

Review

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Anthropometry to advanced technologies: evaluation of growth and body composition in neonates

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Abstract

Neonatal growth assessment during the first 28 days of life is a critical determinant of infant health and survival. Anthropometric measurements provide a simple, inexpensive, and non-invasive means to evaluate neonatal size, nutritional status, and growth, as well as to predict long-term health outcomes. Alongside standard growth curves, methods for assessing neonatal body composition offer additional insights into fat and fat-free mass distribution, which are linked to later risks such as childhood obesity and metabolic complications. This review summarizes the commonly used anthropometric measures and advanced laboratory techniques for assessing neonatal growth and body composition, discusses their advantages and limitations, and highlights the importance of their combined use in clinical and research settings. Understanding these methods is essential for early identification of growth disturbances and for promoting optimal nutrition and health outcomes throughout the life course.

Introduction

The neonatal period, defined as the first four weeks after birth, represents the time when infants are most vulnerable to infections and other complications. It is a critical window for ensuring infant health and survival.¹ According to the World Health Organization (WHO), nearly 2.3 million neonatal deaths occur annually, primarily in low- and middle-income countries, many of which are related to impaired growth, low birth weight, and malnutrition. Early assessment of growth and nutritional status during this period is therefore essential for preventing morbidity and mortality and ensuring optimal developmental outcomes.² Anthropometric measurements during this period are essential for assessing overall health status, reflecting nutritional condition and future survival prospects, identifying risks, monitoring growth, improving maternal and child health services, predicting long-term health outcomes, and standardizing reference values.¹ These measurements typically include birth weight, length, head circumference, chest circumference, and other key body parameters that reflect intrauterine development and postnatal adaptation.³ In clinical and research settings, anthropometric measurements provide a simple, inexpensive, and practical approach for assessing neonatal maturity and nutritional status, particularly in environments where advanced diagnostic tools are unavailable or impractical. Studies have shown that these measurements can be more reliable than some clinical examinations in estimating gestational age, thus playing a critical role in neonatal care and public health surveillance.^{4–6} Monitoring anthropometric parameters over time is equally essential for tracking growth trajectories and ensuring appropriate development. Serial measurements provide valuable information on the effectiveness of nutritional and medical interventions, helping healthcare providers tailor management strategies to individual needs.⁷ In addition, population-level data derived from neonatal anthropometry contribute to the development of reference growth standards and help evaluate the impact of maternal nutrition, socioeconomic factors, and healthcare access on newborn outcomes.

Recent advances in technology have enabled the use of more sophisticated methods, such as air displacement plethysmography (ADP), dual-energy X-ray absorptiometry (DXA), and magnetic resonance imaging (MRI), allowing a more accurate evaluation of neonatal body composition.⁸ These techniques, when combined with anthropometry, provide a more comprehensive understanding of early growth patterns and potential health trajectories. Nevertheless, methodological challenges, cost, and limited accessibility continue to restrict their widespread clinical use, especially in low-resource settings.

Overall, anthropometric evaluation offers essential clinical information that supports neonatal care by identifying infants at risk and guiding effective management and follow-up. As such, these measurements form the cornerstone of neonatal health assessment and remain indispensable in both clinical practice and epidemiological research. This review aims to summarize both main anthropometric and advanced technological approaches to neonatal growth and body

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composition assessment, highlighting their advantages, limitations, and applicability in clinical and research contexts.

The literature review underpinning this manuscript was conducted through a comprehensive search of international databases, including PubMed, Scopus, Web of Science, and Google Scholar, to identify peer-reviewed studies and official guidelines published between 2005 and 2025. Search terms included combinations of “neonatal anthropometry,” “body composition,” “growth assessment,” “air displacement plethysmography,” “dual-energy X-ray absorptiometry,” and “skinfold thickness.” International references such as the WHO guidelines and national references such as those of the Republic of Turkey Ministry of Health were also reviewed to ensure the inclusion of population-specific data and contextually relevant standards. Studies and documents were selected based on their methodological clarity, relevance to neonatal populations, and contribution to understanding both traditional anthropometric and advanced technological approaches. This integrative approach ensured a balanced and evidence-based evaluation of neonatal growth and body composition assessment methods.

Anthropometric assessment of growth in neonates

The primary anthropometric indicators used in neonates are birth weight, length, and head circumference for nutritional assessment in clinical practice and in field studies.³ Birth weight, the most widely used anthropometric marker of neonatal growth, not only reflects the infant's growth, development, and survival but also provides valuable insight into maternal health, nutrition, genetics, socioeconomic status, environmental exposures, and the quality of prenatal care.⁹ Birth weight is measured to the nearest 10 g using a calibrated digital electronic infant scale. Prior to measurement, all clothing, including the diaper, should be removed to ensure accuracy. If measurement without a diaper is not feasible, the infant may be weighed wearing a clean, dry diaper, provided that the scale has been zeroed. In the first days of life, neonates may lose 8%–10% of their body weight, a physiological change attributable to extracellular fluid loss during adaptation to the external environment. If the infant receives adequate breast milk, birth weight is expected to be regained within one to two weeks, and no later than 15 days.¹⁰

Neonatal weight is categorized as follows: >4000 g, macrosomia (high birth weight); 2500–4000 g, normal birth weight; <2500 g, low birth weight; <1500 g, very low birth weight; and <1000 g, extremely low birth weight.³ In addition, weight-for-gestational age classification is commonly applied: infants with weight and/or length below the 10th percentile for gestational age are classified as small-for-gestational-age (SGA); those between the 10th and 90th percentiles as appropriate-for-gestational-age (AGA); and those above the 90th percentile as large-for-gestational-age (LGA). Being born SGA often indicates inadequate intrauterine growth or nutrition, while LGA may be associated with maternal dietary patterns or genetic factors. Both SGA and LGA infants require careful monitoring to reduce risks of complications such as impaired growth and respiratory problems.³

Following birth, neonatal weight should be monthly during the first six months, then every 2–3 months up to two years of age using an infant scale, either unclothed or through the tare weighing method.¹¹ In tare weighing, the mother is first weighed on a scale with a tare function and then reweighed while holding the undressed infant, either without a diaper or wearing a clean, dry one. The infant's weight is calculated by subtracting the maternal weight from the combined measurement.¹²

Neonatal length is measured in the supine position before the age of two years using an infantometer placed on a flat, stable surface. After removing clothing items such as shoes, socks, and hats, the infant is positioned supine with the head resting against the fixed headboard. The head is aligned in the Frankfurt plane (the line from the external auditory canal to the lower margin of the orbit perpendicular to the board), and the body is ensured to be straight with the shoulders touching the board. The legs are gently extended with minimal pressure to avoid injury, and the movable footboard is placed perpendicular to the soles of the feet. Measurements are recorded to the nearest 0.1 cm. According to the WHO growth standards for 0–5 years, recumbent length is recommended until two years of age, after which standing height should be measured. If standing height is recorded in children under two years, 0.7 cm should be added, and if recumbent length is used after two years, 0.7 cm should be subtracted.¹² The average neonatal length at birth is approximately 50 cm, with growth of up to 3.5 cm per month in the first three months.¹³ A study investigating whether leg positioning affects length measurements demonstrated that using both legs extended yielded more accurate and controlled results compared with extending only one leg.¹⁴

In addition to weight and length, head circumference provides important diagnostic and prognostic information, even though it is not a highly sensitive or specific measure. Head circumference is measured to the nearest 0.1 cm with a non-stretchable tape, positioned around the occipital protuberance posteriorly and the glabella anteriorly.¹

Recent research has highlighted the correlation between head circumference at birth and brain growth during neonatal hospitalization and early childhood with cognitive, motor, attentional, and executive control skills.¹⁵ Microcephaly, defined as a head circumference more than two standard deviations below the mean for age and sex, represents a key clinical indicator of impaired brain growth and development. It may be congenital or postnatal in onset, and its etiology ranges from genetic mutations and congenital infections to perinatal hypoxic–ischemic injury, metabolic disorders, and severe malnutrition.¹⁶ Numerous studies have demonstrated that microcephaly is strongly associated with adverse neurodevelopmental outcomes, including global developmental delay, intellectual disability, epilepsy, and motor impairment.^{15,17}

Macrocephaly, defined as a head circumference exceeding two standard deviations above the mean, can arise from benign familial traits or indicate significant neurological pathology.¹⁸ Etiological categories include benign familial macrocephaly, hydrocephalus, megalencephaly, intracranial mass lesions, and numerous genetic or metabolic syndromes.^{19,20} Clinically, macrocephaly may be asymptomatic or associated with developmental delay, autism spectrum disorder, seizures, and cognitive impairment depending on its underlying cause. Several population studies have identified associations between extreme macrocephaly and increased risk for neurodevelopmental disorders, whereas mild familial enlargement without other abnormalities is generally benign.²¹

Measurements are compared against age- and sex-specific reference standards and should be monitored regularly, particularly from birth to three years of age.²² The average neonatal head circumference is approximately 35 cm. During the first postnatal week, it may decrease by 0.5 cm due to extracellular fluid contraction. On average, head circumference increases by 2 cm per month during the first three months, 1 cm per month between three and six months, and 0.5 cm per month in the last six months of infancy, totalling an average 12 cm increase in the first year.

From one to three years, growth slows to 1 cm every six months, and from three to five years to 1 cm per year, with a total increase of about 5 cm between 1–5 ages.^{4,13}

Interpretation of head circumference should also consider parental measurements. A study comparing neonatal anthropometry to WHO standards reported lower weight and length but higher head circumference than international references. This discrepancy was attributed to differences in neonatal growth patterns, gestational age, sociocultural conditions, ethnicity, and geographical or racial variations.¹

The WHO Child Growth Standards emphasize anthropometric indicators such as weight, length/height, and head circumference for assessing growth in children aged 0–5 years. Other indicators, including mid-upper arm circumference (MUAC) and skinfold thickness (SFT), are primarily recommended for children older than three months rather than neonates. MUAC reflects both muscular and adipose compartments and is not advised for routine assessment in neonates due to limited accuracy and unstable reference data in early life.²³ Instead, it becomes a valuable screening tool for acute malnutrition after three months of age and is widely utilized in children aged 6–59 months, particularly in low-resource settings.²⁴ The WHO provides MUAC-for-age charts beginning at three months, reinforcing that routine MUAC monitoring is recommended after this age.²⁵ Although MUAC can technically be measured in newborns and may help identify low birth weight and early neonatal risk (e.g., MUAC ≤ 9.0 cm associated with low birth weight and mortality risk),^{24,26} its precision, sensitivity, and population-specific reference ranges remain limited during the neonatal period when physiological shifts in limb composition and water balance occur.^{6,24} Therefore, MUAC cutoffs are more reliable and clinically valid for nutritional assessments beginning around three months of age, when such transient changes stabilize.²³

Similarly, SFT including triceps or subscapular sites – poses methodological challenges in neonates due to thin skin, minimal subcutaneous fat stores, and difficulty maintaining the infant's stillness during assessment.²⁷ Although SFT is a reliable and noninvasive indicator of body fat and nutritional status in older infants and children, its application in neonates is limited by technical complexity and measurement error.²⁸ Lingwood et al.²⁹ reported that skinfold-based models performed poorly across all early ages (birth to 6 weeks), yielding less accurate estimates than simpler anthropometric models incorporating only weight, length, and sex. Consequently, SFT is better suited for research or for infants older than three months, where it contributes meaningfully to longitudinal growth and nutritional monitoring up to five years of age.²⁸ In summary, while MUAC and SFT constitute valuable anthropometric tools for malnutrition screening and body composition analysis in older infants and young children, their use in neonates remains constrained by physiological variability, methodological difficulties, and practical considerations. Accordingly, routine neonatal assessment should continue to rely primarily on birth weight, length, and head circumference, with MUAC and SFT more appropriately implemented from approximately three months through five years of age, consistent with WHO recommendations and contemporary research evidence.

Assessing growth patterns with standards

The adequacy of a child's growth is determined by comparing anthropometric measurements with those of peers of the same age and sex, as well as by evaluating changes over time. Standardized growth charts are essential tools for this purpose. While a single

measurement provides a “growth assessment,” serial measurements over defined intervals enable “growth monitoring” by capturing growth velocity.³⁰ Growth assessment plays a crucial role in identifying the need for interventions, treatment, or supplementary feeding, particularly in contexts of extreme poverty or emergency situations, thereby helping to prevent neonatal mortality.³¹ The primary aim of monitoring and evaluating growth is to detect and address any stagnation in growth as early as possible. Consequently, growth monitoring has been identified by United Nations Children's Fund (UNICEF) and WHO as one of the key strategies to ensure child health and survival within the “GOBI-FFF” initiative (Growth Monitoring, Oral Rehydration, Breastfeeding, Immunization, Female Education, Family Planning, and Food Supplementation).¹³

WHO growth standards were developed through the Multicentre Growth Reference Study, which included children from Brazil, Ghana, India, Norway, Oman, and the United States. The study was designed to establish normative growth standards by including children raised under optimal conditions, such as exclusive breastfeeding, appropriate pediatric care, and smoke-free environments.³² Term infants were followed from birth to two years, and the resulting standards provide prescriptive benchmarks for optimal growth rather than merely descriptive references. Growth charts that illustrate expected trajectories over time enable healthcare providers to identify children at risk of undernutrition or overweight before reaching critical thresholds.³¹ Accordingly, WHO recommends that neonatal growth be assessed up to five years of age using indices such as length-for-age, weight-for-age, weight-for-length, and head circumference-for-age.¹²

For neonates, growth assessment involves comparing head circumference, body weight, and length with WHO standards, using indices such as weight-for-age, length-for-age, weight-for-length, head circumference-for-age, and body mass index (BMI)-for-age.^{31,33} In preterm infants, growth assessment is recommended using sex-specific Fenton growth charts between 22 and 50 weeks of gestational age.³⁴ Additionally, preterm growth may be evaluated with alternative tools such as the INTERGROWTH-21st standards, which are based on WHO references, or with national standards that incorporate population-specific characteristics, such as the Italian Neonatal Anthropometric Reference (INes).³⁵

Length-for-age is a particularly important indicator for identifying stunting, which results from chronic undernutrition or recurrent illness.³⁶ Weight-for-age, although commonly used due to the ease of measurement and its sensitivity to acute changes, is limited in that it cannot distinguish between undernutrition and overweight. According to WHO standards, weight-for-age should be evaluated by completed weeks up to three months of age and by completed months thereafter until one year.³⁶

Weight-for-length is a useful index in situations where the child's age is unknown, as it identifies wasting (low weight-for-length) due to acute malnutrition or severe illness, as well as overweight and obesity when values are high. BMI-for-age is calculated from the weight-to-length ratio and, in neonates, is assessed by percentiles and z-scores on a weekly basis up to three months.³⁶ Although BMI and weight-for-length correlate strongly with adiposity, they do not accurately reflect fat and fat-free mass (FFM) distribution due to the rapid body composition changes that occur during infancy.³⁷

According to WHO Child Growth Standards, neonatal growth should be interpreted using the z-scores presented in Table 1. Importantly, comprehensive assessment should incorporate all growth indices simultaneously for a more accurate evaluation.³⁶

Table 1. Assessment of children aged 0–5 years according to WHO child growth standards

Z-score	Length/height-for-age	Weight-for-age	Weight-for-length/height/ BMI-for-age
>3 SD	Very tall	A growth problem may be present, but this is better assessed from weight-for-length/height.	Obese
>2 SD	Normal		Overweight
>1 SD			Possible risk of overweight
Median (0)		Normal	
<-1 SD			
<-2 SD	Stunted	Underweight	Wasted
<-3 SD	Severely stunted	Severely underweight	Severely wasted

SD, standard deviation; BMI, body mass index.

Head circumference-for-age has been associated with neonatal nutritional status. In the study by Ochoa-Ramirez et al.³⁸ malnourished infants were found to have lower head circumference values compared with those who were adequately nourished. The authors concluded that head circumference can serve as a useful marker for assessing growth and development in infants and may be an indicator of chronic malnutrition. Moreover, a positive correlation has been observed between neonatal length and head circumference. According to the WHO growth standards, head circumference is assessed by percentile and z-scores for both sexes on a weekly basis until the 13th week of life.³⁶ Importantly, head circumference growth is strongly linked to neurodevelopmental outcomes in preterm infants, particularly from corrected age 18 months to 5.5 years.³⁹ Infants with head circumference measurements above the 97th percentile warrant further evaluation. Likewise, if serial measurements show crossing of one or more major percentile lines, or if head circumference increases by more than 2 cm per month in infants younger than six months, additional investigations are recommended.¹⁸

For preterm infants, the INTERGROWTH-21st standards provide growth assessment based on percentile and z-scores for birth weight, length, and head circumference between 24 and 33 weeks of gestation. For late preterm and term neonates born between 33 and 43 weeks, weight-for-length indices are also included to enable a more comprehensive evaluation of growth.⁴⁰ Unlike WHO standards, these charts were derived from a large multicenter prospective study that tracked fetal growth from 14 weeks of gestation and continued through two years of age in low-risk pregnancies. After term, growth assessment is recommended to follow WHO Child Growth Standards.⁴¹ Comparative studies of INTERGROWTH-21st and Fenton growth charts in preterm infants have revealed discrepancies in the classification of low-birth-weight neonates.^{42,43}

Beyond growth charts, the ponderal index (PI) has also been employed as an indicator of neonatal physical growth.⁴⁴ While BMI is considered the global standard for assessing body proportionality across populations, PI is regarded as a weaker indicator and is less frequently used.⁴⁵ PI is calculated by dividing birth weight (g) by the cube of birth length (cm). A PI between 2.2 and 3.0 is considered normal for neonates.⁴⁴ Clinically, PI is used to evaluate neonatal nutritional status, adequacy of growth, or excessive weight gain. Values below the 10th percentile are indicative of intrauterine growth restriction (IUGR).⁴⁶ A study comparing PI, BMI, and weight-to-length ratios in preterm infants in the United States found that BMI provided a better reflection of body proportionality than PI.⁴⁷

Although WHO recommends a single international growth standard for both developed and developing countries, the development of national growth charts that reflect ethnic, genetic, and population-specific characteristics remains essential. In this context, Neyzi et al. developed Turkish growth charts for boys and girls, adapted from the WHO 2006 growth standards, using an Istanbul-based sample.⁴⁸

Optimal growth and growth monitoring

Growth monitoring is defined as the regular assessment of newborns and infants using standard growth charts, with the aim of identifying significant deviations and taking timely action. Growth faltering is determined during follow-up when weight loss, failure to gain weight in two consecutive assessments, or inadequate weight velocity is observed (i.e., <20 g/day between 0–3 months, <9 g/day between 3–6 months). During serial monitoring, an infant is expected to maintain its percentile trajectory on the growth chart; however, crossing down two major percentile lines is considered an indicator of growth faltering.³⁰ The 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles are generally regarded as major percentile thresholds.¹³

In preterm infants, the goal of optimal growth is to approximate intrauterine growth velocity. Catch-up growth is achieved when weight, length, and head circumference measurements reach the 50th percentile for the infant's corrected age. Typically, preterm infants are expected to achieve head circumference catch-up within the first six months, weight catch-up by 2–3 years of age, and height catch-up between 3 and 7 years.⁴⁹

According to the WHO, standards for age-related changes in growth parameters such as weight, length, and head circumference are used to monitor and evaluate growth and development. Weight gain standards are presented as weekly or biweekly increments during the first 60 days of life, followed by bimonthly increments until 24 months. Length standards are provided as increments at two- to six-month intervals up to 24 months, while head circumference increments are presented in two- to three-month intervals up to 12 months, and in four- to six-month intervals up to 24 months. Weight velocity standards are also available, calculated by dividing the change in weight between two measurements by the time interval. These WHO growth velocity and incremental standards provide globally applicable benchmarks, enabling consistent monitoring of growth and development across populations.⁵⁰

Although WHO does not specify an exact visit schedule for growth monitoring, some countries recommend structured follow-

up visits within the first two years of life (e.g., six visits).¹² In Turkey, the Ministry of Health recommends monitoring at 48 hours, day 15, day 41, and at 2, 3, 4, 6, 9, and 12 months of age, followed by at least every six months between 1–3 years and annually between 4–6 years.³⁰

Assessment of body composition in neonates

It is well established that physiological and metabolic changes occurring during critical periods of life, such as the neonatal stage, can exert long-lasting effects on health throughout growth and development. Traditionally, neonatal growth has been monitored using growth charts based on anthropometric parameters such as weight and length, without directly accounting for fat mass (FM) and FFM. However, monitoring changes in body composition alongside anthropometric indices is crucial for an accurate evaluation of growth. Tracking shifts in body composition provides a qualitative perspective on growth and enables researchers to better understand the relationships between physiological and metabolic processes, lifelong health and disease outcomes, and the impact of nutritional or clinical interventions.^{51,52}

In neonates, brown adipose tissue is metabolically active, but its quantity decreases with age. Body composition also differs by sex: male newborns typically have higher FFM, total body water (TBW), and bone mineral content (BMC), whereas female infants tend to have greater FM.⁵¹ Additionally, the hydration of FFM is approximately 83% at birth, decreasing to 78%–79% by one year of age. In term neonates, FM% typically ranges from 11% to 15%.⁸ Early changes in body weight significantly influence body composition later in childhood and adulthood. Rapid weight gain during the first year of life is strongly associated with subsequent body composition outcomes.⁵¹ Both low and high BMI values in the neonatal period have been linked to adverse health consequences later in childhood. Importantly, the timing and distribution of fat accumulation directly affect the risk of developing obesity-related metabolic complications. Infants with higher FM in early life are more likely to have elevated FM and BMI values in later childhood, contributing to increased obesity risk.^{8,53}

Despite its importance, validated and reliable techniques for assessing body composition in infants up to 5 years of age remain limited, representing one of the major methodological challenges in the field. High and rapidly changing TBW and FFM hydration levels in neonates complicate the establishment of standardized reference datasets.⁵⁴ The most widely used methods for evaluating neonatal body composition are ADP and DXA.⁸

ADP commonly performed using the PeaPod system (COSMED) designed for infants weighing 1–8 kg, involves measuring body weight followed by body volume in a specially designed chamber. Whole-body density is then derived from body weight divided by body volume, and FM and FFM are calculated using prediction equations. ADP is widely considered a safe, non-invasive, and practical method due to its speed, repeatability, and lack of risk to the infant, allowing multiple assessments during infancy.³⁷ One study demonstrated that neonates born to mothers with excessive gestational weight gain had significantly higher birth weight, FM, head circumference-for-age, and weight-for-age z-scores compared with controls, as measured by ADP and anthropometry.⁵⁵

DXA, in contrast, provides simultaneous estimates of BMC, FM, and FFM across different body regions (arms, legs, trunk), though it does not measure brown adipose tissue. Since infants

must remain still during the procedure, swaddling is often used.⁵³ Magnetic resonance imaging (MRI) is increasingly applied to infant body composition analysis, particularly in those weighing up to 12 kg. MRI can estimate FM, FFM, TBW, and skeletal muscle mass (SMM) without exposure to ionizing radiation. It is one of the few techniques capable of morphologically characterizing brown adipose tissue, and it provides high-resolution data on fat distribution, including visceral adiposity, which is particularly valuable for metabolic risk assessment. However, its clinical use is limited by high cost, sensitivity to motion artifacts, and specialized equipment requirements.^{8,37} MRI-derived fat distribution in preterm infants has shown strong correlations with birth weight, BMI, PI, and weight z-scores.⁵⁶

Ultrasonography (USG) offers a portable, radiation-free, and relatively low-cost alternative, making it particularly useful in bedside assessments of critically ill or unstable infants. It can measure subcutaneous fat thickness, muscle thickness, and BMC. Due to its rapid, non-invasive nature, USG has been shown to be reliable for monitoring infant growth, nutritional status, and responses to feeding interventions.⁵⁷ Its practicality and reproducibility have led to growing use in both clinical and research settings for term and preterm neonates.

In cases where direct measurement of FM is not feasible, indirect prediction models based on anthropometric ratios are applied. Indices such as weight-to-length ratio, BMI, and PI have been investigated for their ability to predict body composition. In healthy term newborns, BMI z-score showed a stronger correlation with FM% measured by ADP compared with PI, suggesting that BMI z-score may be preferable to PI as a complementary indicator of body composition.^{58,59} Conversely, a large multicenter study by Villar et al.⁶⁰ found that the weight-to-length ratio was more strongly associated with both FM and FFM than BMI or PI, highlighting its potential as an alternative marker of body composition. Furthermore, anthropometry-based models combining birth weight, length, and SFT improved the accuracy of FM estimation compared with models using only standard measurements.⁵⁹ These results demonstrate that it is possible to develop simple but effective prediction models, particularly for clinical settings and field studies where resources are limited.

Derived indices obtained from direct anthropometric measurements have been suggested to enhance the precision of body assessment. Equations incorporating body weight and length, the mid-arm circumference to head circumference ratio, and upper-arm cross-sectional areas are among the commonly utilized indices for evaluating nutritional status and body proportionality, although further validation is needed for their application in estimating body composition in neonates. In the literature, several FM prediction equations have been developed for the neonatal period, tailored to specific ethnic or geographic populations, often validated against ADP as the reference method (Table 2). Catalano et al.⁶¹ developed the original anthropometric prediction equation for neonatal FM in a general newborn population. Subsequently, Deierlein et al.⁶² incorporated Hispanic newborns into their model, while Aris et al.⁶³ proposed a regression model specific to Asian neonates. More recently, Josefson et al.⁶⁴ recalibrated the coefficients of the original Catalano equation in the Cleveland (USA) cohort, producing two new equations that provided improved accuracy for FM estimation in populations with similar demographic characteristics. In addition, Marano et al.⁶⁵ developed a new equation applicable to the general neonatal population for predicting FM.

The use of anthropometry-based FM prediction equations offers notable advantages. With only three basic anthropometric

Table 2. Population-specific fat mass (kg) prediction equations based on anthropometric measurements

Reference	Population	Equation
Catalano et al. ⁶¹ 1995	General neonatal population	$0.54657 + 0.39055 \times \text{weight (kg)} - 0.03237 \times \text{length (cm)} + 0.0453 \times \text{flank SFT (mm)}$
Deierlein et al. ⁶² 2012	Hispanic	$-0.012 - 0.064 \times \text{gender (male = 1, female = 0)} + 0.0024 \times \text{age (days)} - 0.150 \times \text{weight (kg)} + 0.055 \times \text{weight (kg)}^2 + 0.046 \times \text{ethnicity (Hispanic = 1, non-Hispanic = 0)} + 0.020 \times \text{sum of triceps, subscapular and thigh SFT (mm)}$
Aris et al. ⁶³ 2013	Asian	$-0.022 + 0.307 \times \text{weight (kg)} - 0.077 \times \text{gender (male = 1, female = 0)} - 0.019 \times \text{gestational age (weeks)} + 0.028 \times \text{subscapular SFT (mm)}$
Josefson et al. ⁶⁴ 2019	Cleveland (USA)	$-0.24087 + 0.28396 \times \text{weight (kg)} - 0.00968 \times \text{length (cm)} + 0.06669 \times \text{flank SFT (mm)}$ $0.40367 + 0.34824 \times \text{weight (kg)} - 0.01163 \times \text{length (cm)} + 0.0625 \times \text{flank SFT (mm)} - 0.02168 \times \text{head circumference (cm)}$
Marano et al. ⁶⁵ 2023	General neonatal population	$-0.76638 + 0.2512 \times \text{weight (kg)} + 0.0620 \times \text{triceps SFT (mm)} + 0.0754 \times \text{gender (male = 0, female = 1)}$

kg, kilogram; cm, centimeter; SFT, skinfold thickness; mm, millimeter.

measurements and relatively inexpensive, portable equipment, reliable FM estimates can be obtained, providing a practical tool for both clinical and field settings.⁶⁴ In another study, anthropometry-derived FM estimates showed a strong correlation with ADP-derived FM and FFM values.⁶⁶ However, some researchers argue that anthropometric equations may not reliably capture FM in neonates and emphasize that direct measurement methods should be prioritized when precise body composition data are required.⁶⁷

Evidence comparing preterm and term neonates indicates that preterm infants tend to have higher FM at birth compared with term infants, although this difference diminishes over time. Methodological differences between ADP and DXA in evaluating neonatal body composition have also been noted. DXA measurements tend to yield approximately 3% higher FM values compared with ADP, while both methods provide comparable results for FFM. These discrepancies are likely attributable to fundamental differences in the underlying principles of each technique. DXA estimates body composition based on X-ray attenuation characteristics of fat, lean tissue, and BMC, whereas ADP calculates total body density from measured body mass and volume. Given these differences, ADP may offer more accurate FM estimates in neonates, particularly because it avoids radiation exposure and may be more sensitive to variations in infant hydration status.⁶⁸

Accurate assessment of body composition in neonates remains challenging due to various methodological limitations. Population specificity of prediction equations (anthropometry, BIA), infant crying or movement during testing (ADP, MRI), radiation exposure risks (DXA), high costs, and specialized technical requirements all pose significant barriers. The absence of universally reliable reference data further complicates the development and validation of novel neonatal body composition assessment methods.⁸

In low-resource settings, the most feasible anthropometric measurements for neonates are those that require minimal equipment, training, and cost, while maintaining reasonable accuracy. Birth weight remains a fundamental measurement; however, where reliable scales are unavailable, proxy measures such as MUAC foot length, head circumference, and chest circumference are widely adopted due to their operational simplicity and diagnostic value for identifying low birth weight and prematurity.⁶ Studies indicate that chest circumference and foot length show strong correlations with birth weight and

gestational age, supporting their use as pragmatic screening tools in these environments.^{5,69} Conversely, sophisticated techniques like ADP, DXA, and USG, which provide detailed body composition data including FM and FFM assessments, are primarily confined to research contexts and high-resource clinical settings due to their high costs, technical requirements, and limited portability.^{37,70} Therefore, simple anthropometric measurements continue to be essential in clinical and community neonatal care in resource-limited settings, while advanced body composition assessments remain specialized research tools. The absence of universally reliable reference data further complicates the development and validation of novel neonatal body composition assessment methods.⁸ A concise comparison of these anthropometric and advanced assessment methods, highlighting their respective descriptions, advantages, and limitations, is provided in Table 3.

Conclusions

In conclusion, the use of anthropometric measurements based on age- and sex-appropriate standards plays a critical role in the practical evaluation of growth, development, changes in body composition, and nutritional status in newborns. Regular assessment and monitoring of these measurements are essential for the early detection of growth retardation or overweight status in children. In addition, advanced technologies such as DXA and ADP enable a more detailed and accurate assessment of body composition. Early-life body composition strongly influences later childhood and adulthood outcomes, with increased neonatal adiposity being associated with a higher risk of obesity in adulthood. Thus, body composition measurements can provide valuable insights for identifying undernutrition or overnutrition in advance, as well as for monitoring the adequacy of the growth process.

The combined use of anthropometric methods and advanced technologies offers a more comprehensive understanding of neonatal nutritional and health status. Particularly in critically ill infants, the portability and ease of use of these methods provide significant advantages for clinical practice. Future studies should aim to standardize these assessment techniques, evaluate their validity across different populations, and consider both their advantages and limitations. Ultimately, the early detection of health problems in the neonatal period is of paramount

Table 3. Comparison of anthropometric and advanced techniques for assessing neonatal growth and body composition

Measurement method	Description	Advantages	Limitations
Anthropometric methods			
Birth weight	Measured by infant scale	Simple, inexpensive, widely used, most reliable	Requires calibrated scale, affected by fluid shifts postpartum
Length	Measured using infant meter	Indicates linear growth, essential for growth monitoring	Requires training for accurate measurement, infant cooperation
Head circumference (HC)	Tape measure around largest head circumference	Non-invasive, reflects brain growth	Measurement errors possible, affected by molding
Mid-upper arm circumference (MUAC)	Arm circumference reflecting muscle and fat mass; useful for malnutrition screening after 3 months of age.	Rapid, portable, low-cost, valuable in low-resource settings.	Limited accuracy in neonates due to physiological changes; lack of validated neonatal reference data.
Skinfold thickness (SFT)	Measures subcutaneous fat at standard sites (e.g., triceps, subscapular).	Non-invasive, low-cost, correlates with adiposity in older infants.	Unable to use in neonates due to lack of reference tables; requires training and specialized callipers; poor precision due to compressibility of neonatal skin.
Ponderal index (PI) / Body Mass Index (BMI)	Derived from weight and length to estimate proportionality and nutritional status.	Easily calculated, correlates moderately with adiposity.	Does not directly measure body composition; influenced by hydration status.
Air displacement plethysmography (ADP, e.g., PEA POD)	Measures body volume and weight to estimate fat and fat-free mass based on density.	Non-invasive, accurate, reproducible, safe for serial measurements.	High cost, limited accessibility, requires infant cooperation and stable environmental conditions.
Dual-energy X-ray absorptiometry (DXA)	Uses X-ray attenuation to estimate fat, lean, and bone mass regionally and globally.	Precise, well-validated, differentiates tissue compartments.	Radiation exposure, high cost, limited portability, motion sensitivity.
Magnetic resonance imaging (MRI)	Provides high-resolution images of tissue compartments, including brown adipose tissue and visceral fat.	Gold standard for fat distribution analysis; no ionizing radiation.	Expensive, technically demanding, sensitive to motion artifacts, limited clinical feasibility.
Ultrasonography (USG)	Uses sound waves to assess subcutaneous fat, muscle, and bone thickness.	Portable, radiation-free, low cost.	Operator-dependent; limited validation for total body composition.

importance, as it contributes to the development of a healthy child and adolescent population that will transition into healthy adulthood.

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