

Nutrition assessment of hospitalized very preterm infants: Best practices for accurate anthropometry in neonatal intensive care unit settings.

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Hospitalized very preterm infants, those born <32 weeks of gestation, represent a nutritionally vulnerable population. 1 Not only are growth impairments often present at the time of very preterm birth, 2 for example because of placental dysfunction in utero, but preterm infants also face the risk of growth impairment postnatally during the 2■ to 4■month■long neonatal hospitalization. 3 , 4 Postnatal growth impairment indicates reduced accretion of nutrients into tissues, which results in part from inadequate nutrient delivery relative to individual requirements. 5 Altered digestion, inadequate absorption, metabolic immaturity, systemic inflammation, and prolonged critical illness also reduce nutrient accretion during the neonatal hospitalization. 6 , 7 , 8 These deficits in nutrient accretion occur during a critical period in development and contribute to adverse outcomes in very preterm children. 6 , 9

Anthropometry is a near■universal clinical practice that involves measuring an infant's body weight, length, and head circumference and plotting them on a growth chart to assess current nutrition status and monitor changes over time in comparison with a reference population. 10 Anthropometric indicators are responsive to intakes of multiple nutrients, including protein, energy, and micronutrients such as zinc. 11 , 12 , 13 , 14 They also predict long■term outcomes including neurodevelopment, 15 , 16 , 17 further supporting their utility.

Body weight is a sensitive indicator, but it is nonspecific because changes may represent alterations in fluid status 18 , 19 in addition to changes in lean and/or adipose tissue mass. Body length is insensitive to day■to■day fluid shifts and provides more specific information than body weight about the growth of tissues, particularly skeletal growth. 20 Gain in body length may be considered a proxy for organ growth and predicts future neurodevelopmental outcomes. 15 , 17 , 21 , 22 Head circumference increases over time correlate with brain growth and strongly predict long■term neurodevelopmental outcomes. 15 , 17 , 22 However, head growth may reflect progressive hydrocephalus rather than brain tissue growth in preterm infants who have experienced intraventricular hemorrhage. 23 Taken together, body weight, length, and head circumference provide complementary information about the nutrition status of hospitalized preterm infants and are widely used as nutrition status indicators in neonatal intensive care unit (NICU) settings. 24

Within the NICU, there are many potential sources of error in anthropometric assessment. Medical fragility and the frequent presence of respiratory support and other equipment, as well as the variability in how this equipment is accounted for during measurements, can contribute to error in all measurements. Having different staff members perform anthropometry from week to week may also contribute to error. Training of physicians, nurses, and other clinical staff may be inconsistent or lacking. For body length, common approaches include the paper and pencil method (marking the examination table paper at the top of the infant's head and bottom of the outstretched foot) 25 or directly marking a paper tape placed next to the infant. 26 Both of those approaches are inaccurate compared with the recommended recumbent length board, resulting in misclassification. 26 , 27 Random error can be minimized by repeating measurements. 28 Both systematic and random error can limit the usefulness of anthropometric data for clinical care decision■making. Measurement error also poses challenges for research studies that rely on electronic medical record abstraction of clinically assessed weight, length, and head circumference.

The accuracy of neonatal anthropometry can be enhanced by using standard measurement techniques²⁹ adapted for very preterm infants. Several groups have attempted to improve the quality of anthropometric measurements in the NICU,^{30, 31, 32} yet to our knowledge, few resources exist to support the training of NICU clinical or research staff in these procedures. Through our work, we have developed and implemented feasible standard practices for neonatal anthropometry, drawing on published methods and modifying them to fit the unique needs and practical realities of the NICU. Our aim is to describe and disseminate these approaches to promote more accurate anthropometric assessment of hospitalized preterm infants, thereby driving better clinical decision-making and more rigorous research that will inform improvements in care and outcomes for this vulnerable population.

The overall goals are to maximize the accuracy and precision of anthropometric assessment (Tables 1 and 2) while also avoiding unnecessary burden on infants and staff. In establishing our current approach to anthropometric assessment of hospitalized very preterm infants, we drew on a variety of sources, including a dietetics textbook,³³ a product user manual,³⁴ American Academy of Pediatrics guidelines,³⁵ and methods published by the INTERGROWTH²¹ st Project,^{29, 36} and modified them based on clinical practice and experience in the NICU setting. Here we describe our approach to identifying and training personnel, selecting and maintaining equipment, measuring infants with standard procedures, and ensuring high data quality. Where appropriate, we distinguish research-specific practices from those intended for routine clinical care. Given the myriad of practical challenges working with small, sick infants, as well as the differences in available staff across clinical and research settings, others may adapt these approaches to fit with their environment while still maintaining rigor. Identifying areas of synergy between clinical practice and research protocols has the potential to reduce the overall burden on infants and staff. Ideally, the same set of measurements conducted with high attention to accuracy can serve both clinical and research purposes, with documentation by the clinical team in the electronic medical record and by the research team on the case report form.

Approaches to enhancing accuracy and precision of neonatal intensive care unit anthropometry.

John Wiley & Sons, Ltd. Personnel The composition of teams performing anthropometric assessment in the NICU will depend on the purpose (eg, clinical vs research) as well as the available resources. Staff may have varied professional backgrounds and roles, including nurses, dietitians, physicians, physician assistants, clinical research assistants, and study coordinators. Regardless of background, all staff should be trained in standardized procedures and undergo periodic reliability testing.

A two-person team is recommended for body length and head circumference assessment of newborns.²⁹ This team comprises a primary measurer responsible for the measurement and an assistant responsible for ensuring correct positioning during the measurements (Table 3). In the NICU setting, we recommend that at least one person experienced with handling fragile infants be present to ensure stability for any critically ill infant, typically a NICU nurse. That person may also serve as the primary measurer or assistant once trained, although for infants who are critically ill (eg, intubated and/or with indwelling catheters or other clinical concerns), we recommend a three-person team comprising a primary measurer, an assistant focused on measurement, and a second assistant, such as a nurse or respiratory therapist, who is focused on maintaining infant stability.

Maximum measurement difference between study standard and research staff to ensure precision and accuracy of anthropometric assessment.

Difference between any two measurements by the same examiner.

Compared with the study site standard or study-wide standard anthropometrist.

John Wiley & Sons, Ltd. Whether for clinical or research purposes, it is ideal to have a site standard measurer, meaning a designated expert measurer to whom other measurers at the same site can be compared for ongoing quality control to reduce interrater variability. For multisite research, a designated study-wide standard is also recommended. More information about the site standard and study-wide standard roles and responsibilities are in Table 3 and the “Training and quality monitoring” section.

For >30 years, our unit has had a small, dedicated team of clinical registered dietitians who measure and document body length and head circumference weekly for all infants. Coordinating and performing these measures as part of a hands-on nutrition-focused physical examination 37 also allows for an overall visual assessment of the infant and provides context for their clinical recommendations. Having a dedicated team of trained and practiced staff who routinely measure infants is likely to enhance clinical data quality by reducing error caused by differences in technique across a large number of staff members. Other units may consider forming a dedicated team that includes dietitians and/or other professionals, such as nurses, to conduct routine clinical measurements. Such a team is also well-positioned to contribute to specific research studies that require standardized anthropometric assessment.

Specifically for research studies, considerations for selecting a team to conduct anthropometric assessment include the availability of trained clinical staff, the expected sample size and number and frequency of measurements, the medical complexity of the patient population under study, the two-person approach, and staff schedules (full time and/or part time as well as sick and vacation days).

For infants who are stable enough to be moved for weighing, we use a portable electric newborn scale that measures to 1 g. For small, sick infants who cannot easily be moved, we use the isolette bed scale. Scale calibration should be verified locally with biomedical engineering or another responsible party. For research purposes, if scale calibration is not maintained by the hospital, then the research team should ensure that it is performed annually according to manufacturer specifications.

To measure body length, we use a recumbent length board with a fixed headboard, moveable foot board, and measurement markings to 0.1 cm. Different boards are available for preterm and newborn infants. For example, we have two length board options, one for infants <50 cm (“preemie” 26–50 cm) and one for infants >50 cm (“newborn” 35–70 cm) in length (Ellard Instrumentation). The board(s) should be portable and small enough to fit in an isolette or open crib and made of a material that can be wiped with disinfectant.

To measure head circumference, we use a nonstretchable paper measuring tape. Measuring tapes in clinical spaces are often marked to 0.5 cm; for research, we recommend using a tape marked to 0.1 cm. Excess tape can be cut before measuring the infant for ease of use. We use a mild, hospital-approved disinfectant to wipe down all nondisposable study equipment before and after use.

Sources of error that can be minimized through standard procedures include consistently accounting for clothing and medical equipment and performing repeated measurements. 28 Anthropometric measurements, when performed carefully by experienced personnel, pose minimal risk to the infant. Ultimately, an infant’s clinical status dictates whether measurements will be attempted or deferred. Measurement should be deferred for infants who become physiologically unstable with handling or have a critical airway or based on other clinician discretion. This section describes standard procedures intended to reduce measurement error while ensuring infant stability and comfort. These procedures were developed over time, drawing on a variety of sources. 29 , 33 , 34 , 35 , 36 Specific adaptations for the NICU setting were developed by our team and described here in detail with the goal of providing guidance to others who are similarly attempting to apply existing newborn anthropometric methods to the NICU.

In most NICUs, infants are weighed daily or several times per week by clinical staff, typically the bedside nurse, as part of routine clinical care. Table 4 lists several opportunities for standardization. It is our practice to weigh the infant naked except for a dry diaper. The scale should be zeroed with a clean, dry diaper of the same size. All monitor leads, feeding tubes, and other equipment should be held up and away from the infant while the infant is being weighed. Nasal cannulas should be removed before weighing if possible; if this is not possible, the tubing should be held up while the infant is being weighed. Some medical equipment cannot be removed or held up while the infant is weighed, in which case we recommend subtracting the weight of the equipment from the total weight. Using continuous positive airway pressure (CPAP) as an example, we weigh the infant with the CPAP device in place then subtract the previously determined standard weight of the CPAP interface and associated equipment (eg, hat and straps). We suggest that NICUs maintain and regularly update a list of gram weights for commonly used medical equipment that cannot be fully removed from the infant. For infants who are intubated, a respiratory therapist, nurse, or other appropriate, clinically trained assistant should be present as a second assistant to ensure that the airway remains stable.

Personnel for research anthropometry in the NICU setting.

Abbreviation: NICU, neonatal intensive care unit.

John Wiley & Sons, Ltd. For research studies, and particularly at key study milestones such as the beginning and end of an intervention period, additional steps may be taken to enhance accuracy. For example, we use a single, designated digital portable scale for all infants participating in research; isolette scales are used only if the infant is not stable enough to be moved for weighing. We weigh infants twice. If the two weights differ by $>1\%$ of the infant's body weight, we weigh the infant a third time. We record all measurements and use the average value in the data analysis. The bedside nurse or a NICU research nurse is usually present and involved with weighing the infant. At least one research team member collaborates with the nurse while also ensuring adherence to all steps and ensuring complete documentation on the research case report form.

With appropriate staffing, virtually all infants, even those on mechanical ventilation, can be measured with a recumbent length board. 30 However, length measurement should be deferred in infants who are so critically ill that they cannot tolerate being placed on the length board or have a critical or unstable airway.

Infant body length assessment requires at least two people, 29 with a third person assisting to ensure infant stability when clinically necessary. To prepare, place the bed in a horizontal position. If it is not possible to place the bed horizontally, then ensure that the length board can lie flat by placing the end on a rolled blanket. Consider placing a thin blanket, sheet, or disposable pad on the length board for infant comfort. The assistant lifts the infant, ensuring that any respiratory equipment and/or other medical equipment remain in place and unobstructed, and places the infant on the length board with the top of the head touching the fixed headboard. The assistant then places their hands on either side of the infant's head and around the ears to ensure that the infant is looking upwards with the chin away from the chest and the shoulders away from the ears (Figure 1A). A neutral head position is indicated by an imaginary vertical line from the outer canthus of the eye through the ear canal running perpendicular to the horizontal board (neutral Frankfort vertical plane position, 29 shown in Figure 1B). Respiratory and/or other medical equipment should remain in place and unobstructed.

Correct positioning for measurement of infant body length using a recumbent length board. (A) The assistant places their hands on either side of the infant's head and around the ears, gently ensuring that the top of the head is touching the fixed headboard and that the head is in a neutral position (shown in B). The assistant uses their thumbs and/or index fingers to ensure that the infant is looking upwards with the chin away from the chest and the shoulders away from the ears. The continuous positive airway pressure device is left in place and unobstructed. (B) Side view of the neutral head position with an imaginary vertical line drawn from the outer canthus of the eye

through the ear canal running perpendicular to the horizontal board ("Frankfort vertical plane" position as described by Cheikh Ismail et al 29), shown with the continuous positive airway pressure device in place. (C) The assistant maintains the appropriate head position against the fixed headboard while the primary measurer extends the infant's feet and legs and keeps them in position with the left hand while using the right hand to slide the bottom of the length board to meet the bottom of the infant's feet with gentle compression. The measurement is recorded with the infant's left foot while ensuring that both legs are extended, the hips remain centered, and the back is not arched.

The body is positioned along the board, with hips and shoulders in line and the back straight and not arched (Figure 1C). Once the infant is appropriately positioned, the primary measurer gently presses, scratches, or taps the bottom of the infant's left foot and/or gently presses/massages the back of the calves to initiate reflex straightening of the foot and legs. Keeping both legs in position with the left hand, the primary measurer uses their right hand to slide the bottom of the length board to meet the bottom of the infant's feet so that there is gentle compression of the tissue on the bottom of the left foot, with toes pointing upwards (Figure 1C). Note that other authors 29 recommend ensuring that both feet touch the board, but we have found this approach challenging to achieve consistently in very preterm infants. Thus, we have adopted the approach to extend both legs but to place just the left foot against the length board. We routinely use the left leg for consistency of practice. If the left leg is not accessible (eg, owing to an intravenous catheter), we measure with the right leg instead. Before recording the measurement, ensure the infant's back is not arching and the hips are centered, using gentle pressure to hips and/or knees with the left hand/forearm to keep the infant in position with hips square and legs extended. The length should be recorded to the last completed 0.1 cm (ie, round down).

For both clinical measurements and research studies, we measure length twice, confirming or adjusting the infant's position on the length board before repeating the measurement. If the first and second measurements differ by >0.3 cm (Table 2), we repeat a third measurement. For research studies, we record all measurements and note which leg(s) were measured (both, left, or right) on the case report form. We use the average of all recorded measurements for data analysis.

Approaches to standardizing infant body weight assessment.

Abbreviations: CPAP, continuous positive airway pressure; IV, intravenous.

John Wiley & Sons, Ltd. Head circumference Infant head circumference measurement also requires at least two people. 29 The assistant holds the infant, ideally in an upright, seated position. If the infant cannot be held in a seated position, the head should be raised slightly from the bed so that the measuring tape can pass underneath. For infants on CPAP interfaces that use a hat or other apparatus that interferes with measurement, the hat should be removed, and the prongs or mask held in place, passing the measuring tape underneath any foam or other material that contacts the infant's forehead (Figure 2). The tape should be anchored slightly above the eyebrows, with the zero point on the side closest to the primary measurer, in between the forehead and ear. Wrap the tape around the head, making sure it touches the furthest protuberance on the back of the infant's head. We suggest gently shifting the tape slightly above and below the perceived protuberance and noting the largest value to ensure that the largest circumference is being measured. The tape is pulled snugly around the infant's head and the measurement is recorded to the last completed 0.1 cm (ie, round down).

Head circumference measurement with continuous positive airway pressure device in place. The assistant holds the continuous positive airway pressure mask in place while the primary measurer passes the measuring tape underneath the foam interface. The measuring tape is anchored slightly above the eyebrows and wraps around the head, touching the fullest protuberance on the back of the infant's head to ensure that the largest circumference is being measured. The zero point of the tape measure is on the side closest to the primary measurer, in between the forehead and ear.

For both clinical measurements and research studies, we measure head circumference twice, removing and replacing the tape between measurements. If the first and second measurements differ by >0.1 cm, we repeat a third measurement (Table 2). On research case report forms, we record all measurements and use the average in data analysis.

Taking care to minimize unnecessary tactile and/or auditory stimulation, such as loud voices, and attending and responding to infant behavioral cues can minimize infant discomfort during anthropometric assessment. In our experience, many infants will benefit from a pacifier, keeping hands to midline before and after measurements, gentle containment, and time to settle once in place before proceeding with a measurement.

Reducing intrarater (ie, within-rater) variability ensures precise, reproducible values, whereas reducing interrater (ie, between rater) variability ensures accuracy relative to the true value. One practical approach to reduce variability is to conduct periodic reliability testing for staff who are conducting measurements, particularly body length and head circumference. We have adapted standards and practices from the INTERGROWTH-21 st Project 36 (Table 2) and conduct periodic reliability testing for both clinical and research staff.

For intrarater testing, the staff member takes measurements in duplicate. The difference between measurements should not exceed 0.3 cm for body length and 0.1 cm for head circumference (Table 2). For interrater testing, the staff member performs two to three measurements with the local NICU or study-wide standard anthropometrist. The difference in measurements between the staff member and standard (interrater) should not exceed $\pm 2.5\%$ (Table 2). If more than the acceptable level of error is identified during training, the staff member's technique can be reviewed and quickly corrected. This approach allows for ongoing consistency and quality control even with staff turnover.

For research studies, our team maintains a master document of all measurements taken during training and reliability testing and calculates the technical error of measurement 36 as an added approach to ensure interrater and intrarater reliability remain within acceptable ranges.

Here, we describe our approach to anthropometric assessment of infants hospitalized in the NICU. Our primary purpose is to provide a resource for clinicians who seek to enhance the quality of data used to inform clinical decision-making and for researchers who aim to rigorously evaluate anthropometric outcomes in their studies of preterm infants. We acknowledge practical considerations, including the varied availability of staff and other resources, size of patient or study population, and clinical illness requiring careful infant handling. In our approach, we intentionally balance technical aspects to maximize accuracy and precision with the realities of working with small, sick newborns in the NICU setting. Readers are encouraged to adapt these approaches to fit their environment and purpose.

Anthropometric assessment is prone to systematic and random measurement error. 38 Body length is overestimated when the paper and pencil method is used rather than a recumbent length board, 27 whereas head circumference is underestimated if the tape measure is not placed over the fullest protuberance of the infant's head. 29 Random error occurs when numerous people perform measurements and when standardized procedures are not followed, allowing for differences in technique. Random error makes the detection of between-group differences more difficult and contributes to Type II error (falsely negative study, no difference found when in fact one exists). 38 Both random error and systematic error may lead to misclassification. 38 For example, overestimating length means that some infants will be incorrectly classified as falling within acceptable percentiles for age when in fact they have linear growth stunting. In clinical practice, misclassification might mean a missed opportunity to intervene with increased nutrition support, whereas in research, misclassification may lead to inaccurate conclusions about the effectiveness of an intervention under study. In indices of body proportionality, recorded length values are squared or cubed, magnifying the effect of even small errors in measurement. 39 Similarly, underestimating head circumference will lead to an excess of infants classified as having

microcephaly and potentially unnecessary diagnostic evaluation. Overall, the accuracy of anthropometric assessment directly impacts clinical decision-making and affects the conclusions and, ultimately, the impact of any study.

Anthropometric indicators are most useful when context is provided from a growth reference. Growth references allow the classification of size at birth as small, appropriate, or large for gestational age relative to the reference population and can also be used to track the longitudinal growth of an individual infant relative to the “reference fetus.”¹ Of the commonly used references (INTERGROWTH-21st,⁴⁰ Fenton and Kim,⁴¹ and Olsen et al.⁴²), only INTERGROWTH-21st followed strict procedures for anthropometric assessment in its construction.²⁹ Olsen et al. used clinically available data,⁴² and Fenton and Kim is a meta-analysis of six clinical datasets, including Olsen et al.⁴¹ Although the large sample size underlying all these references reduces the impact of random error,³⁸ systematic overestimation or underestimation has implications for proper classification³⁸ and, potentially, clinical decision-making and/or inferences drawn from research studies. The INTERGROWTH-21st preterm postnatal growth reference was designed explicitly for use in preterm infants, but how methods for anthropometric assessment were adapted to accommodate the hospital setting—and particularly how medical equipment was handled—was not reported.²⁹ Additionally, the cohort used to construct the INTERGROWTH-21st references included very few infants born <33 weeks of gestation.⁴⁰,⁴³ Clinicians and researchers alike should consider the underlying population and be aware of the strengths and limitations of reference data when choosing from available growth charts.

In addition to the indicators discussed here, other anthropometric indicators such as foot length and mid-upper arm circumference correlate with gestational age and birth weight.⁴⁴,⁴⁵ Those indicators may be useful as diagnostic tools to identify preterm and/or low birth weight infants in low-resource settings in which gestational dating is often poor and accurate scales not available.⁴⁴,⁴⁵ However, their utility in clinical practice or research settings to track infants’ progress over time has not yet been established.²⁴

Anthropometric data are used widely in clinical care and research involving NICU populations.²⁴ Where possible, clinicians and researchers should apply standardized procedures like the ones we describe here to enhance accuracy and precision. Using rigorous methods will increase data quality and ultimately improve clinical decision-making, as well as the strength of conclusions drawn from research, leading to better clinical care and outcomes for very preterm infants.

Mandy B. Belfort, Hunter Pepin, and Deirdre Ellard contributed to conceptualization. Hunter Pepin and Sarah Roytek contributed content for the manuscript figures. Mandy B. Belfort and Hunter Pepin contributed to drafting the manuscript. All authors critically revised the manuscript, agree to be fully accountable for ensuring the integrity and accuracy of the work, and read and approved the final manuscript.