3.2 Participants

The study population was healthy term infants born between 37 to 42 weeks of gestation. The exclusion criteria included infants with known chromosomal or genetic abnormalities, congenital disorders affecting growth, inborn error of metabolism, or respiratory distress syndrome. Infants were also excluded if their mothers had any medical conditions during pregnancy that could potentially impact body composition such as hypertension, polycystic ovarian syndrome,

gestational diabetes and pre-eclampsia. Due to the observational nature of the study and convenience sample size, twins and small for gestational age (SGA) or large for gestational age (LGA) infants were not excluded from the study sample.

3.3.3 Recruitment

Infants were recruited between May 2015 and August 2016 from National Women's Health post-natal wards at Auckland City Hospital (ACH), Auckland District Health Board (ADHB), New Zealand. All eligible participants were identified using the information available on the ward/patient list (such as gestational and postnatal age), but only approached upon consulting the respective nurse or midwife caring for the mother. Medical notes were used to gather infant birth parameters, maternal medical history, parity, and type of delivery. Any mothers or infants suffering from serious medical conditions or birth related stress/trauma were not approached. Information about the study was provided verbally by research staff and through a copy of participant information sheet (Appendix 2). They were also encouraged to discuss the study with family/whānau or healthcare professionals (midwife or nurse). Parents who expressed interest in taking part were required to provide written consent and a time for the measurement was organised based on their availability and feeding regime of the infant. Measurements were undertaken prior to feeding or at least an hour after the feed.

3.3.4 Sample size

It was calculated that a total of 350 babies (70 babies in each group) will provide no less than 90% power at a 1% level of significance (allowing for adjustment for multiple groups) to detect a difference of 2.4% lean body mass between the groups assuming a standard deviation of 4.3% (Hawkes et al 2011).

3.3.5 Classification of ethnicity

Ethnicity of the infants and mothers was classified and recorded according to the "Ethnicity Data Protocols for the Health and Disability Sector" and Statistics New Zealand 2001 Census (Statistics New Zealand, 2001; Ministry of Health, 2004, 2016b). As the participants were newborns, parent(s) were given the opportunity to report the ethnicity of their infant. If parents reported multiple ethnicities for their infant, a maximum of three ethnicities were recorded. All the ethnicities were coded according to the classification structure described in the ethnicity data

protocols. Prioritisation output method was used to assign infants to a single ethnic group and to ensure each participant appears only once so the sum of the ethnic group populations adds up to the total study sample size. If Māori was reported as one of the multiple responses by the parent(s), the infant was prioritised as Māori. If one or more of several Pacific Island ethnicities was reported (but not Māori), infants were classified as Pacific. Similarly, if parent(s) reported South East Asian or Indian as their infant's ethnicity (but not Māori or Pacific Island), infants were classified as South East Asian. Infants from Chinese or more of several Asian ethnicities (but not Māori, Pacific Island, Indian, or South East Asian) were classified as Asians. Infants with only New Zealand European as their reported ethnicity were classified as NZ European.

3.3.6 Body composition

Air Displacement Plethysmography (ADP) system (PEA POD Cosmed Ltd) was used to determine fat and fat-free mass in infants. The details regarding the operating principles of the ADP system have been described previously (Sainz & Urlando, 2003; Urlando et al., 2003; IAEA, 2013). Briefly, the ADP system utilises the principles of whole body densitometry to estimate percentage and absolute amounts of fat and fat free mass.

In the present study, the ADP system was calibrated daily prior to testing and research staff who were trained to use the system performed the measurements. The infant was placed in the testing chamber unclothed except for a stocking cap to flatten the hair, identification bands and a plastic umbilical cord clamp. Identical items were placed on the inbuilt electronic scales and in the empty chamber during calibration. The measurement process took approximately two minutes and the door of the room was kept shut during the measurement processes. All the infants in the study were measured within the first 72 hours after birth (day 0-3), as it allowed the best feasible estimate of the neonatal body composition, while minimising the effect of postnatal factors such as the feeding regimen.

3.3.7 Anthropometry

Crown-heel length, weight, head circumference (HC) and waist circumference (WC) were measured by trained researchers using standardised methods (World Health Organization, 2008). Infant length (average of three measurements) was measured with a Holtain Limited Harpenden Neonatometer to the nearest 0.1 cm. Body weight was determined to the nearest 0.1 kilogram prior to body composition measurement, using the tared and calibrated electronic scales on the

ADP system as described above. The HC and WC were measured to the nearest millimetre using a disposable paper tape measure. Birth parameters for weight, length and head circumference were retrieved from the infant's medical record.

3.3.8 Ethical approval

Ethical approval for this study was obtained from the Health and Disability Ethics Committee (HDEC) (15/STH/S2). Auckland District Health Board (ADHB) research office approval (Ref. No. A+6691) was sought to recruit and measure infants at Auckland City Hospital. The study protocol was also reviewed and approved by a Māori advisor at ADHB. Informed written consent was obtained from all the parents prior to the assessment of their infants.

3.3.9 Data analysis

All data was coded and entered into Microsoft Excel and SPSS for statistical analysis (IBM SPSS Inc., Version 23, Chicago, IL, USA). All the variables were tested for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests. As all the predictor variables were normally distributed ($p > 0.05$), t-tests were used to compare two independent groups (e.g. comparison of fat mass between males and females). Categorical variables were presented as frequencies and percentages. All parametric data was expressed as mean ± SD, unless otherwise specified.

Multiple linear regression was used to predict the contribution of ethnicity, gender and age to each of the independent variables tested, these being: FM (g), FFM (g), FM (%), FFM (%), weight (g), length (cm), HC (cm), WC(cm), and waist to length ratio (WLR).

All assumptions for the regression model were met. Due to low participant numbers in the Māori and Pacific groups, these two groups were combined following determination of no significant differences between groups in the independent variables being considered. New Zealand European infants were used as reference, since numerous comparative studies have measured body composition in Caucasian and European infants using similar methods (Eriksson et al., 2010; Wulan et al., 2010; Stanfield et al., 2012). Due to the observational nature of the study, New Zealand European was the only ethnic group to have 70 or more infants and had sufficient statistical power to be a reference group. All the four ethnic groups were transformed into dummy variables by assigning the value of 1 to the first group in the dummy variable and 0 to all the other groups for this variable (New Zealand European= 1, Else=0; Māori-Pacific=1, Else=0; Asian=1,

Else=0; South Asian=1, Else=0). Gender also was coded as a dummy variable, where female=0 and males=1. All the dummy variables, except the reference group (New Zealand European dummy variable) were added to the regression analysis, along with postnatal age and dummy variable for gender (males=1, else=0). The values for ß (parameter coefficient), s.e.m (standard error of mean), R^2 (%) (coefficient of determination), and P (probability) were noted for all the predictor variables in each ethic group. P values <0.05 were considered as significant.

3.4 Results

3.4.1 Description of participants

A total of 282 infants and their mothers were recruited, 68 infants were excluded due to a variety of reasons (see Figure 3.2).

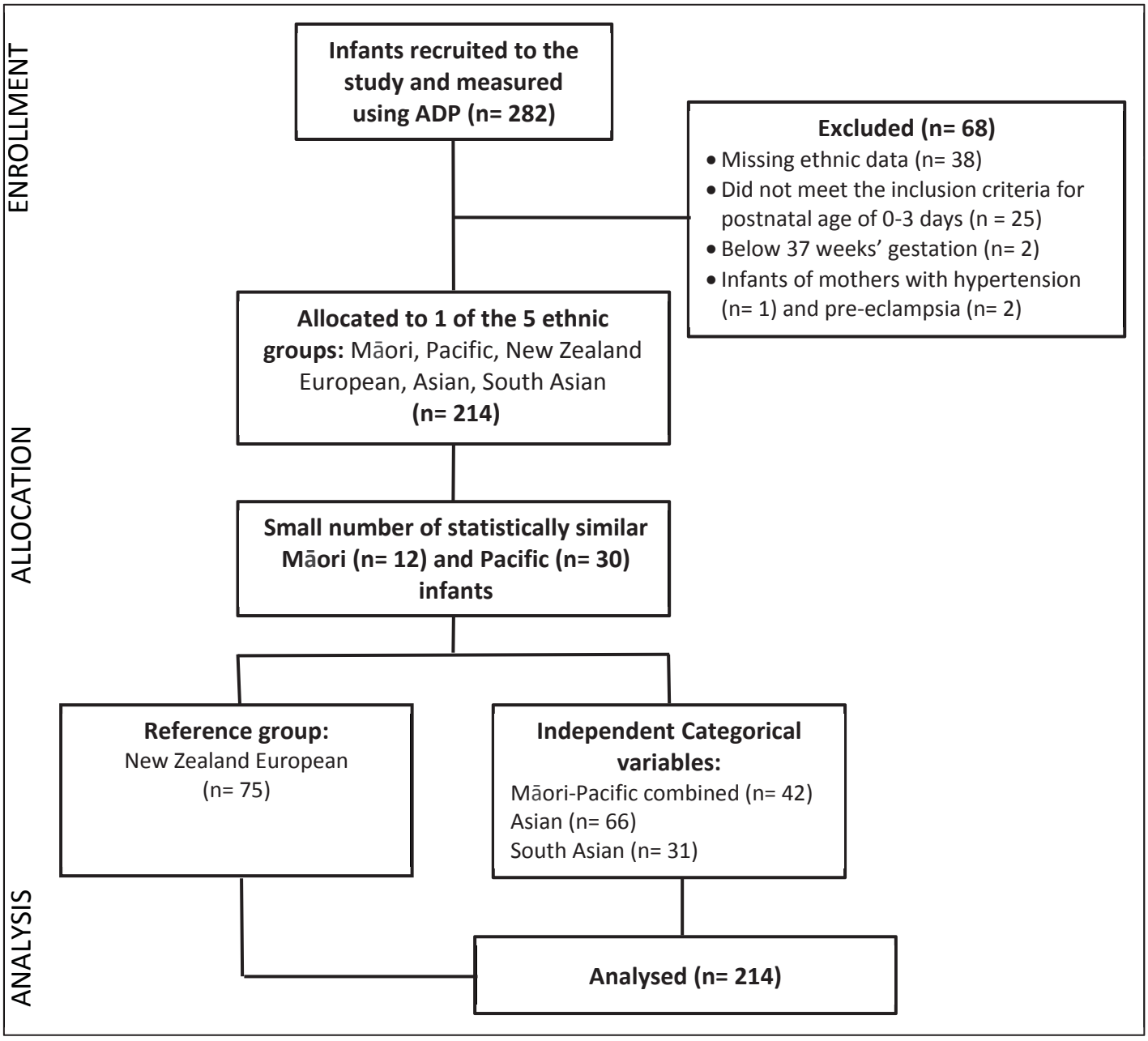

Figure 3.2 Flow diagram of recruitment and categorizing study participants

To detect significant differences in fat mass (FM) and fat free mass (FFM) between ethnic groups would have required 70 infants in each group. In this convenience sample only New Zealand European group had over 70 infants (n=75) and Māori group had the lowest number of infants

(n=12). Due to the small number of Māori infants, we grouped them with Pacific infants, since Māori and Pacific infants were not statistically different in each of the following variables: percentage FM (P= 0.835), percentage FFM (P= 0.936), absolute FM in grams (P= 0.768), absolute FFM in grams (P= 0.967), weight (P= 0.882), length (P= 0.885) , HC (P= 0.342), WC (P= 0.890), and WLR (P= 0.354) (See Appendix 2). We were unable to collect ethnic data for a total of 38 infants. This was due to the practical issues associated with measuring infants in a clinical setting such as infant/parent distress, parents not available in the assessment room, or other family members accompanying the infant instead. In addition, as all the infants included in the study were healthy term born infants, they were discharged to their homes or Birthcare Maternity Hospital (postnatal care) relatively quickly and we did not have permission to follow up the participants or access their medical notes after discharge.

The characteristics of the participants at ≤ 72 hours after birth are presented in Table 3.1. The majority of the infants in this study were of European descent (35.0 %), closely followed by Asian (30.8%). The number of male participants was approximately 10% greater than females. Most of the infants (99.2%) were from singleton birth and categorised as appropriate for gestational age (AGA) (99.2%). All the infants included in the final analysis were born at 37-42 completed weeks of gestation and measured within 72 hours post birth.

Table 3.1 *Characteristics of the study sample (n= 214)*

Characteristics	Mean ± SD or N (%)
Gender	
Males	121 (56.5)
Females	93 (43.5)
Ethnicity†	
New Zealand European*	75 (35.0)
Māori-Pacific combined	42 (19.6)
Asian	66 (30.8)
South Asian/Indian	31 (14.5)
Gestational age (weeks)	39.3 ± 1.2
Birth length (cm)	51.1 ± 2.8
Birth Head circumference (cm)	35.0 ± 1.9
Birth weight (g)	3428.3 ± 522.9
Birth weight categories	
<2500 g (SGA)	2 (0.9)
2500–3000 g (AGA)	205 (95.8)
> 4300 g (LGA)	7 (3.3)
Birth Plurality	
Singleton	212 (99.1)
Twins	2 (0.9)
Triplets	0

Results are presented as number (%) for categorical variables, mean ± standard deviation for continuous variables. ***†*** *Ethnic groups as derived from "Ethnicity Data Protocols for the Health and Disability Sector" and SNZ 2001 Census.*
**New Zealand European was the reference/baseline group.*
Abbreviations: SGA, Small for gestational age; AGA, Appropriate for gestational age; LGA, Large for gestational age.

3.4.2 Infant anthropometry and body composition by gender

The comparison of anthropometry and body composition of males and females is presented in Table 3.2. Females were significantly shorter (P= < 0.001) and lighter than males (P= 0.010). Females also had significantly lower FFM (P= < 0.001) and had significantly smaller head circumference (P= < 0.001) than males. The deficit in body weight was accounted for by the significantly lower FFM in females. There was no significant difference between genders in fat mass or percentage total body fat.

Table 3.2 Comparison of anthropometry and body composition between male and female infants

Variables	Males (n= 121)	Females (n= 93)	P value*
Fat Mass (%)	10.4 ± 4.1	10.8 ± 4.3	0.458
Fat Free Mass (%)	89.5 ± 4.0	89.0 ± 4.2	0.480
Fat Mass (g)	359.8 ± 165.1	347.2 ± 179.5	0.599
Fat Free Mass (g)	2970.3 ± 371.9	2764.3 ± 359.3	0.000*
Weight (g)	3329.4 ± 469.9	3133.9 ± 594.4	0.008*
Length (cm)	51.5 ± 3.6	49.8 ± 3.0	0.000*
Head circumference (cm)	35.4 ± 1.8	34.6 ± 1.6	0.002*
Waist circumference (cm)	32.7 ± 2.3	32.3 ± 2.3	0.140
Waist : Length ratio	0.64 ± 0.06	0.65 ± 0.07	0.073

**Significant difference between groups P <0.05 (Independent t-test).*

3.4.3 Infant anthropometry and body composition by ethnicity

The description of anthropometric and body composition parameters for all four ethnic groups is provided in Tables 3.3.

Table 3.3 Description of anthropometry and body composition by ethnicities

Variables	New Zealand European (n= 75) Mean ± SD	Māori-Pacific (n= 42) Mean ± SD	Asian (n= 66) Mean ± SD	South Asian (n= 31) Mean ± SD
Weight (g)	3352.3 ± 575.8	3220.6 ± 578.4	3230.4 ± 424.7	3045.5 ± 535.2
Length (cm)	51.2 ± 3.3	50.2 ± 3.9	51.1 ± 3.7	49.9 ± 2.6
HC (cm)	35.4 ± 1.7	35.1 ± 1.6	34.9 ± 1.8	34.2 ± 1.7
WC (cm)	33.2 ± 2.1	32.6 ± 2.0	32.3 ± 2.1	31.5 ± 3.0
WLR	0.65 ± 0.06	0.66 ± 0.08	0.63 ± 0.04	0.64 ± 0.07
% FM	10.7 ± 4.1	9.4 ± 4.5	11.2 ± 3.9	10.7 ± 4.9
%FFM	89.2 ± 4.0	90.6 ± 4.5	88.7 ± 3.8	89.3 ± 4.9
FM (g)	363.9 ± 157.8	313.6 ± 187.9	373.85 ± 158.8	343.2 ± 202.0
FFM (g)	2938.6 ± 364.0	2927.5 ± 446.0	2875.1 ± 323.7	2691.7 ± 389.7

Abbreviations: FM, Fat Mass; FFM, Fat Free Mass; HC, Head Circumference; WC, Waist Circumference; WLR, Waist: Length Ratio.

Direct comparison of each ethnic group to the reference group can be seen in Table 3.4. The beta (ß) value indicates the change in the outcome due to unit change in the predictor variables. As dummy variables were used for the analysis, a unit change in the predictor is the change from 0 to 1. As all the dummy variables were analysed in the same regression analysis, the value of 0 represents the baseline category (New Zealand European) and the value of 1 represents all the other ethnic groups. R^2 (%) represents the proportion of variances between the ethnic groups when compared to New Zealand European.

There were significant differences between ethnicities after controlling for postnatal age and gender (See 3.4). As already noted, South Asian infants were smaller than their New Zealand European counterparts. They had significantly smaller HC (34.2 ± 1.7 vs 35.4 ± 1.7; P= 0.002), smaller WC (31.5 ± 3.0 vs 33.2 ± 2.1; P= 0.004), weighed less (3045.5 ± 535.2 vs 3352.3 ± 575.8; P= 0.015); and had lower FFM (2691.7 ± 389.7 vs 2938.6 ± 364.0; P= 0.009). In addition, infants from

Asian descent had significantly smaller WC than New Zealand European (32.3 ± 2.1 vs 33.2 ± 2.1; P= 0.049). No significant differences in absolute or percentage FM were noted between groups.

Table 3.4 *Multiple linear regression analysis for predicting infant anthropometry and body composition differences between three ethnic pairs (NZE vs Māori-Pacific; NZE vs Asian; NZE vs South Asian), after adjusting for postnatal age and infant gender.*

Model 1 Weight (g) (R^2= 0.066)		**ß (S.E.M)**	**P value**
	NZE vs Māori-Pacific	-94.726 (104.196)	0.364
	NZE vs Asian	-124.725 (90.109)	0.168
	NZE vs South Asian	-277.678 (113.205)	0.015*
	Postnatal age	29.775 (43.535)	0.495
	Gender	178.871 (74.321)	0.017*
Model 2 Length (cm) (R^2= 0.077)		**ß (S.E.M)**	**P value**
	NZE vs Māori-Pacific	-0.761 (0.674)	0.260
	NZE vs Asian	-0.209 (0.579)	0.719
	NZE vs South Asian	-1.129 (0.733)	0.125
	Postnatal age	0.200 (0.279)	0.473
	Gender	1.569 (0.480)	0.001*
Model 3 HC (cm) (R^2= 0.098)		**ß (S.E.M)**	**P value**
	NZE vs Māori-Pacific	-0.250 (0.336)	0.459
	NZE vs Asian	-0.522 (0.291)	0.074
	NZE vs South Asian	-1.148 (0.364)	0.002*
	Postnatal age	-0.162 (0.139)	0.245
	Gender	0.742 (0.240)	0.002*
Model 4 WC (cm) (R^2= 0.063)		**ß (S.E.M)**	**P value**
	NZE vs Māori-Pacific	-0.467 (0.473)	0.324
	NZE vs Asian	-0.777 (0.392)	0.049*
	NZE vs South Asian	-1.444 (0.490)	0.004*
	Postnatal age	0.100 (0.187)	0.594
	Gender	0.448 (0.327)	0.172
Model 5 WLR (cm) (R^2= 0.028)		**ß (S.E.M)**	**P value**
	NZE vs Māori-Pacific	0.005 (0.13)	0.713
	NZE vs Asian	-0.013 (0.11)	0.244
	NZE vs South Asian	-0.010 (0.014)	0.443
	Postnatal age	-0.001 (0.005)	0.788
	Gender	-0.015 (0.009)	0.111

Model 6 **FM (g)** **(R^2= 0.019)**		**ß (S.E.M)**	**P value**
	NZE vs Māori-Pacific	-54.401 (34.425)	0.116
	NZE vs Asian	7.270 (29.401)	0.805
	NZE vs South Asian	-23.882 (37.630)	0.526
	Postnatal age	-7.610 (14.375)	0.597
	Gender	6.555 (24.432)	0.789
Model 7 **FFM (g)** **(R^2= 0.118)**		**ß (S.E.M)**	**P value**
	NZE vs Māori-Pacific	26.401 (34.425)	0.710
	NZE vs Asian	-66.482 (-0.081)	0.284
	NZE vs South Asian	-209.939 (79.205)	0.009*
	Postnatal age	24.646 (30.257)	0.416
	Gender	198.919 (51.426)	0.000*
Model 8 **FM (%)** **(R^2= 0.031)**		**ß (S.E.M)**	**P value**
	NZE vs Māori-Pacific	0.494 (0.722)	0.495
	NZE vs Asian	-1.513 (0.846)	0.075
	NZE vs South Asian	-0.179 (0.925)	0.847
	Postnatal age	-0.268 (0.353)	0.449
	Gender	-0.598 (0.600)	0.321
Model 9 **FFM (%)** **(R^2= 0.033)**		**ß (S.E.M)**	**P value**
	NZE vs Māori-Pacific	-0.409 (0.709)	0.564
	NZE vs Asian	1.627 (0.830)	0.051
	NZE vs South Asian	0.331 (0.907)	0.716
	Postnatal age	0.317 (0.346)	0.362
	Gender	0.563 (0.589)	0.340

**Significant difference between groups P <0.05.*

Multiple linear regression using dummy variables was used to compare differences in body composition (FFM and FM) and anthropometry (weight, length, HC, WC, WLR) between ethnic groups, adjusted for infant age at measurement and gender.

Abbreviations: FM, Fat Mass; FFM, Fat Free Mass; HC, Head Circumference; WC, Waist Circumference; WLR, Waist: Length Ratio.

3.5 Discussion

The aim of this cross-sectional observational study was to explore ethnic differences in body composition of New Zealand-born healthy term infants. While this study sample was a convenience sample and not representative of the national population, we found South Asian infants were the smallest and had lowest FFM, as compared with their New Zealand European counterparts. To our knowledge, this is the first study in New Zealand to report body composition in healthy term infants using ADP. The study highlights various methodological challenges with regard to identifying, measuring and then categorising study participants into ethnic groups. This information will potentially inform future researchers about the practical considerations to be made when assessing ethnic differences.

3.5.1 Characteristics of participants

The participants in the study were recruited from Auckland City Hospital (ACH), which has one of the largest maternity services in New Zealand (Auckland District Health Board, 2016, 2017). In 2015, of mothers attending maternal services at ACH 6.8% identified as Māori, 11.6% Pacific, 9.5% Indian, 22.8% Other Asian, 11.9% Other European, 33.0% NZ European, and 4.3% Other ethnicities (Auckland District Health Board, 2015). Hence, ACH provided an ideal setting for recruiting infants from different ethnicities. Furthermore, unlike some of the other comparative studies, all the infants measured were born in the same country (New Zealand). This is an important strength of the study, as it reduces the influence of difference in maternal environment during pregnancy. While conducting the study in a clinical setting facilitated the recruitment of new-born infants, it also meant that we had a short timeframe to measure the eligible infants and attain all the required information before they were discharged to their home or Birthcare Maternity Hospital (postnatal care) services. In addition, often infants and/or parents had other medical procedures and assessments which were a priority and sometimes resulted in a missed opportunity for measuring those infants. Ideally a convenience sample in a clinical setting would have measured every healthy term baby who met the criteria and were born within the timeframe of the study.

We analysed 214 healthy full term infants. The average gestational age of all the participating infants was 39.3 weeks. The average birth weight of the participants was 3.43 kg (Table 3.1). This value is comparable to the average birth weights of 3.42 kg for all New Zealand births in 2010 (Ministry of Health, 2010).

The study population included 35.0 % New Zealand European, 30.8% Asian, 14.5 % South Asian, 5.6% Māori, and 14.0% Pacific. The ethnic groups in our study have similar ethnic profile to those reported at ACH. With small number of infants in each ethnic group meant we had limited statistical power to examine ethnic differences in body composition between the reference group (NZ European) and other four ethnicities (Asian, South Asian, Māori, and Pacific).

3.5.2 Ethnic differences

Our finding of South Asian infants being significantly smaller, lighter and having lower FFM than European infants is in agreement with previous research (Wulan et al., 2010; Stanfield et al., 2012; Jain et al., 2016). Similar to our observations, Stanfield et al. (2012) reported South Asian infants to be lighter in weight, have smaller HC and WC, lower FFM, and greater FM than White European infants. It is noteworthy that only infants with mother and father from the same ethnicity ("Asian" or "White") were eligible to participate in their study (Stanfield et al., 2012). Although, applying these restrictions would have minimised the potential impact of mixed ethnic background on infant body composition, the ethnic mix may not be representative of the London (United Kingdom) population being measured (Stanfield et al., 2012). Having a strict eligibility criteria may be one of the reasons for low sample size (n= 60) of the study (Stanfield et al., 2012). With many New Zealanders now identifying with multiple ethnic groups (Callister et al., 2007) and due to convenience sampling, many parents in the current study reported their infants to be of mixed ethnicity.

The Pune Maternal Nutrition Study was one of the initial studies to compare adiposity in Pune-born Indian infants with UK-born White European infants (Yajnik et al., 2003). The Pune study found that Indian infants had a small stature but larger subscapular skinfold thickness, indicating higher level of adiposity (Yajnik et al., 2003). As the "South Asian" ethnic group in our study also included some infants from Indian descent, these results by Yajnik et al. (2003) are relevant but cannot be compared directly to our findings. This highlights the point that terminology is of great importance when discussing ethnicities; for instance, the umbrella terms like "South Asian" and "Asian" characterises a large and diverse portion of the world's population. Also, important to note in that study is that ethnicity of the infants was not directly recorded, they were categorised as Indian or White-Europeans depending on their country of birth (Yajnik et al., 2003). This reflects that ethnicity can be classified and recorded in a number of different ways, each with its own limitations. In addition, the differences in techniques used to estimate adiposity in infants added

to the difficulty in comparing our results to other studies.

There is some speculation that low FFM and high FM in South Asians may represent the "thrifty gene" effect and they may be linked to ethnic inequalities in health status in later life. This phenotype is particularly regarded as an important contributing factor to the high incidence of Type 2 Diabetes and Chronic Heart Disease (CHD) in this ethnic group (Yajnik et al., 2003; Jain et al., 2016). Similar to other comparative studies, our findings that South Asian infants had small stature and less FFM may align with the "thrifty gene" effect, but this would need to be examined in a prospective study which assessed body composition in early life and later health outcomes (Yajnik et al., 2003; Sletner et al., 2013; Jain et al., 2016).

There were no significant differences found in anthropometric and body composition outcomes between the Māori-Pacific and reference groups. This may be due to insufficient number of infants in the Māori-Pacific ethnic group. A number of other factors such as ethnic intermarriages and ethnic affiliation of the parents, may have also influenced the accuracy of ethnic data and overall results.

Infants categorised in the Asian ethnic group had significantly smaller WC in comparison to New Zealand European infants. The significance of this finding is unclear, as difference in WLR between the two ethnic groups was not significant and WC measurement alone is not commonly used to assess body composition in infants. There is no unified methodology for determination of WC in newborns and it can be influenced by several factors: feeding or defecation, phase of breathing, resistance of the anterior abdominal wall, visceral fat (Meldere et al., 2013). Hence, standardized values for neonatal WC have not been determined yet.

3.5.3 Ethnicity classification and its challenges

Ethnicity is a very important dimensional variable in clinical/epidemiological research (Callister, 2004; Callister et al., 2007). Throughout the world there have been historical shifts around the concepts of ethnicity and ways to measure and report ethnic data (Callister, 2004). In New Zealand, the concept of ethnicity has evolved to revolve around culture; however, key factors such as nationality, country of birth, race, cultural beliefs and religion continue to influence the understanding of ethnicity among individuals and add to the complexities of ethnic data collection (Kukutai, 2004; Howard & Didham, 2007; Bisley, 2008).

Due to high rates of ethnic intermarriages in Māori and Pacific populations in New Zealand, strong variations have been noted within various ethnic groups (Callister, 2004; Howard & Didham, 2007; Bisley, 2008). Existing research in New Zealand suggests that because of high migration rates, the population is undergoing continuous transformation and becoming more heterogeneous (Callister, 2004; Callister et al., 2007; Bisley, 2008). In addition ethnic response may be entirely based on affiliation, which may lead to individuals reporting only one ethnicity despite their mixed ethnic heritage (Callister et al., 2007). Perez (2006) also reports that the ethnic affiliation of the parent reporting the ethnicity of their child or infant may also influence their response. Others factors such as age, context, and environment have also been shown to impact ethnic responses (Callister et al., 2007). Therefore, attaining a true picture of the ethnic distribution is challenging and requires methods that can capture these multiple ethnic identities with minimal loss of information.

Focusing on Pacific population, there are notable cultural differences between islands of origin (such as: Samoan, Cook Island), but this information is often lost when collecting ethic data (Bisley, 2008). Pacific populations also have high a rate of ethnic intermarriage; evidence indicates that ethnic intermarriages can sometimes lead to complex outcomes in terms of cultural/resource sharing and ethnic identity. (Bisley, 2008). Data collected from 42,160 Pacific children showed that approximately 54% of the children had mixed ethnicities (Bisley, 2008). Statistics on New Zealand births record indicate that 69 percent of Māori infants and 50 percent of Pacific infants belonged to two or more ethnic groups (Statistics New Zealand, 2011). In contrast, 67 percent of European babies and 72 percent of Asian babies belonged to only one ethnic group (Statistics New Zealand, 2011). This again highlights the complexities inherent to any ethnic analysis.

Terminology is of great importance when discussing ethnic data. Rasanathan et al. (2006) discusses some valid points about using the term “Asian” when categorising individuals by ethnicity. According to the authors, the category “Asian” is widely and loosely used in the literature without any justifications for its use (Rasanathan et al., 2006). Many users of the term fail to identify that it includes an extremely diverse group of peoples with varied health status (Rasanathan et al., 2006). Hence, it is often difficult to compare ethnic differences between studies, even when they have similar study design.

In New Zealand, a number of methods and adaptations have been considered or put in place to collect and analyse complex ethnic data (Callister, 2004; Callister et al., 2007; Ministry of Health, 2016b). Currently there are no ideal or gold standard measures for categorisation or reporting of the ethnicities. The updated "Ethnicity Data Protocols for the Health and Disability Sector 2016" report three output methods for analysing ethnic data: total response output, prioritised output, and sole/combination output (Ministry of Health, 2016b). Each method has its strengths and limitations; prioritisation is the most commonly used output method (Ministry of Health, 2016b).

In this study, ethnicity of all infants and their mothers was classified using prioritised output method as described in the ethnicity data protocols (Ministry of Health, 2004). This means that when more than one ethnicity was identified by the parent(s), only one ethnicity was assigned according to the following hierarchy: Māori, Pacific, South Asian, Asian, NZ European (Ministry of Health, 2004). Even though this widely used method is designed to simplify ethnic data for analysis, it also leads to somewhat biased statistical results (Ministry of Health, 2004). Firstly, it places respondents in specific ethnic groups based on the priority policy and overlooks the principle that a person can belong to more than one ethnicity. Secondly, to some extent it goes against the principle of self-identification and makes the choice for the respondents, as they may or may not identify more strongly to the assigned ethnicity. Finally, this method over represents certain ethnic groups by following the hierarchical classification system. We acknowledge that using prioritisation output method may not provide a complete representation of the ethnicities reported by the parent(s), it is however a standardised approach for all means and consistently applied by the government and researchers for ethnic data analysis.

3.5.4 Gender differences

Anthropometric differences between male and female infants in this study were similar to those reported by Broere-Brown et al. (2016) who found that males were heavier and had longer body length and bigger head circumference than females. Since, Broere-Brown (2016) assessed anthropometric variables in infants one month of age; it is a possibility that biological changes in hydration levels and overall growth in the one month period may have impacted their mean body weight measurements. Fomon et al. (1982) published reference data on anthropometry and body composition parameters from birth to 10 years of age, which has provided the foundation for most subsequent infant and childhood body composition data. Compared with the birth weights of Fomon's reference male (3.5 kg) and female infant (3.3 kg) (Fomon et al., 1982), the mean birth

weights of the male (3.3 kg) and female (3.1 kg) infants in this study were slightly lower. The Report on Maternity (2015) by Ministry of Health has also reported similar results, with male infants (3.48 kg) having higher average birth weight than female infants (3.37 kg). Conversely, Butte et al. (2000a) did not find a significant difference in birth weight between male and female infants and with males 3.76 kg and females 3.64 kg, the values were much higher than those in our study. A possible explanation for the differences may be the ethnicity of the participants studied. The ethnic distribution in the study by Butte et al. (2000a) (55 Caucasian, 7 African-American, 11 Hispanic and 3 Asian) was very different to our study (75 New Zealand European, 66 Asian, 31 South Asian, and 42 Māori-Pacific), which may have potentially impacted the values. Especially since the ethnic differences in body weight of New Zealand infants are already well established (McCowan & Stewart, 2004; Sundborn et al., 2011; Howe et al., 2015; Rush et al., 2015).

The results for the length of male (51.5 cm) and female (49.8 cm) infants in this study were comparable to the reference values (males 51.6 cm, females 50.5 cm) by Fomon el at., (1982), indicating female infants to be significantly shorter than male infants. In the present study, FM (%) values for both female (10.8%) and male (10.4%) infants were much lower than the reference values reported by Fomon et al (1982) and Butte et al. (2000a). Fomon et al. (1982) reported 1% higher FM in female infants (14.9%) in comparison to male infants (13.7%), while Butte et al. (2000a), reported 14.2% fat in females and 11.4% fat in males. Although, FM (%) values in the present study were lower and the difference between the genders was not significant, the overall pattern of females having more FM (%) than males at birth was still evident. The difference between the results from Fomon et al. (1982), Butte et al. (2000a) and the present study may be due to the variation in methodology. Both studies used a multi-compartment approach and Butte et al. (2000a) measured the infants 14 days post birth. In our study, we found that FFM was significantly higher in male infants than female infants, which is consistent with the current literature (Hull et al., 2008; Andersen et al., 2011; Simon et al., 2013).

3.5.5 Measuring body composition using ADP and its limitations

The key strength of this study is the utilisation of Air Displacement Plethysmography (ADP) to measure fat mass (FM) and fat free mass (FFM) in the participants. The ADP system is a validated body composition method that has been adapted to use in infants (Ma et al., 2004). Similar to other body composition methods, ADP is an indirect measure of body composition and based on several assumptions (Urlando et al., 2003). While it is considered ideal to include a combination of

techniques (Isotope Dilution, Skinfold Thickness) to avoid any potential variations, it can be time consuming and potentially invasive for the infant and often impractical in the paediatric population (Butte et al., 2000a; Demerath & Fields, 2014). Moreover, Butte et al. (2000a) suggests that when multiple body composition measurements are not possible or practical, age and sex specific constants can be used to calculate FFM and FM in two-compartment (2-C) models and attain accurate results. The ADP system is designed to use validated sex and age specific constants by Fomon et al. (1982) and Butte et al. (2000a) to estimate FFM and FM, making it a viable alternative. It is also important to be aware that these reference values do not take into account any ethnic variations (Fomon et al., 1982; Butte et al., 2000a). The ethnic distribution in these studies highlights that the study population predominantly consisted of Caucasian infants and hence these values may not be appropriate for infants from other ethnic background (Fomon et al., 1982; Butte et al., 2000a).

The ADP system has been shown to be accurate, non-invasive and reliable for measuring body composition (Urlando et al., 2003). It also provides FM and FFM values immediately after the measurement; hence, many parent(s)/family members showed interest when the measurement procedure was described to them. However, not all parents consented to participate in the study due to a variety of valid reasons such as scheduled medical tests/procedures, inconsistent feeding regime, distressed infant, and planned discharge. It should also be noted that the use of the ADP is relatively new in paediatrics; hence ADP based reference values for FM and FFM have not been established yet. In an ideal setting ADP would be incorporated into routine medical care and all infants measured using ADP shortly after birth.

Similar to all the other body composition methods (Isotope dilution, Dual X-ray energy absorptiometry, Skinfold thickness), ADP also has certain limitations. It is based on the two-compartment (2-C) model and therefore partitions body weight (BW) into two compartments to estimate fat mass (FM) and fat free mass (FFM) (Butte et al., 2000a). The ADP system is not designed to differentiate between lean mass and bone constituents of FFM, which has been suggested as a source of inaccuracy in FFM values when compared with Dual X-ray energy absorptiometry (Wrottesley et al., 2016). After birth, the percent total body water gradually decreases in neonates, as they undergo reduction in extracellular volume and insensible fluid loss from the skin barrier and respiratory tract (Lindower, 2017). Factors such as gestational age, postnatal age, and clinical conditions, can significantly affect the overall hydration levels in infants

(Lindower, 2017). The ADP system cannot differentiate total body water (TBW) from total FFM; hence the degree of fluid losses may have varied amongst our study population and influenced the accuracy of our results. Ideally all the infants would be measured immediately after birth to have minimal sensible (voiding and stooling) or insensible (skin and the respiratory) fluid losses. The amount of fluid losses also need to be standardised across studies so that results for newborn infants are comparable. In addition, ADP is an expensive system and currently not that widely accessible, with only 2 units in New Zealand currently having this facility. The ADP system is also easily influenced by age/maturation and can only measure infants up to 6 months of age and 8 kg in weight (Butte et al., 2000a; IAEA, 2013; Wrottesley et al., 2016). Hence it may restrict longitudinal follow up, which would be required to fully understand the impact of any differences in body composition at birth. Nonetheless, the best practice for measuring body composition in new-born infants is currently unknown; and despite the limitations, ADP is a validated and non-invasive method for estimating FM and FFM in infants.

A number of maternal characteristics have been shown to influence infant body composition. However, we did not collect information on pre-gravid or pregnancy maternal diet, anthropometric variables, gestational weight gain, physical activity levels, and insulin metabolism. Lack of this information meant we could not measure the impact of maternal characteristics on infant body composition or how these factors may differ across ethnic groups and therefore influence infant body composition. Hence, this is a limitation to the study.

3.5.6 Conclusion

In summary, we provide body composition values in New Zealand-born healthy term infants using ADP. The findings from this study are preliminary in nature but contribute to our understanding of body composition in New Zealand's main ethnic groups. While the number of infants differed in each group and the study sample was not representative of general population, the results noted for South Asian and European infants were similar to other comparative studies in infants. The gender differences noted in this study were more robust than ethnic differences and comparable to previous studies. These associations between ethnicity and body composition at birth are hypothesis generating, and replication in other settings is needed before strong conclusions can be made. Equally important will be prospective investigation in a larger sample size to investigate the significance of the differences identified.

Chapter 4 Conclusions

This research investigated ethnic differences in body composition of healthy term infants from Auckland City Hospital (ACH), using Air Displacement Plethysmography (ADP). With the acknowledgment of the limitation of having insufficient number of infants in each ethnic group, we examined correlations between the reference group (New Zealand European) and four of the main ethnicities in New Zealand (Māori, Pacific, Asian, and South Asian).

4.1 Main findings

In this first New Zealand based study designed to compare the differences in fat mass (FM) and fat free mass (FFM) in infants of different ethnicities, we found strong evidence that South Asian infants had less FFM than New European infants. Anthropometric outcomes (length, weight, head circumference) indicated that South Asian infants had significantly less fat free mass (FFM) and were also smaller, and lighter than European infants. While the sample is not representative of the general New Zealand population, this data has the potential to contribute to our understanding of body composition in early infancy. Our findings for differences in body composition between South Asian and European infants are also consistent with previous comparative studies in infants. However, very few prospective studies have evaluated the significance of these differences. There is limited evidence regarding the implications of these differences in the amount of FM and FFM on later health risks. Furthermore, there are important questions that need to be investigated to determine the underlying contributing factors that result in these ethnic differences. For example, factors like maternal diet, pregravid weight, health conditions, paternal ethnicity, and genetics, may attribute to these differences.

This study extends from using only anthropometric outcomes for measuring body composition. Although, birth weight, head circumference, and length are important indicators of pregnancy outcomes, emerging literature indicates that more sophisticated methodology is needed to better understand the association between later disease risks and body composition. Utilising ADP for measuring fat mass (FM) and fat free mass (FFM) was the key strength of the study, as it allowed for safe, fast and accurate measurements. Moreover, this technology enabled direct estimation of the mass of fat and fat-free tissue. Despite the results being preliminary, they offer a starting point for future studies that aim to measure FM and FFM in new-born infants using ADP. Further

research using ADP and other body composition assessment methods may be valuable for improving the understanding of fetal growth, intrauterine environment, overall health, and nutrition status.

The classification of ethnicity was done through the prioritisation output method as described in the ethnicity data protocols (Ministry of Health, 2004, 2016b). This method is continually being used by researchers and analysts to simplify ethnic data for analysis. Many New Zealanders identify with several ethnic groups and many infants are born to ethnically heterogeneous parents (Callister, 2004; Callister et al., 2007; Bisley, 2008). As described previously, prioritising ethnicities based on a hierarchical classification system has various limitations and can lead to somewhat biased statistical results. It could also be argued that the reported or assigned ethnic affiliation may not necessarily be the strongest ethnicity genetically. Hence, further investigation is required to attain accurate ethnic identity for new-borns, especially because ethnicity is recognised as an important dimension of health inequalities.

4.2 Recommendations

1. Collect information on maternal BMI, gestational weight gain, ethnicity, and medical history, to measure the impact of maternal characteristics on infant body composition. It may also allow to understand how these factors may differ across ethnic groups and therefore influence infant body composition.
2. Collect data from different settings or conduct the trial for a longer period of time to achieve the calculated power in each ethnic group, allowing for direct comparisons between ethnicities.
3. Conduct a large longitudinal study correlating the changes in FM and FFM from birth to adulthood to demonstrate the significance of these early differences.
4. Conduct further research comparing body composition of infants born in other major districts that have large Pacific, Māori, Pacific, Asian, and South Asian populations.
5. Better characterisation of the infant body composition at birth to improve our understanding of the fetal origins of adult disease.
6. Future studies should include a component of familial information about ethnicity to enable more sophisticated categorization.

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Appendices

Appendix 1: Descriptive data for all five ethnic groups

Variables	New Zealand European (n= 75) Mean ±SD	Māori (n=12) Mean ±SD	Pacific (n = 30) Mean ±SD	Asian (n = 66) Mean ±SD	South Asian/Indian (n=31) Mean ±SD
% FM[†]	10.7 ± 4.1	9.7 ± 4.4	9.3 ± 4.6	11.2 ± 3.9	10.7 ± 4.9
%FFM[†]	89.2 ± 4.0	90.2 ± 4.6	90.7 ± 4.6	88.7 ± 3.8	89.3 ± 4.9
FM (g)[†]	363.9 ± 157.8	313.1 ± 150.1	313.8 ± 204.5	373.85 ± 158.8	343.2 ± 202.0
FFM (g)[†]	2938.6 ± 364.0	2887.0 ± 382.6	2944.9 ± 476.1	2875.1 ± 323.7	2691.7 ± 389.7
Weight (g)[†]	3352.3 ± 575.8	3201.7 ± 414.9	3228.3 ± 640.4	3230.4 ± 424.7	3045.5 ± 535.2
Length (cm)[†]	51.2 ± 3.3	51.0 ± 1.7	49.8 ± 4.6	51.1 ± 3.7	49.9 ± 2.6
HC (cm)[†]	35.4 ± 1.7	35.1 ± 1.9	35.1 ± 1.5	34.9 ± 1.8	34.2 ± 1.7
WC (cm)[†]	33.2 ± 2.1	32.7 ± 1.4	32.4 ± 2.3	32.3 ± 2.1	31.5 ± 3.0
WLR[†]	0.65 ± 0.06	0.64 ± 0.03	0.66 ± 0.10	0.63 ± 0.04	0.64 ± 0.07

[†] *Mean ±SD*

Abbreviations: FM, Fat Mass; FFM, Fat Free Mass; HC, Head Circumference; WC, Waist Circumference; WLR, Waist: Length Ratio.

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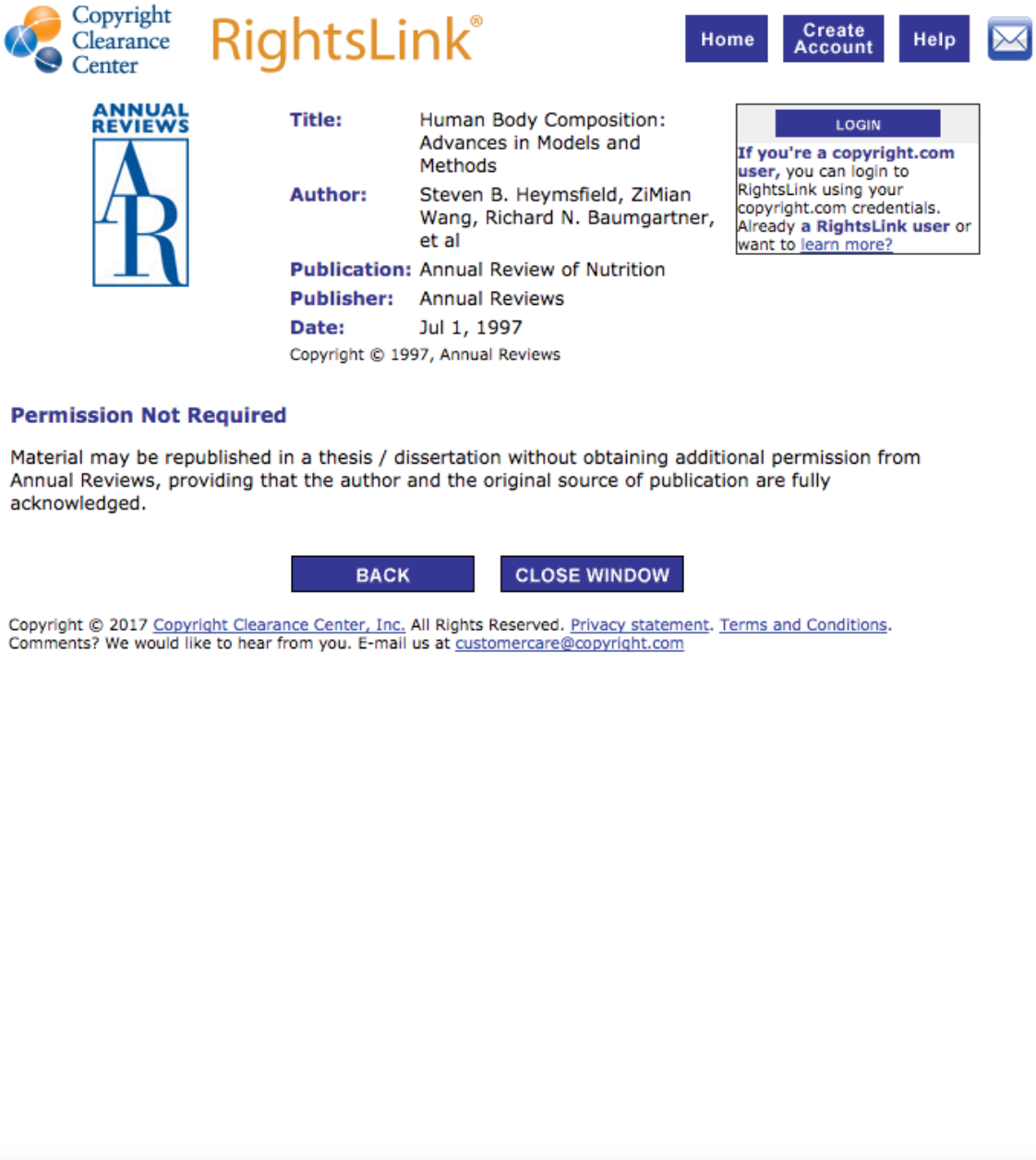

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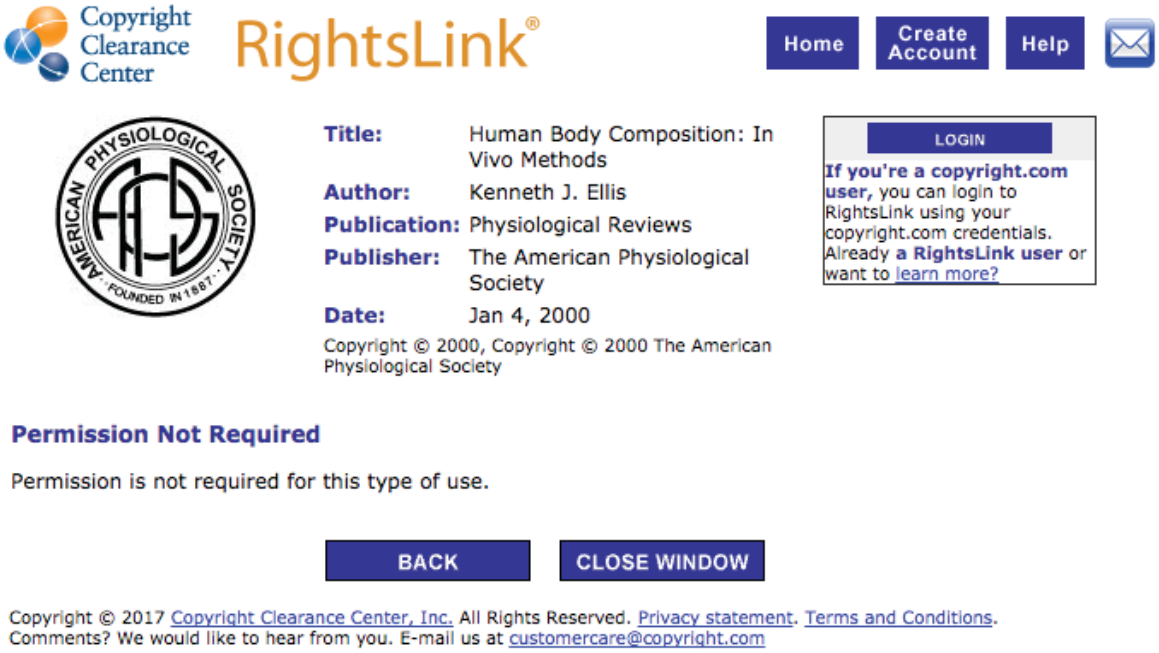

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Appendix 4: Participant information sheet

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Participant Information Sheet

Early nutrition and body composition in babies

You and your baby are invited to take part in a research study looking at nutrition and growth in preterm and term babies.

Please take your time to think about and decide whether you wish to take part in the project. You are encouraged to discuss your baby's participation in the project with family / whanau.

Taking part is a completely voluntary (your choice) and if you decide you do not wish for your baby to take part, it will not affect you or your baby's current or future healthcare in any way. You may withdraw your baby's participation at any time.

Purpose of this study

How babies feed and grow is important for health. Although all babies are weighed after birth, we know very little about the amount of fat in their body relative to muscle (often referred to as body composition). Knowing more about babies' body composition will help us to understand how nutrition can support optimal growth. This study will measure the body composition of babies born both at term and preterm. This will help us to understand the relationships between preterm birth, how preterm babies are fed between birth and discharge from hospital, and body composition and how body composition of preterm babies compares with that of healthy term babies. In the future, this study may help us guide parents of preterm and term babies on the best advice for feeding and growth of their baby.

We are aiming to recruit moderate to late preterm babies (born between 32 and 36 weeks' gestation) and term babies (37 to 42 weeks' gestation). We are able to measure body composition using a technique called air displacement plethysomography in a PeaPod. This non-invasive and completely safe technique is routinely used in the care of many babies worldwide.

Project procedures

All measurements and data collection will be done while your baby is in hospital. For preterm babies we will measure their body composition weekly whilst they are in hospital. For term babies we will measure their body composition once before going home. Babies will be measured in the PeaPod (see picture below), as well as having their length, waist and

head circumference measured. Measuring your baby in the PeaPod is very quick and takes about 5 minutes.

As well as this we will collect data on how your baby has been fed and relevant medical information about your baby from their medical notes.

Data management

Each baby will be issued with a participant code that will be used for all data collection and measurements to ensure all information remains anonymous. Data will be confidential and only members of the research team will have access to it.

All data collected will only be used for the purpose of this study and will be stored securely.

You will be provided with a summary of the findings of the study when it is finished. Results will also be published in a scientific journal and may be presented at a conference to help guide future feeding practices of babies.

What is the PeaPod?

This equipment measures body composition- so it tells us how much fat your baby has. The technique measures the amount of air your baby pushes out of the machine, so it is completely safe, non-invasive and is used routinely in health services around the world.

Participant rights

You are under no obligation to accept this invitation. If you decide to participate, you have the right to:

- *decline to answer any particular question;*
- *decline any measurements of your baby;*
- *withdraw from the study at any time;*
- *ask any questions about the study at any time during participation, and*
- *be given access to a summary of the project findings when it is concluded*

General Information

An interpreter will be provided if required.

You may have a friend, family or whanau support to help you this study and any other explanation you may require prior to deciding whether to participate or not. You,

and/or a friend, family or whanau support can accompany your baby during any measurements.

This study has received ethical approval from the Southern Health and Disability Ethics Regional Ethics Committee (15/STH/52) and locality approval from ADHB Research Review Committee (A+6691).

Project contacts

If you have any questions or concerns about the study at any stage you can contact:

Professor Frank Bloomfield	Dr Cath Conlon:
f.bloomfield@auckland.ac.nz	c.conlon@massey.ac.nz
(09) 923 6107	(09) 414 0800 ext 43658
021 497598	021 1730428
Liggins Institute University of Auckland Private Bag 92019	Massey University Private Bag 102904 North Shore City
Auckland 1142	Auckland

If you have any queries or concerns regarding your rights as a participant in this project you can contact an Independent Health and Disability Advocate. This is a free service provided under the Health & Disability Commissioner:

Telephone (NZ Wide): **0800 555 050**

Free Fax (NZ Wide): **0800 2787 7678 (0800 2 SUPPORT)**

Email: advocacy@hdc.org.nz

If you require Māori cultural support, talk to your whānau in the first instance. Alternatively you may contact the administrator for He Kamaka Waiora (Māori Health Team) by telephoning 09 486 8324 ext 2324

Thank you, tēnā koe, for making the time to read about, and for considering taking part in this project.

Appendix 5: Consent form

Consent Form

Early nutrition and body composition in babies

English	I wish to have an interpreter	Yes	No
English	I wish to have an interpreter	Yes	No
Maori	E hiahia ana ahau ki tetahi kaiwhakamaori / kaiwhaka pakeha korero	Ae	Kao
Cook Island	Ka inangaro au i tetai tangata uri reo	Ae	Kare
Fijian	Au gadreva me dua e vakadewa vosa vei au	Io	Sega
Niuean	Fia manako au ke fakaaoga e taha tagata fakahokohoko kupu	E	Nakai
Samoan	Ou te mana'o ia i ai se fa'amatala upu	Ioe	Leai
Tokelaun	Ko au e fofou ki he tino ke fakaliliu te gagana Peletania ki na gagana o na motu o te Pahefika	Ioe	Leai
Tongan	Oku ou fiema'u ha fakatonulea	Io	Ikai

- I have read and I understand the information sheet dated [Final version 6/3/2015] for volunteers taking part in the project called ***Early nutrition and body composition in babies.*** I have had the opportunity to discuss this project. I am satisfied with the answers I have been given.
- I have had the opportunity to use family / whanau support or a friend to help me ask questions and understand the project.
- I have had time to consider whether to take part in this project.
- I understand that taking part in this project is voluntary (my choice) and that I can stop taking part at any time and this will in no way affect my continuing or future health care.
- I understand that my participation in this project is confidential and that no material which could identify me will be used in any reports.
- I know who to contact if I have questions about the project in general or if I experience any ill effects resulting from my involvement in the project.
- I consent to my baby being measured using the PeaPod and other growth measurements (length, head circumference, waist circumference) being taken from my baby for the purpose of this study.
- I consent to medical information being collected from the medical records made during my baby's hospital admission.
- **I consent to being contacted in the future regarding my baby's progress**

I _____ *(full name)* hereby consent to my baby _____ *(name)* taking part in this study.

Signature: _____

Date: _____ Time: _____

Interpreter:

I _____ translated the project to the participant.

Signature: _____

Date: _____

Appendix 6: Outcome measurement and data collection sheet

Outcome Measurements

Date: _____

Participant ID: _____

Researcher: _____

Measurement #: _____

Date of birth: _____

Gestational age: _____

Time since last feed: _____ hours

PEA POD:

Percentage of fat: _____%

Percentage of fat free mass: _____%

Fat mass: _____ kg

Fat free mass: _____ kg

Body mass: _____ kg

Other measurements:

Length: _____ cm

Head circumference: _____ cm

Waist circumference _____ cm

Appendix 7: Demographic sheet

Date: _____

Participant ID: _____

Demographic and Medical Information

1. Mother's date of birth: _____
2. Mother's ethnicity:

New Zealand European		Fijian	
Other European		Niuean	
New Zealand Māori		Samoan	
Cook Island Māori		Tongan	
Tokelauan		Other Pacific Island	
Chinese		Other Asian	
Other Asian		Indian	
South East Asian		Other	

3. Baby's gender:

Male		Female	

4. Baby's ethnicity:

New Zealand European		Fijian	
Other European		Niuean	
New Zealand Māori		Samoan	
Cook Island Māori		Tongan	
Tokelauan		Other Pacific Island	
Chinese		Other Asian	
Other Asian		Indian	
South East Asian		Other	

5. Birth weight: _____ g
6. Birth length: _____ cm
7. Birth head circumference: _____ cm
8. Was the birth single or multiple?
   - Single
   - Twins
   - Triplets
   - Other

9. Type of delivery:

   - Vaginal birth
   - Caesarean

10. Infant medical complications:

Respiratory distress syndrome		Pneumonia	
Jaundice		Sepsis	
Necrotizing enterolitis		No complications	
IUGR		Other	

_____
_____
_____

11. Maternal medical complications:

_____
_____
_____
_____

12. Parity Number

_____