Child growth and growth charts in the early years

Background

Children's growth is an important marker of their health and development. Poor growth in-utero and early childhood is associated with short and long term effects including increased rate of childhood infection, and development of 'life-style' diseases including coronary heart disease, high blood pressure and diabetes [1, 2]. Over-nutrition and obesity are also linked to poorer health outcomes [3]. Both infant body size during the early years of life and infant growth velocity have been shown to be associated with risk of later overweight and obesity in childhood and adulthood [4]. Growth assessment is the single measurement that defines the health and nutritional status of children because disturbances in health and nutrition almost always affect growth [5]. However growth charts are not a sole diagnostic tool but rather contribute to forming an overall clinical impression for the child being measured [6].

Growth assessment involving the measuring of weight, length or height (and infants' head circumference) followed by accurate plotting on a growth chart is quick, non-invasive and provides valuable information about the general health and well being of the child. At times it can be perceived by some health professionals as a low priority, as reflected by absence of functional equipment in some settings for weighing and measuring children [7]. At other times parameters are recorded but not plotted onto growth charts resulting in missed opportunities for the early detection of health conditions related to altered growth [8, 9]. This is concerning given the increasing rates of childhood obesity [8].

For parents growth assessment can be reassuring if their child is gaining weight steadily; however monitoring too frequently or focusing on weight gain can lead to anxiety and unnecessary referral to secondary services [10]. Growth charts are frequently used to educate parents about their children's growth. However many parents have difficulty understanding the data presented on a chart [11]. Health professionals are encouraged to teach parents how to interpret a growth chart and involve them in decisions on the management of altered growth patterns [12].

Factors affecting growth

Genetics
Parental size has a direct influence on a child's growth potential and predicted adult height. A child with short stature may be of concern because of possible illness or poor nutrition, but for a short child with short parents they are possibly genetically small. Extreme shortness may be due to a combination of genetic and non-genetic factors and should be assessed by an endocrine specialist. Charts may be used to determine a child's predicted height based on mid-parental height. (Refer to the Australian Endocrine Society www.endocrinesociety.org.au accessed 11/4/13). A child whose adjusted stature is still less than expected should be investigated further [13]. Three percent of all children will grow below the 3rd percentile on height for age charts and still be healthy. Genetic disorders and chromosomal abnormalities can also have the potential to alter children's growth e.g. Trisomy 2, Prader-Willi syndrome and others.

Ethnicity
Traditionally it was believed that different ethnic groups show different patterns of growth; on average African-Caribbean groups were believed to be taller and heavier, and Asian and Chinese groups shorter and lighter when compared with Caucasians [14]. However the

Multicentre Growth Reference Study (MGRS) has refuted this belief showing that variability in infant growth was greater within population groups than between the different country groups (Figure 1) [15].

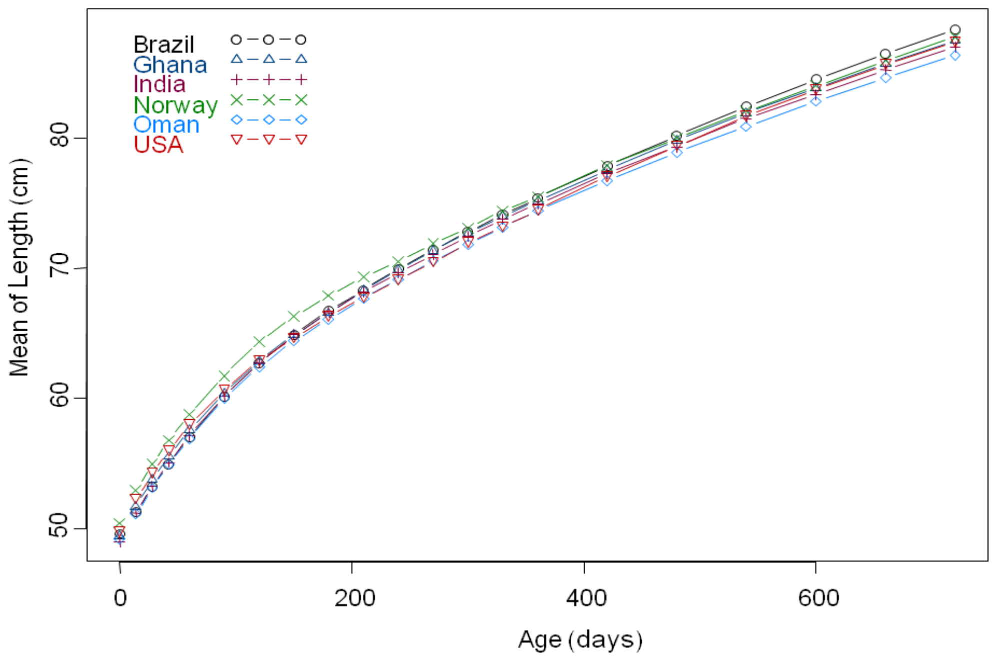

Figure 1 Effect of ethnicity on infant growth - Mean length from 0 – 24 months for the six MGRS sites

Birthweight

Birthweight is universally measured making it one of the most accessible and reliable indicators of not only the infants health but subsequent health risk in adulthood [16]. In general, lower birthweight is associated with higher risk or morbidity [17]. A baby's weight at birth is strongly associated with mortality risk during the first year, with developmental problems in childhood and risk of diseases in adulthood, including cardiovascular disease and some cancers [18]. At a population level, groups with lower mean birth weight often have higher infant mortality (e.g. infants of mothers who smoke or of mothers from lower socioeconomic background). Asthma, lower developmental outcomes and hypertension have all been reported to be more common among small birth weight infants [17].

Babies born prematurely (before 37 weeks completed gestation) or who are born small for gestational age may also be at increased risk of cardiovascular diseases, suggesting that foetal under-nutrition may increase susceptibility to diseases occurring later in life. Evidence from animal studies suggests that the foetus may adapt to an adverse intrauterine environment by slowing down growth and metabolism, and that large birth size may predict increased risk of obesity, diabetes and some cancers [18]

Anomalies in circulating hormones such as growth hormone, insulin like growth factor, testosterone, oestrogen, thyroid hormone, cortisol and insulin can affect birth weight and growth. For example, children who are large for gestational age at birth following exposure to an intrauterine environment of either maternal diabetes or maternal obesity are at increased risk of developing metabolic syndrome. Given the increasing obesity prevalence, these findings have implications for perpetuating the cycle of obesity, insulin resistance and associated consequences in subsequent generations [19].

Nutrition

Nutrition has a direct impact on growth. Inadequate nutrition including energy, protein and micronutrients - whether caused by illness or food insecurity - can slow growth potentially leading to failure to thrive (FTT). Conversely overfeeding associated with rapid weight gains may result in overweight or obesity.

Breastfed infants have been long-recognised to have different growth patterns in the first year of life compared to non-breastfed babies. Significant differences between the growth rates of formula and breastfed infants was first reported in the DARLING (US) study [20] showing that breastfed infants grow more quickly initially, for the first 3 -6 months, and then more slowly over the next 6 – 9 months. At the end of 12 months, breastfed infants were generally 500-600g lighter than formula fed infants. The analysis of pooled data from seven longitudinal studies of infant growth also confirmed that infants breastfed for at least 12 months grew more rapidly in the first 2 months and less rapidly from 3 – 12 months [21].

Environment

General health and maternal age, parity, socio-economic status and substances such as smoking can affect birth weight and growth [18]. Infants born at high altitudes are known to be smaller babies believed due to lower oxygen levels [17].

Health and wellbeing

The presence of medical conditions such as renal disease, congenital heart disease, recurrent infections, developmental delays, feeding difficulties and the need for long term medications can contribute to altered growth patterns in infants and children.

Growth charts

Growth charts show the growth of a reference population and are used for the assessment of individuals and groups of children. Serial measurements of the child's growth plotted on a growth chart are used to identify and assess patterns of growth. Single or 'one-off' measurements for individual children show only a child's size, not their growth.

Growth charts are an essential tool in the monitoring and assessment of children's growth. The interpretation of childhood growth percentile tracking is dependent on the growth charts used. Hence it is important to be aware of the consequences of the methods used in the construction of growth charts when interpreting growth data in the clinical and epidemiological setting [4].

Background to growth charts in Australia

The Best Start inquiry in 2007 recommended that Australian Health Ministers decide on a standard infant growth chart to be used in all states and territories. Through an extensive consultation process in 2010, unanimous support for the implementation of a single standardised national growth chart for infants was evident contingent on comprehensive support and training materials being available [22]. Many Australian organisations including The Australian Medical Association (AMA), the Australian Breastfeeding Association and the Public Health Association strongly supported the adoption of the World Health Organization (WHO) 2006 growth charts. In September 2010, the US Centers for Disease Control (CDC) recommended use of the 2006 WHO growth charts to monitor growth for all children less than 2 years of age and the continued use of the CDC growth charts to monitor growth for children age 2 years and over (Accessed 11/4/13 http://www.cdc.gov/growthcharts/).

Prior to 2003, most Australian health professionals used growth charts developed by the US National Center for Health Statistics (NCHS) in 1977. In 2003 the NHMRC recommended using the CDC 2000 growth charts and these were gradually introduced in Australia over the following two to three years [23]. The CDC 2000 charts were based on a US population with a high proportion of formula fed infants.

In 2012, all Australian jurisdictions agreed to adopt the WHO 2006 growth charts for Australian children aged 0 - 2 years [24, 25]. The WHO growth standards for this age group are already in use in the Northern Territory and Victoria. They will be phased in by other states and territories for use at the primary health care level. The CDC charts remain in use in most jurisdictions for children and adolescents aged 2-18 years; the Northern Territory has adopted the WHO charts for this group.

Development of growth charts

1. NCHS (1977)

The US National Centre for Health Statistics (NCHS) growth reference was used to monitor the growth of children in Australia from the late 1970's to the early 2000's. This reference was produced using cross-sectional data from the United States National Health Examination Survey (NHES II and NHES III. and National Health and Nutrition Examination Survey NHANES I, 1971-74). The major concerns about the NHCS growth charts were that the data was obtained from an unrepresentative group of infants who were mostly artificially fed, and that measurements were made infrequently [26].

2. CDC (2000)

In 2000, the Centers for Disease Control, Atlanta (CDC) produced a revised set of reference growth curves (http://www.cdc.gov/growthcharts/ accessed 11/4/13). These were based on more recent data than NCHS; solely collected from the USA National Health and Nutrition Survey (NHANES) program [26]. Data collection took place between 1963 and 1994 in 5 cross sectional, nationally representative health examination surveys. Exclusions from the survey were made for very low birth weight infants (birth weight <1500g) as these infants are known to grow differently from normal birth weight babies, and data from NHANES III (1988-94) for children 6 years or older because their inclusion would have significantly increased the cut-offs for overweight.

The data from the 5 surveys was combined with a target sample size of 400-500 at each age group in order to generate precise percentile lines. Statistical methods were applied to obtain smooth curves. The population used to generate these charts was considered to be racially and ethnically diverse, and a better representative sample of the US population than the NHCS (1977) charts. Additional growth curves based on Body Mass Index (BMI) and weight for height were developed.

NHCS and CDC growth curves are similar with some minor differences seen for infants. CDC describes the chart as a growth reference, which is defined as a tool enabling comparisons to be made. Criticisms of the CDC growth charts are that the infants were still predominantly formula fed. Only about half of NHANES III mothers initiated breastfeeding and 21% exclusively breastfed for 4 months. The sample size was small especially in the first 6 months (<100 per age group) and there was a skew towards higher weight especially in the older age groups probably because of increasing rates of obesity. Despite these limitations, the CDC charts were believed to be broadly applicable to the Australian children from birth to 18 years.

3. World Health Organization (WHO 2006) Growth Standards for 0 – 5 years

Breastfed babies are known to grow at a different rate to the CDC growth reference curves. Pooling of data from seven longitudinal studies of infant growth confirmed that infants breastfed for at least 12 months grew more rapidly in the first 2 months and less rapidly from 3 – 12 months. This provided the rationale for the WHO working group to develop new standards [20].

In 2006 the World Health Organization (WHO) released a new set of growth standards and charts, based on data from the Multicentre Growth Reference Study (MGRS) (http://www.who.int/childgrowth/standards/en/ accessed 11/4/13) [27]. The WHO recommends the application of these standards for all children worldwide, regardless of ethnicity, socioeconomic status and type of feeding [28]. WHO describe these as a standard – how children should grow; they establish breastfeeding as the 'norm' and the breastfed infant as the standard for measuring healthy growth. In 2011 over 140 countries were at various stages of implementing the 2006 WHO Growth Standards [29].

The MGRS involved children from 6 countries representing different regions of the world: Brazil, Ghana, India, Norway, Oman and the United States. Site inclusion criteria included socioeconomic status that does not constrain growth, indicated by low infant mortality rates, and rates of stunting wasting and underweight lower than 5% at 12-23 months of age. Other characteristics of sites included altitude less than 1500 metres above sea level, low mobility of the population to allow follow-up, at least 20% of mothers willing to follow the feeding recommendations, and existence of breastfeeding support services. Eligibility criteria included:

- no health, environmental, economic constraints on growth
- willingness of the mother to exclusive or predominant breastfeed for the first 4 months, starting complementary food by 6 months and continuing breastfeeding to at least 1 year
- single birth; gestational age >37 and <42 weeks
- exclusion of preterm and very low birth weight infants
- optimal health care including immunisations and good routine paediatric care
- absence of significant morbidity and
- absence of maternal smoking before and after delivery

The total sample size was approximately 8500 children consisting of a longitudinal cohort of 1743 children followed from birth until 24 months. Children were visited and measured 21 times in the longitudinal study. Of the 1743 children followed longitudinally, there were 882 who complied with the constraints of the study. Between 67 and 220 infants from each of the 6 participating countries were included and the sample size was 238 boys and 454 girls for the study. Data collection took place between 1997 and 2003.

The WHO standards initially consisted of sex specific weight-for-age, length/height-for-age, weight-for- length/height, and body mass index-for-age charts. In addition to anthropometric measures a chart outlining motor development milestones, which were also monitored in the survey was provided. A further set of charts comprising: mid upper arm circumference-for-age, head circumference-for-age, sub-scapular skin fold-for-age and triceps skin fold-for-age were released early in 2007, followed by a set of growth velocity charts in 2009. All charts are available with both percentiles and Z-scores.

A survey of 125 countries adopting the WHO standards indicated that the anthropometric indicators used for the assessment of growth varied. Weight-for-age was adopted almost universally, with a large number also adopting the length/height-for-age and weight-for-length/height. Less than half the countries surveyed reported adopting the BMI-for-age and head circumference-for-age [30]. Further research is needed to validate the use of BMI-for-age to assess nutritional status in the first two years of life [6]. In preschool children BMI-for-age and weight for length or height (WFLH) provide similar information hence there is no need to monitor both indicators [30].

4. WHO Growth reference for age 5 - 20 years

Growth charts for children over 5 years were released in mid 2007 [31]. A decision was made that a multicentre study similar to that used for under 5 year olds was not feasible, because it would not be possible to control for environmental factors which may interfere with growth. It was also recognised that using a descriptive sample of a current population may not be appropriate because of the trends towards overweight. This would lead to upward movement of the growth reference and result in an underestimate of obesity and an overestimate of undernutrition. Therefore a growth reference was constructed from existing historical data. After reviewing 115 available data sets from 45 countries, the NCHS/WHO 1977 growth reference based on a non-obese sample was reconstructed using a sample size of 22,917 and merged with data from the under 5's cross-sectional sample of children to smooth the transition between the two samples. Outliers both for height and weight for age and BMI for age were removed from the data set (2.8% of boys and 3% of girls) to avoid the influence of unhealthy weights for height. Data was merged with the under 5's growth standards data and smooth growth curves generated. BMI charts were created for 5 – 19 year olds, the +1 SD at 19 years are equivalent to the overweight cut off for adults (25 kg/m^2) and +2 SD equivalent to the adult cut off for obesity (30 kg/m^2) [31]. WHO describes the charts for 5-20 year olds as a growth reference.

Advantages of using the WHO standards for 0 – 2 year old children

The recommendation for adopting the WHO standards is based on several considerations.

Breastfeeding:

The WHO growth standard promotes breastfeeding as the norm reflecting growth patterns among children who were exclusively or predominantly breastfed for at least 4 months and still breastfeeding at 12 months. This is consistent with the Australian Dietary Guidelines 2013 [24] which recommend exclusive breastfeeding until around six months and then continued breastfeeding while solid foods are introduced and until 12 months of age and beyond for as long as the mother and infant wish.

Although the CDC charts were based on a higher percentage of breastfed infants than the older NCHS data they replaced, they were created by pooling data from breastfed and formula-fed infants. As a result, the CDC growth curves reflect a different pattern of growth than typically observed in healthy breastfed infants.

Growth standard versus growth reference:

Children in the WHO sample were raised under optimal circumstances and health conditions. As such the WHO growth charts are described as standards identifying how children should grow when provided with optimal conditions [6, 15].

CDC charts show a snapshot of weight and heights of the sample population, regardless of whether their rate of growth was optimal or not. Although very low birthweight babies (less than 1500g) were excluded, no other restrictions were made to limit the infants to those who were healthy and growing optimally. Therefore the CDC charts potentially show the growth of some infants who may have been fed sub-optimally, raised in substandard environmental circumstances; or had infections, chronic illness or disease.

Longitudinal versus cross-sectional growth monitoring:

Growth of the infants in the WHO growth study was followed incrementally, with each infant measured 21 times between birth and two years. The shorter measurement intervals results in a better tool for monitoring the rapid and changing rate of growth in early infancy [15].

The CDC curves were based on compiled anthropometric measurements that were performed only once on the infants and toddlers sampled. National survey data were unavailable for the first two to three months of life, so supplementary data was incorporated. Weight data were not available between birth and two months of age and sample sizes for the remainder of infancy were significantly below the 200 observations per sex and age group recommended for construction of growth curves. The cross-sectional nature of the CDC charts represents achieved size of infants; it does not describe rates of growth as accurately as growth represented in longitudinal growth charts.

International sample population:
The varied cultural and ethnic backgrounds of the sample population used to develop the WHO standards, and the similarity in growth between sites, are relevant not only to growth monitoring in the global community, but also for the multicultural mix of children living in Australia. Whilst not all races were sampled, the fact that only small differences in growth were associated with cultural/racial background is suggested by WHO as evidence that trends in growth of children from non-sampled cultures would be similar. WHO field-tested their growth standards prior to their release in 4 countries (Maldives, Pakistan, Argentina and Italy) by comparing children's length-for-age and weight-for-length z-scores with clinicians' assessments of the same children. In all sites, children classified by clinicians as 'thin' were classified correctly as 'wasted' (WHZ <-2SD) on the charts [28]. Similarly, comparison of weight assessment using the WHO and CDC growth charts for children less than 2 years of age admitted to a tertiary health facility in Canada were quantified [32].

Strengths and limitations of growth charts

Comparison of the WHO and CDC growth charts shows important differences that vary by age group. These differences have the potential to impact on the interpretation of growth and feeding advice at a clinical level and the estimation of prevalence of over and underweight at an epidemiological level [4].

Criticisms of the WHO charts mostly relate to the fact that they were produced from a highly selected group of healthy breastfed children living in optimal conditions. This can be considered as both a strength and a weakness. Concern has been expressed that comparing the growth of children who are not being raised in such ideal conditions or who are formula fed to the WHO standards might not be appropriate. Conversely growth of some children who do live in optimal circumstances may deviate from the standard but they are not unhealthy. Growth may not always follow the WHO curves.

The WHO standards reflect the growth of breastfed babies and show a faster rate of weight gain during the first 3 months of life compared to the CDC charts. From about 3 months of age the rate of weight gain starts to slow such that from about 6 months the WHO charts show babies to be a lower weight compared to the CDC charts. The interpretation of growth may therefore differ according to the growth chart used which in turn may have implications for the advice given to mothers concerning breastfeeding, supplementation with formula and the introduction of solid foods [33].

These differences have raised concerns that when using the WHO charts to assess the growth of formula fed infants, these infants might be identified as growing too slowly during the first few months of life but then identified as growing too quickly after approximately 3 months [34]. Health workers need to understand these differences in growth pattern and not misinterpret the infant as having faltering growth. To avoid inappropriate advice about feeding the infant's general health and weight relative to length should be considered [12].

It is worth noting that the protein content of infant formula is now lower than when the CDC charts were developed hence the current growth patterns of formula fed infants may not be the same as that represented on the CDC growth charts [34]. A multicentre European study comparing the growth of breastfed infants with infants fed either a lower or high protein formula demonstrated that growth in the lower protein group was closer to breastfed infants [35].

The higher than expected weight from birth to 6 months of the WHO standards has been attributed to selective dropout of study infants. 50% of infants did not comply with exclusive breastfeeding for 4 months and were excluded from the MGRS study. It is suggested that infants who discontinue exclusive breastfeeding tend to be smaller, thus the charts represent infants with a relatively high weight [36]. Some have expressed concern that the resulting high weight percentiles may have the unintended effect of causing mothers to discontinue breastfeeding before 6 months [37]. To date there are no observations to support these concerns but the possibility cannot be dismissed [36].

Estimates of the prevalence of overweight and underweight vary according to the growth chart and the cut-off used. Traditionally the CDC charts have used the 5th and 95th percentiles as cut-offs to identify children who may not be growing normally. These percentiles are arbitrary and not based on health outcomes. The WHO has arbitrarily chosen the 2.3rd and 97.7th percentiles which is equivalent to +/- 2 standard deviations.

Use of WHO recommended percentiles on WHO charts in the USA results in a prevalence of overweight that is similar to prevalence from CDC curves using CDC cut-offs. However use of the CDC cut-offs on WHO charts results in 10% of the WHO growth curve population to being categorised as underweight or overweight, even although the population comprises healthy children who were fed according to international recommendations. This might lead to an overestimate of the prevalence of short stature, underweight and overweight in the United States [34].

The second percentile of the WHO chart is considered equivalent to the 5th percentile of the CDC charts [24]. The CDC has modified the WHO charts for use in the US to include the 2nd and 98th percentiles in addition to 5th and 95th percentiles (http://www.cdc.gov/growthcharts/ accessed 11/4/13). Theoretically, children in the WHO population would be expected to be healthy and thus more extreme cut-off values are more appropriate to define the extremes of growth of children rather than those values used in a descriptive reference (CDC Online WHO growth chart training http://www.cdc.gov/nccdphp/dnpao/growthcharts/who/index.htm accessed 11/4/13).

Fewer children aged from 6 months to 2 years will be identified as having low weight-for-age when using the WHO charts. However those identified as having low weight-for-age on the WHO growth charts will be more likely to have a substantial deficiency that requires further assessment. Differences in length-for-age are small [34].

Preference for local references or charts has been cited as one reason for not adopting the WHO standards in some countries [30]. However an important finding from the WHO growth study was that, in spite of racial and ethnic background, there were minimal differences in the rates of linear growth observed among the six countries. After adjusting for age and sex, the variability in the measured length of participants from birth to 24 months was overwhelmingly due to differences amongst individuals (70% of total variance) and only minimally to differences amongst countries (3% of variance)[15]. This strengthens the argument that children of all ethnic backgrounds have similar potential for growth when raised in environmental conditions favourable to growth, particularly smoke-free households, and access to health care and good nutrition.

The WHO standards describe how children grow in defined optimal conditions and despite the concerns and criticisms they are recommended for use in all infants from birth to 2 years [34]. To ensure appropriate feeding advice is given to parents it is essential to understand the strengths and weaknesses of growth charts when assessing growth. Regardless of which growth chart is used, serial measurements of a child's length and weight plotted on a growth chart are essential for determining a child's pattern of growth.

Interpreting child growth

Interpretation of children's growth requires competent staff trained in the use of child growth equipment and growth chart interpretation. Growth charts are needed for the assessment and monitoring of individual children and populations and are used universally in paediatrics [38].

One-off measurements plotted on a growth chart describe a child's size and may be useful to screen children at nutritional risk however they do not describe a child's growth. To describe a child's pattern of growth serial measurements over time, plotted on a growth chart are needed. Growth assessment involves looking at the overall trajectory of weight-for-age, length-for-age and weight compared to length, or BMI-for- age (over 2 year olds) to determine whether a child is tracking along the growth curves, or crossing percentiles upwards or downwards. The direction of serial measurements on the curve is more important than the actual percentile.

Growth chart 'percentile' lines show the reference range of weights and heights for a particular age and gender. For example, 50% of the population are expected to be below the 50th percentile; 90% below the 90th percentile. Half of all children at a given age are usually between the 25th and 75th percentiles, but parents and professionals should not feel under any pressure to try and ensure that the child's weight should be on or near the 50th percentile at any age [10].

Very few infants grow along the same percentile line from birth; about half cross at least one percentile band (the distance between 2 percentile lines) up or down during the first year. Infants who are large at birth are more likely to move to a lower percentile, whereas the opposite is true for infants of low birthweight. Infant growth is not a linear process (despite how growth is represented by percentile lines), and children measured too frequently may see times of 'zero' growth [39].

Poor growth is reflected by an extreme measurement percentile on a single occasion, or evidence of percentile 'crossing'. An 'ideal' weight-for-height is when the weight percentile is close to the height percentile [39].

Children with either weight or length/height measurements 'crossing' percentile spaces in either the upwards or downwards direction, or BMI above the 85th percentile or below the 5th percentile (over 2 year olds) should be monitored more closely. A mid-parental stature should be considered if there are concerns about the child's short-stature. This involves calculating the ‘average’ of mother and father’s heights and provides context for the child’s predicted height potential. Despite many parents’ perceptions, the 50th percentile is not the goal for each child. Children often shift percentiles for both length and weight, especially in the first 6 months, with the majority settling into a curve towards the 50th percentile rather than away. Except for the first 2 years when shifts are normal, a sharp incline or decline in growth, or a growth line that remains flat, are suggestive of a problem.

Growth monitoring provides an opportunity for discussion about child growth and development. Although recent reviews suggest insufficient evidence that routine growth monitoring is of benefit to child health in either developing or developed countries [40], and little evidence for monitoring weight beyond 12 months [41], parents can be readily reassured about their child’s health and development through discussions arising during growth monitoring. Counselling sessions about child growth have been shown to account for a large proportion of discussions with parents during well-child health checks [42].

There are widespread concerns about the increasing prevalence of overweight and obesity in children and adolescents in Australia and growth monitoring is an important assessment and monitoring tool. BMI for age is an effective screening tool for children, but not a diagnostic tool. It should be used for guidance for further assessment, referral or intervention, rather than as diagnostic criterion for classifying children. Children who are crossing BMI percentiles in an upward direction may be at risk of becoming overweight or obese. Unlike adults, age-related increases in BMI during growth are associated with increases in both fat mass and fat-free mass [6].

Unusual or concerning patterns of weight gain and growth sometimes go unrecognised for various reasons:

- Measurements taken incorrectly, plotted on a growth chart inaccurately, or not plotted at all, may lead to erroneous interpretation of growth patterns and missed or unnecessary referrals
- Growth assessment is not effective in improving child health unless what is revealed by the growth monitoring is discussed with the family. Information about adequate or inadequate changes in growth is used to reinforce or motivate positive nutritional and healthy lifestyle practices with the family.

Possible causes of growth problems

Fluctuations in weight percentiles are much more common than height or head circumference changes. They are also more easily rectified. Crossing of height percentiles represents longer term influences on growth and is more significant, particularly if slowing. Crossing of head circumference is cause for concern and needs further investigation [43]. Possible causes of growth problems are described in Table 1:

Crossing percentiles	Possible causes	
Increasing weight percentiles	**Energy imbalance**[1]	Excessive food Inadequate physical activity
	Endocrine disorders	Hypothyroidism Excess cortisol (Cushings) Pituitary disease
	Genetic disorders	Prader-Willi Downs syndrome
Decreasing weight percentiles	**Acute illness**	Short term illness, vomiting, diarrhoea
	Chronic illness	Including, but not limited to cardiac, respiratory, gastrointestinal, renal disease
	Physical and/or developmental concerns	Neurological conditions, cerebral palsy
	Nutritional	Inadequate energy intake
Increasing height percentiles	Endocrine disorders	Excessive growth hormone Hyperthyroidism Rare genetic syndromes
Decreasing height percentiles	Endocrine	Growth hormone deficiency Hypothyroidism Ricketts
	Chronic illness	Chronic anaemia Chronic illness Systemic failure (e.g. renal, cardiac)
	Genetics	Chromosomal disorders
	Nutritional	Long-term primary or secondary malnutrition i.e. infection
Increasing head circumference percentile	Hydrocephalus, chromosomal abnormality, Developmental delay	
Decreasing head circumference percentile	Prenatal insult	Maternal substance abuse, maternal infection
	Birth complication	
	Chromosomal abnormality	

Table 1 Possible causes of abnormal child growth

[1] Causes listed in **bold** are more common

Monitoring growth for children with special needs

Monitoring the growth of children with special health needs such as prematurity, medical conditions known to alter growth, genetic disorders, developmental delays and disabilities requires additional considerations.

A child born before 37 completed weeks gestation is considered preterm [12]. Alternative charts are available to assess the growth of preterm infants in the neonatal intensive care unit however uncertainty exists regarding the most suitable curves to use [44]. Once a corrected age of 40 weeks is reached, the WHO standards can be used to monitor ongoing growth [44]. Corrected age should be used until 2 years of age. If the child catches up before this then chronological age can be used (http://www.cdc.gov/growthcharts/ accessed 11/4/13). The appropriate rate of weight gain or catch up growth is unknown and concern has been raised that aggressive nutritional supplementation with rapid weight gain will promote increased adiposity and later increased risk of metabolic syndrome [45].

Some conditions alter a child's growth potential e.g. chromosomal disorders such as Trisomy 21, Cornelia de Lange syndrome while others such as neurological disorders associated with feeding difficulties or immobility may alter a child's potential for growth. Syndrome specific charts have been developed for a range of conditions. However, due to the limitations in the development of these charts it is recommended that all children have their growth monitored using age appropriate charts for healthy children i.e. WHO standards for children under 2 and CDC charts from 2-18 years (http://www.cdc.gov/growthcharts/ accessed 11/4/13). Syndrome specific charts may be useful to provide a comparison provided the clinician fully understands the limitations of the chart. Further details on monitoring growth in children with special needs can be obtained at http://depts.washington.edu/growth/ (accessed 11/4/13).

Poor growth

Children displaying slow growth may be described as 'failing to thrive' however there is no consensus on a definition of what constitutes failure to thrive (FTT) or at what level of poor growth there are adverse consequences for children [46, 47]. The frequently quoted chart-based definitions of poor growth in children under the age of 2 include: a child whose weight is below the 3rd percentile for age on more than one consecutive occasion, a child whose weight drops down two major percentile lines, a child whose weight is less than 80% of the ideal weight for age, and a child who is below the 3rd or 5th percentile on the weight for length curve. However all of these criteria have limitations [48]. Weight alone was determined to be the simplest and most reasonable marker of poor growth in one analysis [49]. As the term 'failure to thrive' implies failure, not only of growth, but also other aspects of a child's development, chart-based definitions of poor growth should always be used in the context of assessing the whole child.

Changing from one set of growth charts to another may result in different numbers of children classified with poor growth [50]. Also, some infants and young children may cross percentile lines on growth curves during a normal course of growth [48]. Thus regardless of the definition or the growth chart used children identified as having poor growth should have a full growth evaluation including a detailed family history, a description of associated symptoms, a physical examination and review of the child's growth records (http://www.cdc.gov/growthcharts/ accessed 11/4/13).

For children without a medical reason for poor growth, some will re-establish healthy growth rates with nutrition intervention, but for others poor weight gain persists [51]. This group includes children classified as 'fussy' eaters, oral-motor problems, poor appetite regulation, hypersensitivity, aversions to certain textures, and /or behavioural problems associated with mealtimes. Feeding problems and concern about child growth are known to impact negatively on the parent-child relationship [51]. Research evidence suggests that certain children who appear to have slow growth may be biologically programmed to be smaller and thinner than most children. Insulin resistance may be a mechanism, and aggressive nutritional intervention may put these children at risk of developing metabolic syndrome [48].

The ideal rate of catch-up growth is not known. There is increasing concern that rapid catch-up growth in undernourished children increases the risk of chronic illness later in life [52] however some evidence suggests this is not likely in children under 2 years despite severe malnutrition and rapid catch up growth [2]. This scenario differs from the cases of individual children's 'catch up' following illness and a return to their previous growth trajectory.

Population growth assessment

For populations, single measures can be used for monitoring and surveillance of under or over nutrition, international comparison and evaluating effectiveness of nutrition programs. In the analysis of population growth data, preference is given to the use of standard deviation (SD) z-scores and population distributions. Cut-offs (for example -2SD) are used for comparison of prevalence and for screening of populations [53].

The WHO defines 'underweight' (severe acute malnutrition) as a weight-for-age of 3 SD below the median WHO growth standard, the presence of bilateral pitting oedema, or a mid-upper arm circumference less than 110mm in children aged 1 – 5 years [54]. Globally, severe acute malnutrition (SAM) affects approximately 3% of children under 5 and is associated with several hundred thousand child deaths each year [55]. Moderate acute malnutrition (MAM) is defined as a weight-for-age between -3 and -2 z-scores below the median of the WHO child growth standards [56], and is associated with an increased risk of mortality [57]. MAM may progress to severe acute malnutrition (SAM) (severe wasting and/or oedema) or severe stunting (height-for-age less than -3 z-scores), which are both life-threatening conditions.

'Wasting' (low weight-for-height) refers to a deficit in tissue and fat mass compared with the amount expected in a child the same height or length, and may result either from failure to gain weight or from weight loss. It can develop rapidly, but under favourable conditions can be restored rapidly [53]. Rates of wasting are used to classify populations at risk; for example greater than 15% of children under 5 years with wasting indicates 'very high' levels of malnutrition, and warrants an emergency response.

'Stunting' signifies slowing in skeletal growth. Stunting is frequently found to be associated with poor overall economic conditions, especially mild to moderate chronic or repeated infections, as well as inadequate nutrition [53]. The prevalence of wasting in developing countries is greatest between 12 and 24 months of age, when dietary deficiencies are common and diarrhoeal diseases more frequent and tends to reduce later on. In contrast, the prevalence of stunting increases over time up to the age of 2 – 3 years.

A systematic review [2] from five longstanding prospective cohort studies from developing countries suggested that lower birth weight and undernutrition in childhood are risk factors for high glucose concentrations, high blood pressure, and high blood lipids once adult BMI and height are adjusted for, suggesting that rapid postnatal weight gain – especially after infancy – is linked to these conditions. This has led some to question the approach of 'Catch up' growth in these populations [52], although other evidence suggests that catch up growth before 2 years of age does not have the same longer-term implications [2].

The WHO defines 'thinness' as BMI at age 18 as less than 17 kg/m^2 [58]. This same cut-off applied to the WHO data at 18 years of age gives a mean BMI close to a z-score of -2. Therefore it matches existing criteria for wasting in children based on weight and height. For each dataset, percentile curves were drawn to pass through the cutpoint BMI 17 kg/m^2 at 18 years. Similar cut-points were derived based on BMI 16 kg/m^2 (severe malnutrition) and 18.5 kg/m^2 (mild malnutrition). Practical application of this new research has identified some inconsistencies in the use of BMI using the WHO standards for older children [32].

Overweight

In 2011 – 12, 25.3 % of Australian children were overweight or obese, comprised of 17.7% overweight and 7.6% obese. There has been no change in the proportion of children overweight or obese between 2007 – 08 and 2011 – 12 (NHMRC Draft Obesity Guidelines). Obesity predisposes children to a range of serious medical conditions including insulin resistance, diabetes, cardiovascular disease and liver disease [3] Overweight children are also at risk of low self-esteem, negative self-image and social isolation [59]. Children with one obese parent have a 40% risk and with two obese parents 80% risk of developing obesity. Recent studies suggest that on a population basis children are heavier than they used to be, and that the overweight children are now more overweight than in the past. This corresponds to adult studies which indicate that while more adults are obese, it is in the category of the morbidly obese that there is the greatest change [60].

Child overweight has previously been defined as weight for height above the 90th percentile on the NCHS growth charts or weight above 120% of the median for weight taking into account a child's sex, age and height [61]. BMI is now commonly used as the standard measurement. BMI does not directly measure body fat but is a useful predictor of adiposity in children. It is also used as a predictor of risk for medical complications of obesity. CDC suggests that children above the 85th percentile BMI are 'at risk of overweight' and above the 95th percentile are 'overweight'; recognising that weight status may improve before the child reaches adulthood. The NHMRC definition classifies children above the 85th percentile as 'overweight' and over the 95th percentile as 'obese'.

During childhood it is possible to see the early signs of later indicators such as high blood pressure and raised lipids, with tracking into adult life. For a number of adult health problems, the morbidity and mortality is higher in those who have been overweight as adolescents, even if they are no longer overweight. This includes cardiovascular problems, some cancers and some gastrointestinal problems [62].

Despite growing concern about childhood obesity in Australia, most of the mothers surveyed in a community-based cohort of 4 year old children were not concerned about their child's weight, and many mothers did not perceive their overweight children as different from their peers [63]. The prevalence of overweight was 19%, but only 5% of mothers indicated concern about their children being currently overweight.

Estimates of the prevalence of overweight and obesity vary according to the growth chart used. The proportion of all infants and toddlers plotting above the 85th percentile weight-for-length is greater using WHO (21%) compared with CDC (16.6%) charts according to a recent comparative study. The greatest disparity between the 2 charts occurs in weight-for-length percentiles in children between 6 months and 2 years [32].

Questions about the applicability of the BMI percentiles in the WHO reference charts have also been raised for preschool children. For example the prevalence of overweight in a sample of 5 year old girls is 3.4% using the WHO and 15.3% using other internationally recognised definitions for child obesity [64]. Research is urgently needed to identify, BMI cut-offs for the WHO standard that are associated with an increased risk of overweight and obesity and associated health outcomes later in life. BMI charts from the CDC reference for children 2-18 years are recommended by the NHMRC in Australia at this stage.

For children 0-2 years there is lack of evidence that BMI for age is more effective than weight-for-age or weight for-length at assessing adequacy of feeding, and under or overweight. (http://www.cdc.gov/growthcharts/ accessed 11/4/13). Further research is needed to validate the use of BMI in this age group, with emphasis on identifying associations between BMI and subsequent health outcomes [6].

Waist circumference may be used as an additional indicator to BMI to identify overweight and obesity in children (NHMRC Draft Obesity Guidelines). As the relationship between waist measure and metabolic complications in children and adolescents also remains undefined, there are no universally accepted thresholds for increased risk. A waist-to-height ratio of more than 0.5 in children as young as 6 years may be useful in predicting cardiovascular risk in children, and is easy to calculate (NHMRC Draft Obesity Guidelines).

Role of BMI

Unlike adults where a single BMI can be applied across all ages, BMI for children depends on age and stage of growth, and use of BMI in children needs to take this into account. In infancy and as toddlers children have a relatively higher proportion of fat. During primary school ages BMI falls as children become relatively leaner, and then increases as puberty approaches and body composition approaches that of adulthood. When using BMI for children BMI-for-age charts must be used.

In adults the accepted normal range for BMI range (the 'Healthy Weight Range') is generally accepted as between 18.5 – 24.9 kg/m^2 and has been determined by data based on health risk. A BMI range of 18.5 – 24.9 kg/m^2 is associated with lowest health risk. Children's BMI curves are an alternative to weight for height percentile curves. In children, BMI decreases from birth until the point of 'adiposity rebound' at around 5 – 6 years [65] and increases to adult levels by 18 – 20 years. The point at which the adiposity rebound is reached is considered relevant to development of obesity. In children health-risk data is not available; use of the 85th percentile as overweight or risk of obesity and of the 95th percentile as obese is somewhat based on outcome, and somewhat arbitrary.

There is no perfect weight index of over and underweight, but BMI is a reasonable index from age 2years to adulthood [66]. BMI screening in children over the age of 2 years is recommended with a goal to identify as early as possible children who may be at risk of overweight and obesity with a view to prevent obesity rather than reverse it. The CDC - BMI percentile charts are available with the standard weight and height for age growth charts. (http://www.cdc.gov/growthcharts/ accessed 11/4/13).

Glossary

SGA	small for gestational age refers to the weight status at birth
IUGR	Intra-uterine growth failure**.** Infants that are born after 37 weeks of gestation and weigh less than 2500 g at birth are considered IUGR, OR birth weight is less than 10th percentile for gestational age
Premature	less than 37 completed weeks gestational age
LBW	low birth weight; less than 2.5 kg
VLBW	very low birth weight; less than 1.5 kg
ELBW	extremely low birth weight;
Corrected age	Equal to chronological age; minus the number of weeks premature at birth
Growth monitoring	serial weighing and measuring of the length/height (and head circumference in under 2's) of a child and graphing both measurements on a growth chart
Growth reference	describes the growth pattern of a defined population without making any claims about health status
Growth standard	defines a recommended pattern of growth that has been associated empirically with specific health outcomes and minimisation of long-term risks of disease. It represents 'healthy' growth of a population and suggest a model or target pattern of growth for all children to achieve.
Failure to Thrive	general description for child with growth faltering
Malnutrition	deficiencies (excesses or imbalances) in intake of energy, protein and or/other nutrients.
Overnutrition	food is in excess of dietary energy requirements, resulting in overweight or obesity.
Undernutrition	result of food intake that is continuously insufficient to meet dietary requirements, poor absorption, and/or poor biological use of food consumed.
Z-scores	Also known as standard deviation (SD) scores. Z-scores have no 'units' and are used to describe how far a measurement is from the mean (average). Percentiles are commonly used in the clinical or community setting because they indicate simply and clearly a child's position within the context of the reference population. Z-scores are useful for population and research purposes. For comparison purposes, the 50th percentile is equal to a z-score of 0. Comparison of z-scores and percentiles are shown in Table 2.

Z-score	Exact Percentile	Rounded Percentile
-3	0.1	1st
-2	2.3	3rd
-1	15.9	15th
0	50	50th
+1	84.1	85th
+2	97.7	97th
+3	99.9	99th

Table 2 Comparison of z-scores and percentiles

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