Use of Physical Growth Measurements to Assess Infant Growth: Birth to 6 Months of Age

A White Paper

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by

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Infancy is a period of rapid growth in body size. The very rapid intrauterine growth almost stops just before birth, and many full-term infants will lose some weight shortly after birth. By 8 to 10 days after birth normal healthy infants have regained their birth weight and are again growing rapidly (Moore and Roche, 1987). The most useful measures of infant growth are weight, recumbent length, and head circumference (Chumlea and Guo, 1999). Weight measures the growth of all body tissues; recumbent length describes the amount of linear growth, and head circumference reflects brain growth. At birth, the head is disproportionately large compared to the size of the body. The diameter of the head is greater than that of the chest, and its length is about a quarter of the body's total length (Moore and Roche, 1987).

Body dimensions increase during infancy at a greater rate than at any other time in postnatal life. In the first 6-months of life, on average, weight increases about 115%, body length about 34%, and head circumference about 22% (Kuczmarski et al., 2000). An infant whose birth weight is at the 5^{th} % will increase their weight by about 135% by 6-months of age, while an infant whose birth weight is at the 95^{th} % will only increase their weight by about 105% by 6-months of age. To achieve these increases, the rate of growth in weight ranges from an average of about 1.1 to 1.2 kg/month for girls and boys after the first month of age to about 0.4 to 0.5 kg/month for girls and boys at 6 months of life (Roche and Himes 1980; Roche et al., 1989). Similarly, the rate of growth in length ranges from an average of about 3.5 to 3.9 cm/month for girls and boys after the first month of age to about 1.8 cm/month for girls and boys at 6 months of life. This rate of growth in weight and length declines rapidly in the first 3 months of life and less so between 3 and 6 months of age (Roche and Himes 1980; Roche et al., 1989).

Assessment of Growth Status

Accurate and reliable measurements are necessary to assess the growth status of an infant. This is important if the rate of growth is to be calculated because that requires very precise techniques. Measurement techniques for weight, recumbent length and head circumference and other body measures are described on videotapes available from the National Center for Health Statistics (NCHS, 1994), the

World Health Organization (De Onis, personal communication) and on several web sites. These media demonstrate standardized methods for collecting physical growth measures of infants and children. The following descriptions are similar if not identical to those presented in these media and to the techniques used to collect corresponding measurements in the Third National Health and Nutrition Examination Survey or NHANES III (USDHHS, 1996), the current NHANES and the World Health Organization's Multicentre Growth Reference Study (De Onis and Garza 1997). These descriptions are also similar to corresponding methods listed in the Anthropometric Standardization Reference Manual (Lohman et al., 1988).

Measurement Methods

Regardless of the standardized techniques used, the collection of accurate and reliable growth data requires the assistance of two technicians for the roles of examiner and recorder. The examiner positions the infant and takes each measurement. The recorder assists the examiner in taking the measurements by helping to position the infant and equipment properly and by recording the values of the examiner. Each technician should take all of the anthropometric measurements once then the two technicians should switch roles and repeat the measurements. The technicians should honestly record the measurements and understand that a certain amount of variation is expected between them and is not a reflection of inability or failure.

The two technicians should compare their measurement values to ensure that the differences between paired measurements fall within allowed paired differences. Any measurement paired differences falling outside that allowed should be repeated by both technicians and the new values entered on the data-recording sheet. Only one re-measurement should occur per variable. These allowable differences are primarily to prevent data recording errors such as the transposition of numbers and the miss recording of values by the technicians. Before ending the anthropometric session the technicians should check the data recording form for completeness.

For all measurement sessions, it is assumed that the mother, father, or some caregiver will be present at all times. It is preferable to have the infant nude during the measurement session, but obviously blankets and diapers should be handy. The measurement sessions can be conducted in a clinical setting or the equipment can be taken to the home and the infant measured there depending on the study protocol.

Weight: The infant can be weighed alone on a variety of new commercially available electronic scales or the infant can be weighed while being held by the mother and the mother's weight subtracted to get the infant's weight. The latter may be preferable so that the infant remains calm and cooperative during the measurement. There are electronic scales that can tare the mother's weight so that the displayed value is that of the infant only.

Before weighing the mother, ask her to take off shoes and any heavy clothing or other heavy objects. Mothers should be advised to wear similar light clothing for all visits. The mother is weighed first and then the mother and her child are weighed together. The weight of the infant is derived by subtraction or the mother's weight is tarred depending upon the type of scale available. If the infant is weighed alone, many of the electronic scales can be tarred to account for the weight of a blanket or diaper. If the infant is clothed in undergarments, 0.1 kg is subtracted from the reading. Spring-type bathroom scales and beam balance scales are not recommended because they are inaccurate for research or clinical purposes.

Recumbent Length: Recumbent length should be measured on an accurate device, and two technicians should be used. The infant lies on the measuring board such that the head is positioned in the Frankfort Plane (the lower orbits of the eyes on the same vertical plane as the external auditory meati), the shoulders and buttocks are resting on the board and the shoulders and hips are aligned at right angles to the long axis of the body (i.e., in the median or mid-sagittal plane). One technician positions the infant's head against the headboard with the infant looking straight up. The other technician positions the infant down the length of the center of the device with the shoulders and hips perpendicular to the trunk. The mother can stand beside to hold, touch or comfort the infant. The second technician straightens the legs and brings the footboard up against the soles of the feet. The first technician holds the head throughout the measurement procedure to ensure that its position is maintained and to ensure that the top of the head maintains contact with the vertical headboard. The second technician ensures that the child is relaxed, or at least not arching the spine or bending the knees. This observer holds the feet such that the ankles are at right angles and the toes not bending over to interfere with the footboard. The footboard is then moved into contact with the heels and slight pressure is applied to the ankles to straighten the legs and extend the spine. The measurement is recorded to the last completed unit (mm).

Head Circumference: Head circumference is measured with an inelastic tape. Infants must be seated on the lap of the mother. The tape is positioned just over the eyebrows and is level across the front of the head with the infant. The greatest circumference of the head is located by moving the tape across the back of the head, and the pulling the tape tight to take the reading. Objects, for example pins, are removed from the hair and the head is held straight or in the Frankfort Horizontal Plane with the eyes looking forward. The tape is tightened slightly to compress the hair and the measurement read to the last completed unit (mm).

Additional Growth Measurements and Indices

Other anthropometric measures possibly useful for assessing infant growth are crown-rump length, chest circumference, limb lengths and skinfold thicknesses (Moore and Roche, 1987; Lohman et al., 1988). However, these measurements have a restricted utility, high measurement error and limited availability of suitable reference data. Crown-rump length and chest circumference are possible indicators of prenatal malnutrition but are of little value in describing post-natal growth compared with weight and recumbent length in healthy infants. Limb lengths can be used as surrogate measures of linear growth, but they are difficult to measure and do not provide any additional information over that of recumbent length in healthy infants. Skinfolds are measures of the thickness of subcutaneous fat that reflects caloric reserves and nutritional status (Paul et al., 1998). Skinfolds are difficult to measure in children and adults and are even more problematic in infants. Despite their recommendation by some and the availability of reference data (Paul et al., 1998), the use of skinfolds in infants is not recommended in these proposed studies.

Measuring skinfolds on an infant is difficult because of their small size and it is difficult to get a good separation of subcutaneous adipose tissue from the muscle tissue. Measurement errors are high. Reference data are available for skinfold thickness of White, Black, and Hispanic children 2 months of age and older from NCHS (NCHS, 1994). Since most of the adipose tissue in infants is subcutaneous, skinfolds would appear to be informative. However, if the measure of interest is total body fat, then devices such as DXA and possibly MRI would in most instances provide more accurate and reliable estimates of body fat in infants than can be obtained from skinfolds (Lukaski, 1993; Harrington et al., 2002).

Weight standardized for length is an index descriptive of the relative level of leanness or adiposity. This index can be used for infants starting at birth (Kuczmarski et al., 2000). A high percentile value indicates that the proportion of weight for an infant's length is greater than that of an infant with a lower percentile value implying greater adiposity for the first infant. Recently, the body mass index or BMI (wt in kg/stature or length^2 in cm) has been introduced as a descriptive index of the degree of overweight/obesity for infants and children (Troiano et al., 1995; Whitaker et al., 1997), but its use in infants is questionable. The BMI is recommended for children starting at 2 years of age by the CDC/NCHS (Kuczmarski et al., 2000). Despite its use by some, BMI in infants has not been related to measures of body composition (WHO, 1995). BMI is an adult measure that has well documented relationships with body composition, morbidity and mortality (Guo et al., 1994). It is useful in children in describing risk relationships with possible overweight/obesity at during adolescence and in adulthood (Guo et al., 1994). BMI in infants is affected by the disproportionality of the infant body where the head is 25% of body length. In addition, the relationship of BMI with direct measures of body composition in infants has not been well established.

Measurement Frequency and Measurement Errors

The frequency at which measurements are taken is determined by the study protocol, but it is also affected by the errors inherent in their collection. These errors are a function of the equipment, its calibration, the technicians and the infant. Because of the small size of infants, the size of a measurement error is relatively greater in relation to the measured value than occurs for older and larger children. As a result, measurement errors can have a proportionally greater impact on growth measurements of infants and especially on the interpretation of calculated growth increments.

If high quality equipment is used and its calibration is checked and maintained regularly, then this source of error is usually small. The frequency at which this occurs depends on the frequency of data collection. If measurements are taken on a regular daily basis, then the equipment calibration should be checked just as frequently.

The technicians need to be trained in a standardized method to take the measurements. This requires the collection of reliability data during training and at regular intervals during the course of the study. Both inter- and intra-observer reliability should be collected, and these data can be compared to the reliability of a master trainer at regular intervals. This level of quality control again depends on the frequency of data collection and the number if infants in the study. At a minimum, it should be done monthly. The quality control for technicians is of greater concern when multiple data collection centers are utilized. In such a case, the standardization of measurement techniques, training and reliability is very important because of the hazard of inter-center effects on the data.

Generally infants are not cooperative when they are measured and great care has to be taken to control for or reduce this source of measurement error. If the infant is kicking and crying and moving around on the scale, then the weight is difficult to read, but these problems are reduced somewhat by the newer digital scales that calculate an average from several readings. Taking recumbent length and head circumference are also affected if the infant wants to kick, not remain still or moves the head a lot. These problems can be reduced by the mother or caregiver. The data recording form should have a space for comments or some descriptive entry code regarding the measurement session. If the infant is very co-operative or very upset and difficult to measure, then this information should be noted or recorded as it may help to explain variations in the data during analysis.

With a goal of monitoring and documenting normal growth, the schedule of observation should include at a minimum a baseline, interim and final measurement over the first 6 months of life. The timing of these observations is somewhat arbitrary but should include a measurement during the very rapid growth shortly after birth before 2 months of age and a measurement when growth is slowing after about 4 months of age. Healthy infants, should be observed starting at about 14 days of age (not before 10 days of age) so that the weight loss following birth has been replaced. The baseline observation should not be later than one month of age. If the growth in weight is to be adequately accounted for, then preferrably an infant should be measured at 1-month, 2-months, 4-months and at 6-months of age. Frequent measurements when growth is rapid provides a better description of the status and changes that are really occurring than can be ascertained from less frequent observations. In addition, it is assumed that birth weight would be available so that the pattern of infant growth can be modeled statistically over the first 6-months of life or longer (Guo et al., 1997). Clearly, weight is the most important measurement. However, if the sample of infants is to be described correctly, then information on the recumbent lengths and head circumferences of the infants would be informative. The collection of recumbent length and head circumference data is important in describing the sample if it is collected at the beginning and the end of the study. Interim data collection would not provide any additional information on the growth of the infants than is attained from weight.

Growth Status

Weight, recumbent length along with head circumference are representative of general growth, and they provide information on present growth status or any progress or response to treatment (Moore and Roche 1987). Interpretation of these measurements is best understood in healthy children when plotted on growth charts. Growth charts provide an assessment or comparison of how the values of these measurements for an infant compare with the percentile distribution of other infants at the same age for these measures (Chumlea and Guo, 1999).

It is recommended that the growth of United States infants be plotted on the revised growth charts from the Centers for Disease Control/National Center for Health Statistics (Kuczmarski et al., 2000). The infant's position on the chart, however, will be displaced as a function of the difference in his or her genetic background and that of the children used to construct the charts. These growth charts are sex-specific because of the distinct differences between infant boys and girls in their body size. Although the sex difference in birth weight is slight, shortly afterwards, the 50^{th} % for weight in girls, up to and beyond 6-months of age, is equivalent to the 25^{th} % for weight in boys at the same ages. This degree of displacement occurs among the other percentiles for weight between boys and girls from birth to 6-months of age. This same level of sex difference occurs for the percentiles for recumbent length also.

Growth Velocity or Growth Increments

When growth is measured at repeated visits, the amount of change in a pair of measurements or increments in weight, recumbent length and head circumference from one visit to the next can be quantified. This information is an additional perspective on infant growth and can be used to monitor growth progress. Plots of increments are records of the velocity or the rate of growth per unit of time. Increment growth data including tables of percentiles and charts for weight and recumbent length (and head circumference) are available for children aged 3 years and younger and more specifically from birth to 12 months of age (Roche and Himes, 1980; Roche et al., 1989). Use of these increment data helps to determine whether an infant's rate of growth is unusual by comparison with that of other healthy infants at the same ages when this information may not be clear from the status information on the CDC/NCHS growth charts. These data are distributions of growth increments from a group of healthy children, and there is no proof that children represented at the median (50th percentile) are healthier than other children at other percentiles at the same or other ages. These data should be used to supplement the revised growth charts in which attained size is plotted relative to chronological age. The availability of growth increments requires longitudinal data that is rare and expensive to collect from healthy children. The present available increment data is for children in the Fels Longitudinal Study. These Fels children were born between 1929 and 1985, the majority are white and most were only partially breast-fed (Roche et al., 1989). Currently, the WHO is collecting longitudinal data from infants as part of their MultiCentre Growth Study (De Onis and Garza 1997), but these increment data are not yet available.

Sex-specific increment data are presented for weight and recumbent length, although the differences between boys and girls in the means and percentile values are small. In many instances the between sex differences in the 50th % for weight are in hundredths of a kilogram per month. These differences can easily be obscured by measurement errors. It would be possible to calculate a single set of growth increment data from birth to 6 months of age or to simply use the increment data already avaliable for boys or girls alone as a reference. The use of increment data very much requires strict attention to data collection methodology so that measurement errors are documented and kept to a minimum. Any interpretation or use of increment growth data requires consideration of measurement errors in the analysis (Guo et al., 2000).

Clinical Significance

When is the growth of an infant of clinical significance? An infant formula is expected to provide a sample of infants with adequate nutrition, so that the distribution of their growth measures would be the same as if these infants were receiving some proven nutritionally adequate diet. If the formula is nutritionally inadequate then the growth of the sample of infants will not be normal, but how is this abnormal growth detectable over a 6 month period? The plotting of growth values for an infant on the growth charts may indicate that the values are changing percentiles from one visit to the next, but this information is not quantifiable. The best method of detecting abnormal growth is with growth increments. After the first observation, weight status and weight increment data should be looked at closely for each infant. If an infant's weight status values are at or below the 5th % or above the 95th %, then this is an indication of possible abnormal growth and further clinical investigation should be considered. However, if the weight increment values are at or below the 5th % or above the 95th %, then this is an indication that the rate of growth for the past time period has not been normal and a clinical investigation is necessary.

Control and Reference Groups

What is the appropriate reference or comparison for judging the growth of a sample of infants who are receiving a new formula? An additional question is what is the ethnic mixture of the sample of infants. If breast milk is the best nutrition for infants, then a control group consisting of exclusively breast fed infants is the most appropriate reference group or a control group of infants receiving an already approved formula (Dewey et al., 1995). However, using a control group increases the cost of a study and can be complicated by sampling issues, loss of infants from the study for a variety or reasons and at different points in time. If a control group is used, then the sample size of the control and experimental groups needs to be calculated so that the selected level of difference in weight can be statistically determined depending on the number of observations over the course of the study. At the same time, operational aspects of the study need to be considered such as a loss to follow up of infants from both groups, whether these infants are replaced and intention to treat issues.

In place of a control group, available reference data can be used. This consists of the growth charts from the CDC/NCHS and the incremental data or large longitudinal databases of infant growth data. If the CDC/NCHS growth charts are used, then the comparison is to the population of infants in the United States. The smoothed growth percentiles on these charts represents the distribution of normal growth for non-Hispanic white, non-Hispanic black and Mexican-American infants in the United States between 1988 and 1994. Growth charts are being developed by the WHO from their MultiCentre study but these are not presently available (De Onis and Garza 1997). The incremental growth data are from infants in the Fels Longitudinal Study who were born between 1930 and 1984.

There are only a few existing long term serial growth studies with databases that can serve as comparisons and most of these include a mixture of breast and formula fed infants. The use of such a database would require many of the same concerns as the use of a control sample. There should be sufficient numbers of infants at similar observation intervals so that analytical comparisons could be made.

Links between Infancy and Adulthood

The ability of growth data in infancy or even birthweight to predict possible status or risk later in life is limited. First, to be able to document such relationships requires long term serial data from birth into adulthood. There are few studies in the world that have such information. These studies are also affected by secular trends and genetic relationships among the study participants (Roche, 1992). What is presently referred to as the "Barker" hypothesis, that an unfavourable uterine environment reflected in a low birth weight can affect or program the body for disease later in life (Barker and Osmond, 1987), is difficult to prove and questionable considering all that occurs in a person's life between birth and adulthood. When relationships between measured (not recalled) events in infancy in the Fels Longitudinal Study have been analyzed in relation to outcomes in adulthood, there was nothing significant. However, by the time that infants were 2 years of age and older, then documented associations with growth outcomes in adolescence and adulthood have been documented (Guo et al., 1994).

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