Pediatrics and Neonatology (2019) 60, 121–128

Available online at www.sciencedirect.com

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journal homepage: http://www.pediatr-neonatol.com

Review Article

Factors affecting body composition in preterm infants: Assessment techniques and nutritional interventions

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Received Sep 28, 2016; received in revised form Jul 26, 2017; accepted Oct 20, 2017
Available online 28 October 2017

Key Words
body composition;
developing country;
nutritional interventions;
preterm infant;
skinfold thickness

Abstract Limited research has been conducted that elucidates the growth and body composition of preterm infants. It is known that these infants do not necessarily achieve extra-utero growth rates and body composition similar to those of their term counterparts. Preterm infants, who have difficulty in achieving these growth rates, could suffer from growth failure. These infants display an increased intra-abdominal adiposity and abnormal body composition when they achieve catch-up growth. These factors affect the quality of weight gain, as these infants are not only shorter and lighter than term infants, they also have more fat mass (FM) and less fat-free mass (FFM), resulting in a higher total fat percentage. This could cause metabolic syndrome and cardiovascular problems to develop later in a preterm infant's life. The methods used to determine body composition in preterm infants should be simple, quick, non-invasive and inexpensive. Available literature was reviewed and the Dauncey anthropometric model, which includes skinfold thickness at two primary sites and nine body dimensions, is considered in this review the best method to accurately determine body composition in preterm infants, especially in resource-poor countries. It is imperative to accurately assess the quality of growth and body composition of this fragile population in order to determine whether currently prescribed nutritional interventions are beneficial to the overall

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https://doi.org/10.1016/j.pedneo.2017.10.007

nutritional status and quality of life—in the short- and long-term—of the preterm infant, and to enable timely implementation of appropriate interventions, if required.

1. Bibliographic search

The bibliographic search was performed electronically using PubMed and SUNLearn databases as search engines. The following keywords were used: "Air Displacement Plethysmography (ADP) preterm infant", "anthropometry preterm infant", "assessment of body composition preterm infant", "bioelectrical impedance preterm infant", "body composition preterm infant", "compartment models body composition", "Dauncey anthropometric model preterm infant", "developing country body composition preterm infant", "DXA preterm infant", "equipment body composition", "formula feeds body composition preterm infant", "fortification of human breast milk", "growth preterm infant", "Holtain calipers skinfolds preterm infant", "human breast milk body composition preterm infant", "measuring methods body composition", "medication preterm infant body composition", "nutritional interventions preterm infant", "nutritional status preterm infant", "resource-poor setting body composition preterm infant", "skinfold thickness preterm infant", "South Africa body composition preterm infant", total parenteral nutrition body composition preterm infant", "zinc preterm infant body composition", and "zinc preterm infant growth".

2. Introduction

According to an article in a 2012 edition of *The Lancet*, it was estimated that in 2010 14.9 million babies worldwide were born preterm, with this number rising. Fifty-two percent of global livebirths occur in Sub-Saharan Africa and South Asia, and of these 60% are born preterm. On average, 12% and 9% of preterm infants are born in low-income and higher-income countries respectively.[1]

There is an increasing interest in the relationship between nutritional status during early infancy and childhood, and the increased risk for adverse health effects as adults. Nutritional care of preterm infants attempts to achieve growth rates similar to the term infant in relation to size, anthropometry and body composition at term equivalent age (TEA).[2–5]

However, it has been found that these infants generally do not meet the required growth rates, resulting in growth failure and adverse outcomes. Infants who experience rapid catch-up growth develop an increased intra-abdominal adiposity, resulting in an abnormal body composition.[6] Preterm infants are not only shorter and lighter than term infants, but have more FM and less FFM, resulting in a higher total body fat percentage.[7] These factors can increase their risk of developing metabolic syndrome and cardiovascular diseases in later life.[6,8–12]

A number of methods exist to determine body composition in the preterm infant. These methods range from highly sophisticated, invasive and expensive to simple, quick, non-invasive and inexpensive. They are used to determine accurate measurements of anthropometric status and body composition. Assessing the quality (fat and muscle mass) of weight gain and growth in the preterm infant is more important than assessing weight gain only, even in a developing country where resources are limited.

Published research on nutritional interventions and the effect thereof on preterm body composition is scarce.[9,13] The purpose of this article is to review existing publications on body composition in the preterm infant with special focus on different assessment methods and different nutritional interventions. In addition, the effect of various interventions on the short- and long-term overall growth and body composition of these fragile infants will also be considered.

3. Body composition in preterm infants

Limited literature exists on the assessment of preterm body composition, with only a few studies focusing on the growth and development of preterm infants.[8,14] Research shows that preterm infants should achieve extra-utero growth rates in relation to size, anthropometry and body composition similar to the term infant still growing in utero.[2–5] However, preterm infants generally do not meet these growth rates resulting in growth failure and debilitating outcomes.[6,15] A systematic review and meta-analysis by Johnson et al.[13] confirmed this by comparing the FM, FFM and total body fat percentage (TBF%) of preterm infants to term equivalent age (TEA). The review concluded that infants born preterm did not achieve the reference data for either growth nor body composition at TEA.

The meta-analysis comprised eight studies, which compared the body composition of appropriate for gestational age (AGA) preterm infants with a mean gestational age of 30 weeks, to term infants. The study concluded that the body composition of TEA preterm infants displayed more similar FM and less FFM, resulting in a higher percentage TBF than infants born at term.[5,13] These results were supported by Giannì et al.[8] and showed that preterm infants at TEA are not only shorter and lighter; they also displayed more FM and less FFM when compared to reference data of term infants.[2,12,15–17]

3.1. The relation of body composition to growth in preterm infants

Little research has been conducted on the changes in body composition in preterm infants during the first few months after birth. It is imperative to determine neonatal adiposity as it can be used to predict morbidity during the first few months of life and thereafter.[8,14] Preterm small for gestational age (SGA) infants who experience rapid catch-up growth throughout infancy have shown to be at risk to develop increased intra-abdominal adiposity, abnormal body composition and an altered isolated decline in insulin sensitivity. These factors increase their risk of developing metabolic syndrome in later life.[8,10–12] A recent study by Simesk et al.[18] concluded that preterm infants tend to have a higher percentage TBF at TEA when compared to term newborn infants. This may increase the chances of preterm infants to develop cardiovascular problems in the future.[6]

Research confirms that weight loss in term and preterm infants during the first week of life is common.[4] However, rather than focusing on weight gain only, neonatologists and dietitians in the clinical setting need to know the body composition of preterm infants to evaluate the treatment progress and special nutritional care of these fragile infants.[19] Non-invasive and accurate measurements of the preterm infant are valuable to assess the quality of anthropometry and body composition, allowing the monitoring of nutritional requirements and the possible effect of nutritional interventions on these components.[7]

3.2. Compartment models of body composition

Compartment models divide the body into different compartments, each containing distinctive components. These models allow for the opportunity to develop new methods of assessing unidentified components by using an identified component.[20] According to current literature, four main compartment models are identified: 2-compartment (2-C), 3-compartment (3-C), 4-compartment (4-C) and 5-compartment or multi-compartment models. Please refer to Fig. 1. Each compartment model is an expansion on the more basic model. For example, the 3-C model is an expansion on the 2-C model, the 4-C model is an expansion on the 3-C model, and so on.

The most recent literature states that the 3-C model was developed to decrease limitations when used on healthy adults and children. Therefore, it is not suitable for use on newborns, infants and subjects experiencing muscle wastage or depleted bone mineral mass (BMM).[20–23] The generally accepted 5-C or multi-compartment model, which requires a structural framework, was reviewed by Ellis,[24] who concluded that this method had become the standard for body composition research.[21,25] According to a review by Lee and Gallagher,[26] the 4-C model is the most applicable and commonly used criteria method to assess body composition in children. Their conclusion was based on the fact that the 4-C model includes the Extra Cellular Water (ECW) component that measures hydration status. However, they do not disclose whether this method is suitable for newborns and infants.

Compartment models are useful when one body compartment has not or cannot be measured, but the values of other compartments within the model are known. Using simple arithmetic, the value of the unknown compartment can be determined.

The compartment models are dependent on the different body components for assessment or research, and different types of measuring methods to assess body composition are dependent on the number of compartments assessed or researched.

3.3. Assessment of body composition

Basic non-invasive anthropometric measurements such as weight, length and head circumference assess basic

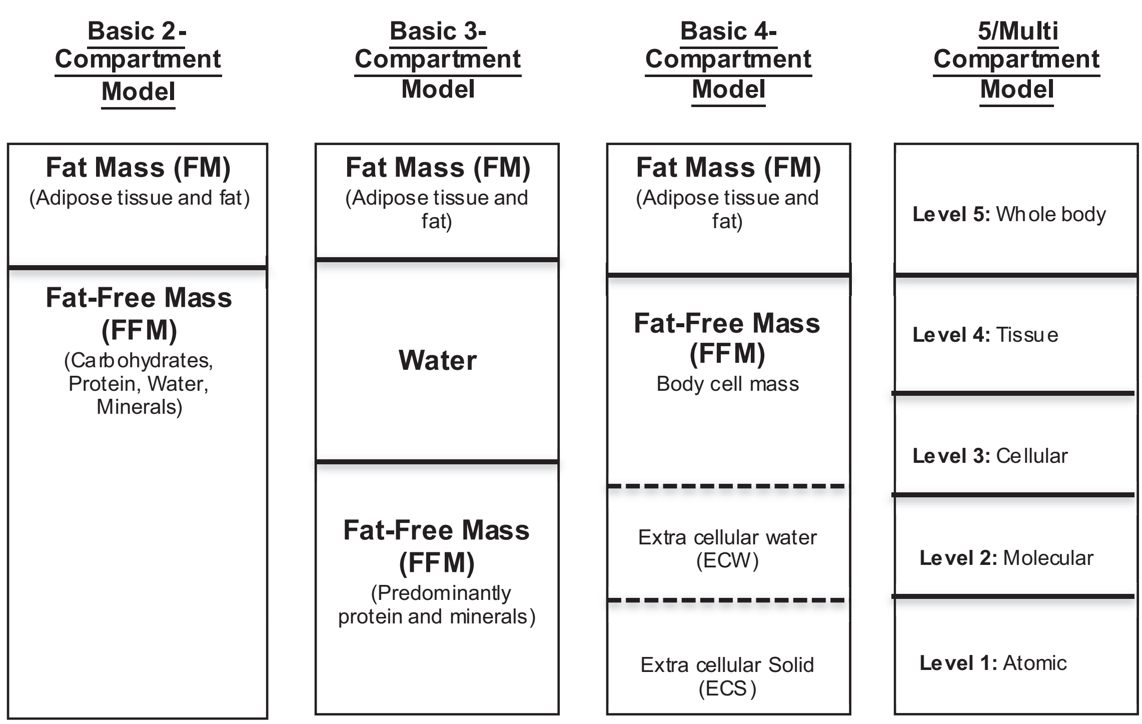

Figure 1 Basic compartment model figure adapted from Ellis,[24] "Human body composition: In Vivio methods".

growth of the preterm infant. A need exists to accurately assess relative components such as FM, FFM and the quality of weight gain to predict body composition.[9] Body composition can predict short- and long-term adverse outcomes, which are associated with altered fat deposition and a high TBF%.[27] There are many different types of equipment and measuring methods available to assess body composition in the preterm infant. The equipment and measuring methods range from simple, quick, non-invasive, safe and inexpensive to complex, sophisticated and expensive.

3.3.1. Skinfolds

Even though standard anthropometric assessment of preterm infants such as weight, length and head circumference is easy to record in the clinical setting, it is not appropriate for a full assessment of the nutritional status and body composition of this population.[13,18,19] Therefore, more sophisticated methods to assess and measure the body composition of these infants are suggested as a priority in early life.[13]

Performing Skinfold Thickness (SFT) measurements on fragile preterm infants could perhaps be considered controversial and invasive due to the size of the instrument in comparison to the infant. In addition, the possibility exists of injuring the skin of the premature infant when SFT measurements are taken, especially in the case of an extremely low birth weight (ELBW) infant. However, these measurements are useful, simple, inexpensive and non-invasive to determine body composition in these infants.[18,28,29] Determining neonatal subcutaneous fat with caliper SFT measurements allows for the evaluation of the distribution of FM in specific areas of the body.[30] Caution is advised when measuring SFT in infants with immature, friable skin, as in the case of ELBW infants. In such cases, conducting SFT measurements may not be indicated.

Holtain calipers provide a common method to assess and measure SFT in order to determine subcutaneous fat stores in preterm infants, their term counterparts and children.[18,30–35] However, SFT is notoriously influenced by the hydration status of the preterm infant. In order to obtain more precise body composition measurements it is recommended to use additional sophisticated methods with specialized technology.[26]

Dauncey et al.[36] conducted a study to assess the TBF in infants by using SFT at two sites (subscapular and triceps) in conjunction with nine other body dimensions. The formula has been tentatively applied to infants up to the GA of 40 weeks and for preterm infants. The measurements needed for the dimensions include circumferences (head, chest, the abdomen at the umbilicus, mid-upper arm, mid-thigh and mid-calf) and lengths (upper arm, lower arm and crown-rump length). The triceps and subscapular SFT measurements are used to determine the amount of fat covering the limbs and trunk respectively.[36,37]

3.3.2. Bioelectric impedance

Bioelectric Impedance Analysis (BIA) is described as a method for assessing body composition by measuring the impedance or resistance of the body. This is done by passing a weak alternating electrical current at a fixed frequency, usually 50 kHZZ, through the body.[9] The measure of impedance is directly and inversely proportional to the volume of the conductor through which the current flows. In the human body the conductor is the total body water (TBW), as it is almost entirely found in the lean body mass (LBM) and made up of water and electrolytes, which are both excellent conductors. Therefore, it can be used as an estimate to calculate FFM. FM and bone are resistant to electrical current. In conclusion, BIA measures the TBW, which provides for the calculation of FM and FFM.[38]

At present, BIA has been identified as a method with great potential value to assess body composition in preterm infants.[19] This method is inexpensive, simple, quick, safe, portable and minimally invasive, as it does not involve the removal of supportive ventilation and monitoring cords of the preterm infant, or the removal of the infant from the Neonatal Intensive Care Unit (NICU).[5,9,19,26,38,39,29,40–42] However, conflicting results from Dung et al.[19] suggested that no research evidence confirmed the use of FFM prediction equations in neonates using BIA.

3.3.3. Dual-energy X-ray Absorptiometry (DEXA) and Air Displacement Plethysmography (ADP)

Specialized equipment, such as the common Dual-energy X-ray Absorptiometry (DEXA)[19] and gold standard Air Displacement Plethysmography (ADP),[14] is expensive to use to assess body composition in preterm infants. These assessments can be challenging to perform on preterm infants as the DEXA method requires the infant to be removed from the NICU and minimal movement from the infant is required for accurate results.[16,18,22,43] The ADP method, on the other hand, requires the infant to be removed from the incubator and placed in the PEA POD® machine for an average of 2 min.[18,44] Both apparatus are quick, safe and non-invasive when used to determine body composition in preterm infants, but do require immobilization of the infant.[19,45]

Continuous assessment and monitoring of body composition by means of simple as well as sophisticated methods are imperative to obtain accurate results in preterm infants. According to the literature available, the best method with which preterm body composition can be assessed is the anthropometric model of Dauncey.[29,36,37,46] This method is safe, inexpensive, quick, non-invasive and can be conducted at the patient's bedside.[46] Little well-documented research regarding preterm infants and body composition exists, especially in the South African context. With the above-mentioned measuring methods available, valuable research can be done to investigate these fragile populations. Please refer to Table 1: Summarizing the advantages and disadvantages of different techniques for measuring body composition in preterm infants.

3.4. Interventions affecting body composition in preterm infants

3.4.1. Nutritional interventions

Preterm infants require high recommended daily allowances to help them achieve in utero growth rates.[6,39] Due

Table 1 Summarizing the advantages and disadvantages of different techniques for measuring body composition in preterm infants.

Technique	Advantages	Disadvantages
SFT and the Dauncey anthropometric model	Evaluation of the distribution of FM in specific areas of the body. Simple, inexpensive and non-invasive and can be done at the bedside. Assess the quality of weight gain and indicates a pattern of change over a time period.	Can be considered controversial and invasive due to the size of the instrument in comparison to the infant. Influenced by the hydration status.
BIA	Measures the TBW, which provides for the calculation of FM and FFM. Simple, inexpensive, quick, safe, portable and minimally invasive. Does not require removal of supportive ventilation and monitoring cords.	Dung et al.[19] suggested that no research evidence confirmed the use of FFM prediction equations in neonates using BIA.
DEXA	Quick, safe and non-invasive.	Expensive. Infant needs to be removed from the NICU. Minimal movement from preterm infant to ensure accurate readings.
ADP	Golden standard. Quick, safe and non-invasive.	Expensive. Preterm infant is removed from the incubator and placed in the PEA POD®.

ADP, Air Displacement Plethysmography; BIA, Bioelectrical Impedance; DEXA; Dual-energy X-ray Absorptiometry; FM, Fat Mass; FFM Fat-Free Mass; NICU, Neonatal Intensive Care Unit; SFT, Skinfold Thickness; TBW, Total Body Water.
Conclusion: In a resource poor setting, the use of the Dauncey anthropometric model is one of the best methods to determine body composition in the preterm infant in terms of FM and FFM as it is accurate, safe, inexpensive, non-invasive and can be performed at the bedside.

to the underdeveloped and immature systems of the preterm infant, growth failure is common. However, high postnatal weight gain can also result in adverse outcomes in the long term.[6,9,10,15]

Preterm infants, especially those born with a very low birth weight (<1500 g), are challenging to feed due to the high recommended daily allowance (RDA) of energy, protein and nutrients required to achieve in utero growth rates. The European Society for Pediatric Gastroenterology, Hepatology and Nutrition (ESPGHAN) recommends enteral and parenteral energy intakes of 110—135 kcal/kg/day and 110—120 kcal/kg/day respectively and a protein intake of 3.5—4 g/kg/day. Growth failure in the preterm infant is common, which can put these fragile infants at risk of poor neurodevelopment, complications, detrimental effects and adverse outcomes.[2,4,9,10,47,48]

It is suggested that rapid weight gain in the preterm infant (which is associated with aggressive nutritional management) can increase the risk of developing metabolic disease and cardiovascular problems in later life.[6,9,10,15]

Limited literature exists on nutritional interventions and the effect thereof on the quality of growth and body composition of the preterm infant.[9] This is supported by a meta-analysis of the detailed relationship between nutritional interventions and body composition in preterm infants.[12]

The primary nutritional interventions prescribed for preterm infants include: human breast milk, supplemented or fortified human breast milk, formula feed and total parenteral nutrition. These are explained in more detail below.

3.4.1.1. Human breast milk. Human breast milk is globally accepted as the optimal nutritional intervention for infants and preterm infants. Intake is associated with better neurodevelopmental outcomes.[49]

Despite its benefits, human breast milk alone is considered inadequate to meet the preterm nutritional requirements during early neonatal life, especially in infants born with very low birth weight (VLBW), as it only provides about 60% of the protein requirements when fed in adequate amounts to obtain energy requirements in preterm infants. This is of concern as a low protein-energy ratio can result in fat retention during growth.[2,49] However, Atkinson and Randall-Simpson[16] were of the opinion that this needed further investigation.

3.4.1.2. Fortification of human breast milk. Supplementation of human breast milk with a fortifier (protein, nutrients, vitamins and minerals) is common practice in many NICUs to achieve nutritional requirements and successive intrauterine growth rates in preterm infants, while the benefits of human breast milk are continually derived.[49] A study comparing post-breastfeeding practices and supplementation of breast milk with formula-feeding practices after hospital discharge found that the fortification of breast milk showed improvements in short-term growth. However, there appears to be no benefit for long-term outcomes with regard to growth and body composition.[49] Furthermore, VLBW infants who received fortified breast milk or formula feed, achieved recommended intrauterine growth rates, but showed a significant increase in adiposity, when assessed at TEA.[17]

3.4.1.3. Formula feeds. Often formula feeds are given to infants when human breast milk is unavailable. Roggero et al.[7] studied the changes in body composition of 48 preterm infants with a birth weight of ≤1800 g and a GA of ≤34 weeks. The infants received exclusive formula feed on demand, from birth to discharge, and the changes in body composition were studied in relation to protein and energy intakes from term until 3 months corrected age (CA). According to the results from this study the high-protein intake was indirectly proportional to the percentage FM and the high-energy intake had no effect on the percentage FM. The study concluded that a high-protein intake with an adequate energy supply resulted in a lower weight gain but a higher percentage LBM during the first month of CA.

3.4.1.4. Total parenteral nutrition. An evident gap in literature exists regarding the effect of Total Parenteral Nutrition (TPN) on the body composition of preterm infants.[47] For this reason, this area requires more research.

The various nutritional interventions all strive towards similar outcomes for preterm infants. The most important factor to consider when nutritional intervention is necessary, is the energy-protein ratio of the preterm infant. Research showed that a high protein nutritional intervention resulted in preterm infants having a lower overall weight gain but a higher LBM. This is beneficial to the health of the preterm infant in the long term.[2] Breast milk is universally known as the most optimal feed for preterm infants. However, it is also a known fact that the protein-energy ratio is not achieved when preterm infants receive solely breast milk.[2] Therefore, fortification of breast milk is necessary to achieve optimal growth rates. The type of sector, such as hospitals in a developing country or resource-poor setting, could have an influence on the type of nutritional interventions prescribed for preterm infants. This could in turn have an effect on the nutritional status, body composition and future outcomes of preterm infants.

3.4.2. Preterm infants: pharmacological interventions

A gap in investigatory literature exists regarding the effects of certain medications commonly prescribed to preterm infants on their body composition. These medications include antenatal corticosteroids,[50] surfactant,[51] dopamine, antibiotics,[52] diuretics and micronutrient supplementation. The TBF% in extremely preterm infants can be as little as 1%. Infants and neonates have higher TBF% and intracellular and extracellular water volumes when compared to adults.[53]

Several nutritional intervention studies indicate that zinc supplementation has a positive effect on linear growth in preterm infants.[54,55] A longitudinal, double-blind, randomized clinical trial found higher mean values in total body weight in the group that received supplementation. However, no significant difference in FM was noted, which could indicate a positive effect of zinc supplementation on FFM.[56] It is known that antenatal corticosteroids can influence an infant's gestational size, increase postnatal growth, impair muscle mass accretion and result in growth failure, all of which are associated with changes in adult body composition.[50,57] A recent study by Simon et al.[50] found that antenatal corticosteroid treatment had a significant influence on the preterm infant's body composition at hospital discharge, resulting in preterm infants having a greater FM and impaired FFM deposition in the neonatal period. Postnatal glucocorticoid treatment has also been known to increase protein breakdown in the preterm infant.

4. Conclusion

A gap in published research regarding the relationship between preterm infants, nutritional and pharmacological interventions and body composition exists,[8,13,14] particularly in a resource-poor setting as there is a definitive nonentity regarding this.

There are many different types of factors with regards to measuring techniques that can affect the assessment of body composition in preterm infants. These factors include equipment and techniques which range from simple, quick, non-invasive, safe and inexpensive to complex, sophisticated and expensive. The effect of nutritional interventions on the body composition of preterm infants is determined by and dependent on the protein-energy ratio of the feed. Fortification of breast milk allows for ideal achievement of protein-energy ratio as well as optimal growth rates in the preterm infant, which could have an effect on the body composition and nutritional status of these infants.

Available literature confirms the use of the Dauncey anthropometric model, which includes SFT at two primary sites and nine body dimensions, as one of the best methods to determine body composition in the preterm infant in terms of FM and FFM. The use of this method to determine body composition is accurate, safe, inexpensive, non-invasive and can be performed at the bedside,[29,36,37,46] which therefore does not excessively disturb these fragile infants.[36] Nonetheless, great care should still be taken during SFT measurements on the preterm infant due to the infant's delicate skin and general fragility.

Accurate assessment of this population is imperative when appropriate nutritional interventions are prescribed to increase the quality of life for these fragile infants. Such research could be important to researchers, neonatologists and dietitians in a resource-poor setting, as it could allow experts in the field to better understand the nutritional status, body composition and growth of the preterm infant, future outcomes and how to implement timely and appropriate interventions.

Conflict of interest

The author declares no conflict of interest with respect to the research, authorship, and/or publication of this article.

Acknowledgements

The authors would like to acknowledge and thank: Dr. Wanda Smith for her efficient and accurate editing work.

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