INTERGROWTH-21st

International Fetal and Newborn Growth Standards for the 21st Century

The International Fetal and Newborn Growth Consortium

ANTHROPOMETRY HANDBOOK

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UNIVERSITY OF OXFORD

This Anthropometry Handbook was prepared by the INTERGROWTH-21st Anthropometry Group, based on the published anthropometry protocol of the WHO Multicentre Growth Reference Study (MGRS). It aims to follow the methodology used in the MGRS as closely as possible. We are thankful to the WHO-MGRS team for permitting us to do so.

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The INTERGROWTH-21st study is a large project involving health institutions from eight geographically diverse countries. It is therefore essential that the participating institutions follow the same data collection procedures. This manual is designed to familiarize all staff involved in anthropometric measurement with the study procedures for selection of personnel, measurement equipment and technique, and quality control procedures.

Please read this Anthropometry Handbook carefully and refer to it throughout the study if any clarification is needed.

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Introduction

Anthropometry in INTERGROWTH-21st

This document describes the methods used to perform accurate, precise and standardized anthropometric measurements for all components of the INTERGROWTH-21st study. The anthropometric measurements in the INTERGROWTH-21st study are:

- Height and weight of all pregnant mothers in the Fetal Growth Longitudinal Study (FGLS) and weight at each follow-up visit to monitor maternal weight changes in pregnancy. The height of each father is also to be taken once if this can be coordinated during one of the mother's visits.
- Birth weight, length and head circumference of the newborns in the Fetal Growth Longitudinal Study (FGLS).
- Repeated measures of weight, length and head circumference of the cohort of preterm babies in the Preterm Postnatal Follow-up Study (PPFS) who are followed and measured up to 2 years of age.
- Birth weight, length and head circumference of the 50,000 newborns in the Newborn Cross-Sectional Study (NCSS), as well as maternal height.

Aims of Standardization

The primary aim of this study is to develop "prescriptive" standards of normal fetal and preterm growth and newborn nutritional status in geographically diverse populations, and to relate these standards to neonatal health risk. The worldwide use of these tools should improve infants' health and nutritional status. All efforts are made to ensure that the measurements used to construct these standards are minimally influenced by other sources of variation. This is obtained by the standardization of procedures that leads to maximal validity of the resulting standards as indicators of growth/nutrition.

In order for these data to be comparable across measurers and study sites over the course of the study, all anthropometric procedures must be standardised. The procedures need to be internally consistent, within and between the multiple study sites from which data will be pooled to construct the standards. There is also the issue of "external" consistency. The

measurement protocol should be reproducible, comprehensible, and acceptable to future users of the standards.

It is important that each study site use the same equipment and procedures (as described below) so that the data collected at each site can be combined into a single data set for the purposes of generating the new standards. All equipment is provided to study sites directly by INTERGROWTH-21st. Some sites might have unique conditions that cause the local study team to want to depart from this standardized measurement protocol. However, where this occurs the Principal Investigator should contact the study Coordinating Unit to determine that such a departure meets with their approval.

Sources of Error

Data used to construct the standards are the result of a complex process of interactions among the setting in which the measurements are taken, within-subject variation unrelated to growth/nutrition (e.g. stomach and bladder content in the case of weight measurements, diurnal variation in the case of length measurements), the behaviour of the subject measured and the accuracy and precision of the instruments. In addition to being determined by growth and nutritional status of the measured subject, the measurer's technical qualities (training, experience, reliability), fitness and mood, the methods of data recording (reading, writing down), data control, data entry and, finally, data transformations before analysis also affect the construction of the standards.

Errors in infant measurement can result from the infant's agitation. An infant's crying can be unsettling to the mother, so it is important to reassure her. When an infant is agitated, it may be best to delay taking a measurement rather than to take one that will be far off the mark. Moreover, if the mother is unsettled about a procedure, she may be less willing to remain in the study if she thinks the measurers are not sensitive to the infant. In all cases, cultural and individual mothers' sensitivity to infant's crying should be appreciated and taken into account when deciding how far to go when a baby is agitated.

Selection and Training of Anthropometry Personnel

At each site, anthropometrists must be selected and trained. The number of people to be trained should be larger than the number needed daily for several reasons. Some

anthropometrists will get sick, or demotivated and will have to be replaced. It is also necessary to have some people on reserve at times when the workload will be very high, e.g. for the duration of the Newborn Cross Sectional Study (NCSS). The selected candidates should be motivated, educated to secondary school level or higher and healthy, capable of working in the clinical environment, have legible handwriting, speak the local language(s), able to socialize easily with mothers of that socioeconomic stratum and be full/part-time available to work on the study. All anthropometric staff must successfully complete the training period. Selecting experienced anthropometrists is preferable because they would understand what needs to be done, know the anatomical landmarks, and they have an appreciation for precision, etc. However, it is sometimes more difficult to break old habits if they have routinely been measuring differently from this protocol. Sometimes, even if they comply during training, there is still the risk that over the course of the study they can deviate from the study protocol as they revert back to their old ways. In this case, periodic monitoring becomes crucial.

In training, the measurers are taught standardizing techniques to reduce variability within and between sites. The training period familiarises the anthropometrists with the study equipment and teaches the following skills to the anthropometrists:

- To measure an infant according to the standardized measurement protocol (see Part I: Infant Anthropometry).
- To take accurate and precise measurements of adults (see Part II: Adult Anthropometry)

During training, the anthropometrists are taught to understand the reason specific procedures are followed. For example**, measurements taken twice by independent measurers give a more reliable estimate of the *true* measurement than a single measurement, hence the requirement to take two readings.** Even where only one reading is requested, the measurer should retake any measurements that look incorrect at first reading. For this, he/she needs to be self-confident and never feel rushed in his/her work. On the other hand, he/she should know when to leave out a measurement that could only be inaccurate because the infant is extremely agitated or uncooperative.

Besides learning the measurement techniques, the anthropometrists should also learn to read the instruments correctly and record the readings accurately. Other errors in the data can occur due to digit preference and transposition of numbers, for example, 39.8 instead of 38.9

cm. Measurements are recorded as soon as they are taken to avoid losing or mixing up the numbers. Usually, the recording sheet lists measurements in an order. This ordering is meant to facilitate taking the measurements and to ensure accurate data recording. If circumstances dictate a different sequence of measurements, the anthropometrists should follow what is most logical, taking care to enter each reading in its correct place on the form. For example, if the baby is breast feeding or has just fallen asleep, beginning with head circumference measurements is better than beginning with the weight measurement.

Writing legibly reduces mistakes during data transfer and is very important. Training the lead anthropometrists (one per site) is carried out by international anthropometry experts. The local lead anthropometrist from each site will then conduct local training and standardization sessions before data collection begins. Study site performance will be monitored by the local lead anthropometrist, using the procedures described in this protocol. **It is very important that field workers receive all training and follow the study protocol closely.**
During data collection an international anthropometry expert will visit the study sites as needed.

When supervising anthropometry, the lead anthropometrist needs to look for the development of incorrect techniques and deteriorating quality of work. Proper training of field staff is the first step in quality control, followed by regular monitoring, motivation and reinforcement to maintain high quality work, and most important, the **field workers should be re-standardized every three months.** Those who have difficulty measuring the same way twice (lack of precision) will require re-training and standardization, those who are biased (lack of accuracy) will need corrective training targeted at their specific problem.

Reliability Assessment

The reliability of a measurement is determined by the accuracy and precision of instruments and measurers. An important goal of training measurers is to help them develop and refine measurement techniques so that they take *accurate* measurements. It is equally important that measurements are taken with a high level of *precision* to yield *repeatable* or *reproducible* values.

Accuracy

- Instrument accuracy: an instrument is accurate if, on the average, it measures true size. It is inaccurate (*decalibrated*) if it has a tendency to give values that are too low or too high in comparison with the true value. **Calibrate the instruments regularly (minimum twice a week)** to avoid problems of instrument inaccuracy.

- Measurer Accuracy: a measurer is accurate if, on average, he/she measures (with an accurate instrument) getting values that are consistently close to the true value. He or she is inaccurate (*biased*) if he/she has a tendency to record values that are consistently higher (positively biased) or consistently lower (negatively biased) than the true value. The problem is that in anthropometry, real size is never known with certainty. Measurers should be trained to obtain measurements that are on average equal to measurements of an experienced anthropometrist who is considered as the "gold standard". Lack of accuracy (bias) can be assessed in a test-retest study in which a number of children are measured by the expert and by the measurer. Bias is calculated as the average difference between the expert and measurer values.

Precision

- Instrument precision: an instrument is precise if the recorded values are close to that of the true value and are not widely dispersed around it. Instruments with a known high precision are to be used because the usual source of instrument imprecision is that the units of measurement on the counter/display have become decalibrated. This is why regular calibration is so important.

- Measurer Precision: A measurer is precise if, when remeasuring the same child (within an interval during which the child has not grown and the instrument not decalibrated), he or she records values that are close to each other and not widely dispersed. This is independent of whether their average is close to the true value or not and thus independent of accuracy. High precision is only possible if measurement procedures are highly standardized and reproducible between centres. Measurers should be trained to achieve a high precision that is close in value to the experts' precision. Measurer precision can be assessed in a test-retest study in which a series of subjects is measured twice by the measurer, after which the differences between pairs of measurements are analysed. With perfect precision, the second measurement will always give the same value as the first. The less precision, the larger the average absolute differences between the duplicate measurements. All parameters of precision are variants of that principle. The most commonly used parameter of precision is the Technical Error of Measurement (TEM).

Accuracy and precision are independent of each other. For example, in measuring a child's length, the measurer who takes two measurements with the child's knees bent at the same angle both times may obtain equal but inaccurate measurements of the child's length. Consider the example given in Table 1, where each measurer takes two measurements of a baby whose true length is 50 cm:

Table 1: Illustration of the difference between precision and accuracy

Measurer	Measurement			Precision	Accuracy (estimate of the mean)
	1	2	mean		
Expert	50	50	50	precise	unbiased
1	48	52	50	imprecise	unbiased
2	48	48	48	precise	negatively biased
3	52	52	52	precise	positively biased

In this example, the Expert and Measurers 2 and 3 would have TEM's of zero (0) (or perfect precision) if they measured several subjects with the same precision as shown in table 4. However, looking at the means column, one notices that the two measurers did not measure

accurately: Measurer 2 underestimated, while Measurer 3 overestimated the child's length compared to the expert values. Unlike the other two measurers, Measurer 1's measurements were different from each other, but he or she obtained an unbiased estimate of the child's length.

The initial reliability assessment (i.e., initial standardization session) should take place at each site immediately following the field workers' training by the local lead anthropometrist. Standardization is accomplished by a test-retest reliability study where an adequate number of newborns/infants are measured twice by each measurer on the same day. In the INTERGROWTH-21st this process should take 1-2 days depending on the availability of newborns/infants and the local organization. The required number of newborns/infants for the initial standardization is twenty, and for the quarterly session thereafter a minimum of ten. The standardization session is organised to ensure independence of repeated measurements on an infant by the same measurer and of an infant by different measurers. A detailed description of the organisation of the standardization sessions and reliability analysis is provided later in this manual.

Part I: Infant Anthropometry

Equipment and Calibration

The following instruments are to be used by the infant anthropometry team:

Baby Scale

Seca 376 - Portable electronic weighing scales that have a tare facility and weigh in kilograms to the nearest 5g up to 7.5kg and to the nearest 10g up to 20kg.
Calibration weights: 2 x ½ kilogram, 3 x 1kg, 1 x 2kg and 1 x 5kg

Calibration of the baby scale

- Calibration of the baby scale is done twice a week at a minimum.
- Ensure that the scale is placed on an even, flat surface. Check whether the scale is level using the bubble on the far right-hand leg of the scale. If you find that the scale is not level, the legs of the scale may be individually adjusted until the bubble lies in the centre of the window. There must be enough light to read the display.
- Turn on the scale by pressing the START button so SECA 88888 and then 0.000 appears. Mark the value that appears on the calibration form (see Table 2).
- The scale should be kept on position [2] (up to 20kg with 10g precision) at all times. To change the position, hold down the NET button for several seconds. *Please note: in newer version of the scales, the selection between position [1] and [2] is automatic.*
- Beginning with the 0.5kg weight, place the weight in the middle of the scale. The display should now read 0.500. Mark the value on the calibration form.
- Repeat this process with the 1kg, 2kg, 3kg 5kg and 8kg weights. This will allow checking across the full range of weights required for this study. Record the obtained values on the calibration form.
- Also calibrate the scale using the tare function. Place the 0.5kg on the scale, press the NET button for 2 seconds. The word NET appears. Wait until the display stops flashing and shows 0.000. Then place the 2kg weight on the scale and check that the value is 2kg.
- If the reading deviates from the expected value, remove the weight, ensure that the scale is on an even surface and that nothing is interfering with the weighing platform. Repeat the measurement again.
- If the reading still deviates from the expected value, inform the lead anthropometrist.

Infantometer

The Harpenden Infantometer (range 300-1100 mm) with digital counter readings to 1 mm. For standardization across sites, **locally made measuring boards are not to be used.**
Calibration rods: Metal (aluminium) calibration rods of 40cm and 75cm
Spare digital counters: x 5

Calibration of Infantometer

- Calibration of the infantometer is to be done twice a week at a minimum.
- Ensure that the infantometer is placed on an even, perfectly flat surface. There must be enough light that the display is easily readable.
- First, ensure that the board is clear of any small objects then move the footboard of the infantometer to the minimum length position.
- Check the minimum value on the display with the minimum value on the board. Mark minimum value registered by the counter on the calibration form (see Table 2).
- Next, use the 40cm metal rod provided. Place the rod between the headboard and the footboard of the infantometer and take the reading. Check that the display reads 40.00 and mark the display value on the calibration form. Repeat the procedure with the 75cm metal rod.
- Review the calibration form. If there are consistent deviations of more than 3mm, repeat the measurement to check for errors.
- If deviations persist, inform the lead anthropometrist, who should take the following steps to recalibrate the infantometer:
    - Unfasten the screws that hold the digital counter in position (a magnetic screwdriver works best) and slide it out of its case.
    - Then hold a rod of known length in a horizontal position and bring the footboard to rest on it.
    - Adjust the reading of the counter manually to the length of the rod and slide the counter, showing the correct reading, back into its case and screw it back firmly.
    - If after this the counter still gives incorrect readings, it needs to be replaced by a new one. Place the new counter in the socket, move the foot board to the minimum length position and adjust the counter to the minimum reading before locking it in place.

Head Circumference Tape

Special metal tape measure (CMS ref.3105); flat metal blade with blank lead-in, self-retracting, 0.7cm wide, range 0-2m, precise to 1mm.

CMS steel tape measures are robust for accuracy under virtually all circumstances. Some spare tape measures should be available in case damage occurs. Calibration is not necessary.

Table 2. Sample Calibration Form (Infant Measurements)

Instrument	**Date**						
Infantometer							
Minimum value							
40.0 cm							
75.0 cm							
Baby Scale							
0.0 value							
0.5 kg							
1.0 kg							
2.0 kg							
3.0 kg							
5.0 kg							
8.0 kg							
Tared (0.5kg + 2kg)							

Maintenance

Maintenance is important for keeping the equipment accurate and extending their lifespan. All equipment should be handled with care during storage, transportation and use. They should be kept clean and the parts stored and transported in their right places. Cool and dry storage is a standard requirement for anthropometric equipment. Different instruments and parts will require different materials for cleaning and regular care.

The **Harpenden infantometer** is robust for accuracy if handled with care, however, it may move unstably because the ball bearings in the digital counter need lubrication, or the metal guide along which the counter wheel runs is bent. Moving the footboard quickly can cause the gears to skid and give an inaccurate reading. Over-rapid movement of the carriage can also cause counter failure so careful handling is necessary. It is important that some spare screws and replacement digit counters are kept handy. Five spare digit counters are supplied with each infantometer.

The **Seca baby scale 376** should be stored at normal indoor temperatures and protected against humidity. If it has been transported under hot conditions, it should be put in a cool, dry place for 15 minutes before using it. The scale should be handled with care under all circumstances.

Important: the lithium batteries must be replaced every 4 months (before any indication to replace the batteries is given). This is because batteries reaching the end of their lifetime can generate measurement errors that can remain undetected for several weeks. Please make a log book of dates for battery replacement for each piece of equipment that is battery-operated. In the unlikely event that replacement batteries cannot be found, each baby scale is supplied with a main electrical adaptor or electrical plug that is to be used under these circumstances. Note that the batteries must be removed from the scale before using the electrical adaptor.

The **head circumference tape** requires no special maintenance. The markings on the tapes may begin to fade over time. Ensure that several spare tapes are kept at each centre to replace them when necessary. It is advisable to clean the tape with disinfectant after the measurement of each baby.

General Notes on Infant Anthropometry

1. All measurements are taken and recorded independently (blinded) by two measurers measuring the baby once (one after the other). Measurements are to be recorded on the appropriate data collection form.

2. All measuring of infants takes place either in the delivery ward, the nursery, the NICU or the preterm follow-up clinic.

3. Lengths and head circumferences are recorded **to the last completed unit,** not to the nearest unit. For example, if the head circumference measurement value lies between 34.2 and 34.3 the value of 34.2 is recorded.

4. Each measurer records their measurements of each baby on their own page of the form, so that measurers record the measurements independently of each other. All forms were designed centrally by the Coordinating Unit (see Pregnancy and Delivery Form and Preterm Follow-up Study Forms).

5. Each measurer must wash their hands thoroughly before and after handling infants.

Measurement Procedure

The general operational procedures for obtaining the measurements are as follows:

1. After introducing yourself to the mother, one measurer explains to her all the procedures that you are about to undertake. If she has any fears about any of them respond to her questions, and show her the procedures beforehand. Most mothers will appreciate advance information about how to prepare the infant for the measurements (specific preparations are included in the description of the measurements). The measurer's confidence and poise will do much to reassure the mother.

2. The other measurer prepares the scale according to instructions. The baby scale should be placed on a flat, level and hard surface with the display clearly visible. The surface of the scale should be clean. Indoor temperature should not exceed 40°C and there should be enough light in the room. The Harpenden infantometer should be placed on a table. One measurer must be able to stand right behind the headboard so that he/she can easily hold the infant's head and make sure the infant is lying in a straight line axis. The other measurer also must be able to approach the infantometer easily.

3. During the measurements, each measurer should:
    - Maintain composure and assume comfortable positions for taking measurements; for example, sit to measure head circumferences, and ask the mother or the assistant measurer to turn the infant around to the correct positions.
    - Every so often, step back -mentally and physically- to review the process as a whole: is the infant comfortable? Are you following the right procedures and applying the right techniques? If the infant becomes very agitated during measurements, the measurers should wait for him or her to calm down before continuing. This is important for both mothers and babies.

4. Ask the mother to remove all of the infant's clothes, including the diaper. **It is very important that the infant is naked during the weight measurement.** In cold

climates it is possible to tare the scale with a blanket/cloth. This allows the weight of the blanket/cloth to be ignored in the results. Please refer to page 22 for instructions on how to tare the scale.

5. The first measurer takes and records each anthropometric measurement (weight, head circumference and length) **without revealing the values obtained to the second measurer**. The second measurer then independently repeats the same measurements. Each measurer records their own values independently, with no knowledge of the values recorded by the other measurer. Detailed instructions for each measurement are given separately below.

6. After collecting the data, the two measurers will compare their measurements to ensure that the differences between their measurements fall within the maximum allowed differences (7mm for length, 5mm for head circumference and 50g for weight). Any pair of measurements falling outside the maximum allowed differences are repeated by both measurers and entered on the data recording sheet in the second column. If this second pair of measurement values again exceeds the limits for that measurement, the measurers repeat the measurement for a third and final time. All measurements are entered on the form.

7. Before ending the anthropometry session check the forms for completeness.

8. In the case of an extremely sick infant admitted to Neonatal Intensive Care Unit, where the infant cannot be taken out of the incubator at all during the first 24 hours (e.g. an endotracheal tube is positioned), the electronic scale of the incubator can be used (if applicable). The calibration of the incubator scale should be done following the same checklist as for the baby scale and as frequently as possible. For these babies, head circumference can be taken following the normal procedure. As for the length, it can be taken within the first 7 days of life. The date and time of measurements should be recorded on the form to correspond with the date and time of weight and head circumference measures.

Measurement Schedule

Fetal Growth Longitudinal Study (FGLS) and Newborn Cross-Sectional Study (NCSS)

The three anthropometric measurements are taken within 12 hours of the infant's birth (absolutely no later than 24 hours).

Preterm Follow-up Study (PPFS)

The anthropometric measurements include weight, length and head circumference. The three measurements taken on the day of birth, at 48-72 hours, every 2 weeks during the first 8 weeks of life, and then every month until 8 postnatal months. Further measurements have since been added at 12, 15, 18, 21 and 24 months of age. The maximum allowable delay of measurements is 10% of the child's age - for example, three days at 4 weeks, or 18 days at 6 months (see Table 3). However, all data are to be retained even if the delay is greater than 10%.

If the preterm baby is in the NICU or high dependency unit, the measurements are done there. If the baby is well enough to be discharged, arrangements must be made with the mother to bring in the infant to the preterm follow-up clinic for the follow-up appointments. If the mother is unable to bring the infant to the clinic, the study team should be prepared to visit her at home to take the infant's measurements.

Table 3. PPFS Follow-up Schedule

Visit	Age	Form	Visit	Age	Form
0	Within 12 hours of birth	DEV	9	6 months (6 months from birth ± 18 days)	IFU
1	48-72 hours after birth	PSE	10	7 months (7 months from birth ± 21 days)	IFU
2	2 weeks (14 days form birth ± 2 days)	NFU	11	8 months (8 months from birth ± 24 days)	IFU
3	4 weeks (28 days from birth ± 3 days)	NFU	12*	12 months (12 months from birth ± 24 days)	PIFS1
4	6 weeks (42 days from birth ± 4 days)	NFU	13*	15 months (15 months from birth ± 24 days)	PIFS1
5	8 weeks (56 days from birth ± 5 days)	NFU	14*	18 months (18 months from birth ± 24 days)	PIFS1
6	3 months (3 months from birth ± 9 days)	IFU	15**	21 months (21 months from birth ± 24 days)	PIFS1
7	4 months (4 months from birth ± 12 days)	IFU	16*	24 months (24 months from birth ± 24 days)	PIFS2
8	5 months (5 months from birth ± 15 days)	IFU	* PIFS forms are not in PPFS booklets		

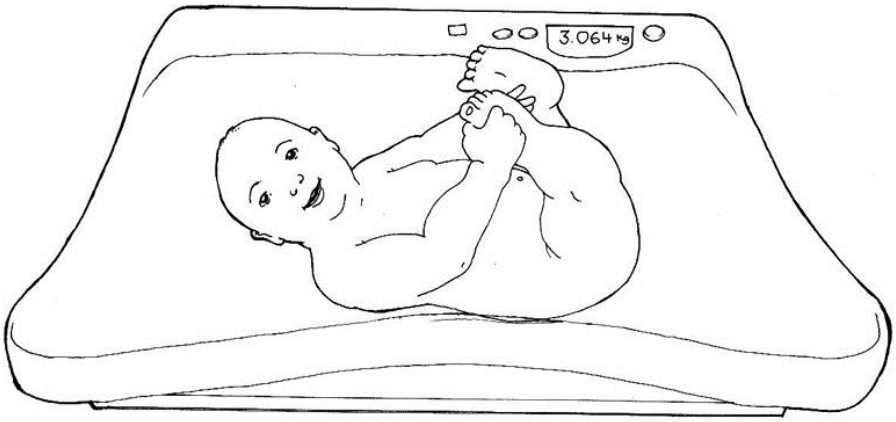
Measurement Technique

Measurements are taken as described below. A checklist at the end of each section is a summary of the main points to remember whilst taking a measurement. Best order of measurements: weight, head circumference, length.

Weight

1. Infant weights are measured using the Seca Baby Scale 376 which weighs in kilograms to the nearest 5g up to 7.5kg and to the nearest 10g up to 20kg.
2. Check the scale is on a flat, level surface, with no obstructions.
3. Turn scale on: With the scale empty, press the green START button. When you press it, the word SECA 88888 and the figure 0.000, appears on the display. Ensure that the scale is set to position 2, ([2] should appear to the left of the display). If the display shows [1], depress the NET button for several seconds to switch positions. The scale is now ready for use. *Please note: in newer version of the scale, the selection between position [1] and [2] is automatic.*
4. The baby should be naked. In cold climates, an incandescent light bulb can be positioned over the scale to warm the surface of the weighting pan, making it more comfortable for the baby. In cultures where it is unacceptable to undress the baby, the scale can be tared using a blanket (see instruction in box below).

To tare the scale:
Place the blanket or cloth on the scale; press the NET button for 2 seconds. The word NET appears. Wait until the display stops flashing and shows 0.000. Then place the baby on the scale and wrap the blanket around him. Record the value on the form as it appears on the scale.



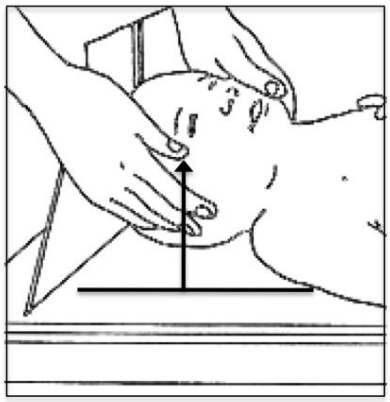
5. Place the baby carefully on the scale and wait for the baby to stop moving.
6. Once the baby has stopped moving, press the HOLD button. The display should flash when a stable weight is measured. The word HOLD and the symbol Δ! should appear on the display. The display is then frozen and the baby can be removed and given to the mother.
7. Record the weight on the form.
8. The hold function is turned off by pressing the HOLD key again. 0.000 should then appear.
9. If the baby is agitated and cannot be calmed, ask for the mother's help. If the baby remains very agitated, it is best to give the baby back to the mother until he/she calms down.

Length

Length is measured on a Harpenden infantometer, which has a fixed headboard and moveable footboard.

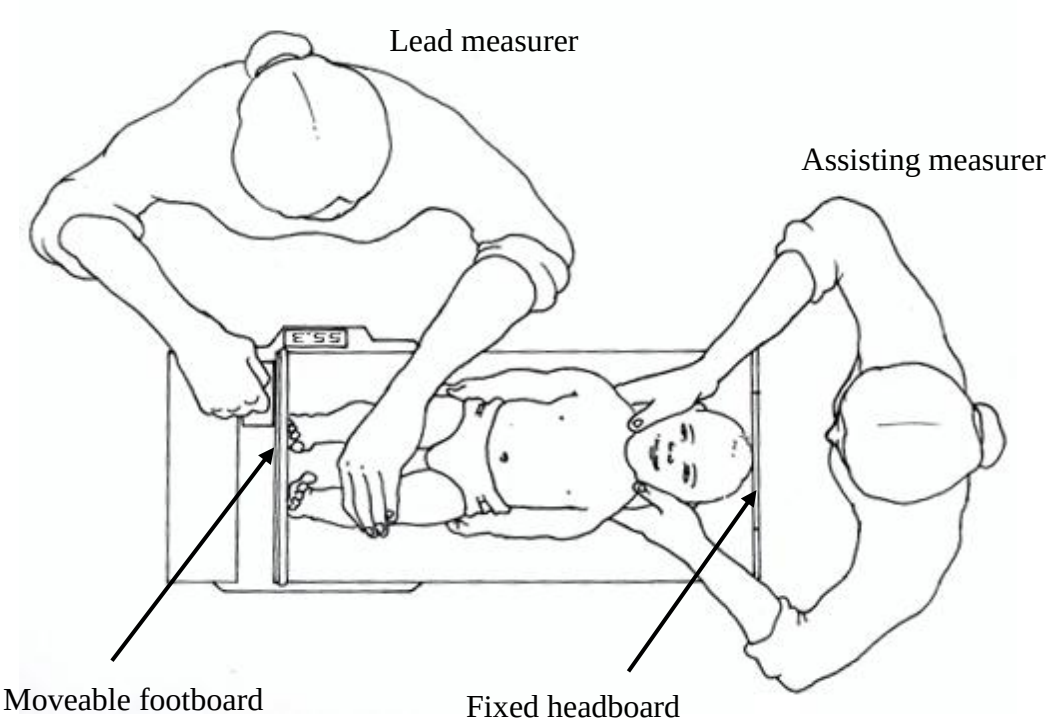
1. The infantometer is placed on a raised flat surface like a large table so that it is level and stable.
2. Ask the mother to remove the infant's clothes if this has not already been done for the weight measurement. Measuring length can provoke anxiety and crying in infants. The mother should be asked to calm the baby. To avoid causing discomfort, cover the horizontal board with a thin cloth or soft paper.

3. Any hair ornaments should be removed if they interfere with positioning the head. Diapers increase the difficulty of holding the infant's legs together and straightening them out, so they should be removed for this measurement.
4. The lead measurer stands on the side to hold down the baby's legs with one hand and move the foot board with the other hand. The assisting measurer stands at the head board and positions the infant's head.
5. **The head should be positioned correctly and legs and feet held firmly to allow an accurate measurement.** The assisting measurer holds the infant's head so that the top of the head touches the fixed headboard. Position the infant's head such that a vertical line from the ear canal to the lower border of the eye socket is perpendicular to the horizontal board. This head position is known as the Frankfort Vertical Plane.



Frankfort Vertical Plane

To keep the infant's head in the correct position, the assisting measurer gently cups his or her hands over the infant's ears. The mother can stand close on the side to reassure the infant. The lead measurer positions the infant so that shoulders and hips are aligned at right angles to the long axis of the body. Gentle pressure is applied on the knees to straighten the legs.



6. To take the measurement, the foot board is positioned gently against the infant's feet. The soles of the feet should be flat on the board, toes pointing upwards. If the infant bends the toes and prevents the foot board touching the soles of his or her feet, scratch the soles slightly and draw in the foot board when he or she draws the toes up. Take care that the knees are straightened only as far as they can go without causing harm to the infant. Be aware that for newborns and very premature infants, it is impossible to straighten the knees to the same degree as in older infants as they can be very fragile and could easily be injured if too much pressure is applied to their legs. Therefore, the measurer should apply only very minimum pressure on their knees. The assisting measurer should check that the infant is not arching the spine when the reading is taken, and should alert the lead measurer should the infant shift out of position. The footboard is pressed against the feet gently so that there is small compression of the tissue on the feet. The measurement is recorded to the last completed 1mm. For example, if the length is between 61.3cm and 61.4cm, write 61.3cm.
7. As a general principle, if the measurer cannot hold both legs because the infant is restless, obtain a one-leg measurement.
8. Read the measurement as soon as possible after the footboard has been positioned and make a note of this.

9. Hand the infant back to the mother.
10. Write the value obtained in the corresponding section of the form without delay.

Head Circumference

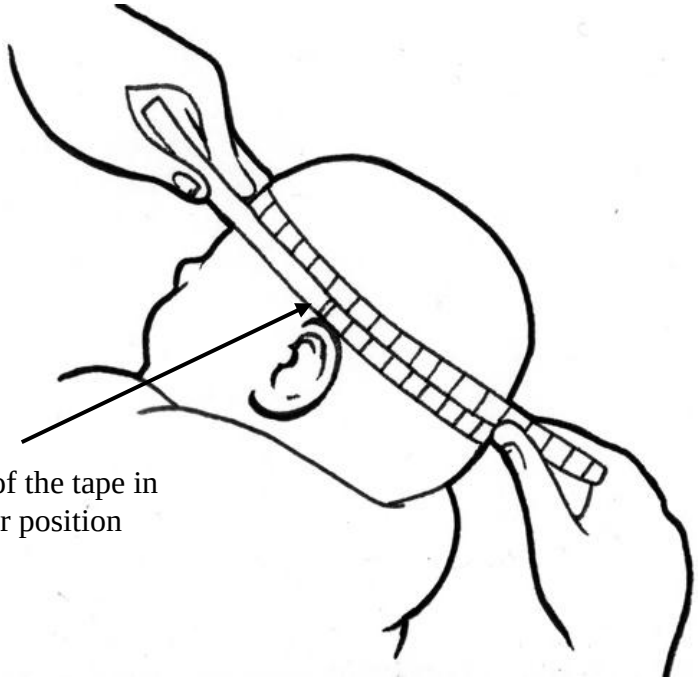
A metal tape marked in centimetres and millimetres is used to measure head circumference.

1. Hair pins or head bands should be removed as they interfere with the positioning of the tape around the head.
2. The infant is held on the assistant measurer or mother's lap. It is not always easy for the measurer to manipulate and secure the tape correctly around the head because many infants, especially the older infants, find this measurement uncomfortable.

3. The lead measurer sits by the side of the mother or of the observer, who is holding the infant.
4. Take care that the side of the tape marked in centimetres is on the outside for the reading, with the zero end in the inferior position.
5. Loop the tape before slipping it over the head.
6. The measurer anchors the tape just above the eyebrows, with the zero point on the side closest to him or her. *In some manuals, it is recommended to wrap the tape*

around the fullest head circumference. However, the forehead anchor point is important for standardized measurement within and across sites.

7. At the back of the head, the tape is positioned over the fullest protuberance of the skull.
8. The other measurer helps by positioning the tape correctly, i.e. level, on the other side of the head.
9. Once the tape is positioned correctly, pull tight to compress the hair and skin. Be careful not to pull the tape too tight and cause injury to newborns. Keep hands and fingers out of the way for the reading.



10. Take the reading to the last completed 1mm and remove the tape from the infant's head.
11. Write the value obtained in the corresponding section of the form.

Second Observer Measurements

Now it is time for the measurers to swap roles and perform the second set of measurements. **Remember that the two measurers do not look at each others' results until both sets have been completed**. The form contains two sections on different pages (one for each measurer) so as to allow this blinding of results.

Infant Anthropometry Checklist

Weight:

1. Turn scale on
2. Tare if necessary
3. Place baby on scale
4. Press HOLD
5. Remove baby
6. Record to the nearest gram.

Length:

1. Position head
2. Top of head (vertex) touching headboard
3. Body straight
4. Legs straight
5. Footboard to touch heel(s)
6. Read to last completed unit (mm)

Head circumference:

1. Position head
2. Anchor tape just above eyebrows
3. Palpate most posterior part of head
4. Pass tape around head
5. Cross-over tape ends
6. Hold tape against front and back of head
7. Pull tight
8. Read to last completed unit (mm)

Part II: Adult Anthropometry

Equipment and Calibration

The following instruments are used for the measurement of adults:

Adult Scale

The **Seca 877 Scale** is used to measure maternal weight. The scale has footmarks pasted on to show exactly where subjects stand.

Calibration weights: 8 x 10 kg standard weights.

Calibration of the adult scale

- Calibration of the adult scale should be done twice a week at a minimum.
- Ensure that the scale is placed on a flat, level surface. You can check whether the scale is flat using the bubble in the circular window on the scale's upper surface. If the scale is not level, the legs of the scale can be individually adjusted until the bubble lies in the centre of the window. There must be enough light to read the display.
- Turn on the scale by gently touching the surface of the scale with your foot. The word SECA should appear, followed by 88:8888. When the number 0.0 appears, the scale is ready for use. Write the weight that appears on the calibration form.
- Now place 4 of the 10kg weights in the middle of the scale. They should stack on top of one another easily. Write the value that appears on the calibration form (See Table 3).
- Now begin a new pile and add 2 of the 10kg weights onto the scale, and write the value that appears on the calibration sheet.
- Repeat this process once more with the 8 x 10kg weights. This is important to allow checking across the full range of weights required for this study. Record the obtained values on the calibration form.
- If the readings deviate from the expected value, remove the weights, ensure that the scale is on an even surface and that there is nothing interfering with the weighing platform. Repeat the measurement again.
- If the readings deviate from the expected value, inform the lead anthropometrist, who should inform the principal investigator.

Stadiometers

Two models of stadiometer are being used. **Seca Stadiometer 242** (old model) has been superseded by **Seca Stadiometer 264**. Please read the section corresponding to the stadiometer available in your center. Seca Stadiometer 264 is different from the Seca Stadiometer 264 insofar that it has a foot mat on which the person to be measured stands on and the display housing has been integrated into the head stop.

Important: It is important that the stadiometer is assembled by an experienced maintenance person, carefully following the instructions in the manufacturer's manual. The rod must be screwed or attached to the wall at a perfectly vertical angle or plumb to the floor.

The **Seca Stadiometer 242** (range 62-210 cm) is used to measure adult height with an accuracy of ±2mm.

Calibration rods: Aluminium calibration rods of 150cm and 200cm.

Calibration of the Stadiometer 242

- Calibration of the stadiometer should be done twice a week at a minimum.
- First, press the START key on the display housing. ----- is displayed initially.
- Push the head stop down as far as possible.
- Read the height measure displayed on the unit.
- Write down the value on the calibration form (See Table 4).
- Push the head stop far enough up the rod so that the 150cm metal rod can be placed under the headboard easily. If there is need stand on a chair.
- Ensure that the rod is perfectly vertical.
- Now slide the head stop down until it touches the top of the rod.
- Read the height measure displayed on the unit.
- Write down the value on the calibration form.
- Remove the 150cm rod and repeat the steps above for the 200cm rod. It may be necessary to stand on a chair to perform the operation. Record the value obtained on the calibration sheet.

- The general indication for decalibration in height equipment is 3mm off the mark. If the digital display on the stadiometer gives an inaccurate reading, inform the lead anthropometrist, who should take the following steps to recalibrate (adapted from the Seca manual)
    - Keep the **ZERO** key depressed and then turn on the display housing by pressing the START key. A flashing number appears – this is the calibration counter.
    - Release the **ZERO** key and then press it again for at least 1.5 seconds.
    - Place the 150cm metal rod underneath the head stop and bring the head down to rest on top of the rod
    - Record the value displayed and compare it with the actual value.
    - In order to change the value displayed so that it agrees with the actual value:
        - To increase the displayed value, press the **cm/ins** key to increase the value in 0.5mm increments. If you also press the **ZERO** key, the value changes rapidly.
        - To decrease the displayed value, press the **ZERO** key to reduce the value in 0.5mm increments. If you also press the **cm/ins** key, the value changes rapidly.
    - Complete the calibration process by keeping the **ZERO** key depressed for at least 5 seconds.

If the problem persists, please inform the local PI.

The **Seca Stadiometer 264** (range 30-220 cm) is used to measure adult height with an accuracy of ±2mm.

Calibration rods: Aluminium calibration rods of 150cm and 200cm.

Calibration of the Stadiometer 264

- Calibration of the stadiometer should be done twice a week at a minimum.
- First, press the Start key on the head stop. "----" is displayed initially.
- Keep the brake button pressed down and move the head stop until a length value appears in the display.
- Hold down the brake button and push the head stop down as far as possible.
- Read the height measurement displayed on the unit.

- Write down the value on the calibration form (See Table 4).
- Hold the brake button down and push the head stop far enough up the rod so that the 150cm metal rod can be placed under the headboard easily. It may be necessary to stand on a chair to perform the operation.
- Record the value obtained on the calibration sheet.
- Ensure that the rod is perfectly vertical.
- Now slide the head stop down until it touches the top of the rod, remembering to press the brake button down.
- Read the height measurement displayed on the unit.
- Write down the value on the calibration form.
- Remove the 150cm rod and repeat the steps above for the 200cm rod. It may be necessary to stand on a chair to perform the operation. Record the value obtained on the calibration sheet.
- The general indication for decalibration in height equipment is 3mm off the mark. If the digital display on the stadiometer gives an inaccurate reading, inform the lead anthropometrist, who should take the following steps to recalibrate (adapted from the Seca manual)
    - Press the Start key on the head stop, "----" appears in the display
    - Keep the brake button pressed down and move the head slide until a length value appears in the display
    - Use on the rods supplied by the study (150cm or 200cm). Position the rod vertically on the foot mat and hold it in this position and push the head slide onto it
    - **Simultaneously** press the Enter key (send/print) and the arrow key (hold/zero) to open the menu. The last menu item selected is shown in the display
    - Press the arrow key (hold/zero) until "CAL" appears in the display - confirm your selection with the Enter key (send/print)
    - Use the arrow key (hold/zero) to select the "Yes" setting
    - Confirm your selection with the Enter key (send/print). The display "Auto" appears
    - Use the arrow key (hold/zero) to enter the length of the object
    - Confirm the set value with the Enter key (send/print)

The device is calibrated. You can perform height measurements with the device. **If the problem persists, please inform the local PI.**

BMI Calculator

The Seca BMI calculator 491 is used to calculate BMI of women at the screening phase, to determine if they are eligible for the study.

Calibration of the BMI calculator is not necessary.

Table 4. Sample Calibration Form (Adult Measurements)

Instrument	**Date**						
Adult Stadiometer							
Minimum value							
150.0 cm							
200.0 cm							
Adult Scale							
0.0 value							
40.0 kg							
60.0 kg							
80.0 kg							

Maintenance

Maintenance is important to keep the equipment accurate and extend their lifespan. All equipment should be handled with care during storage, transportation and use. The equipment should be kept clean and parts stored and transported in their proper places. Cool and dry storage is a standard requirement for anthropometric equipment. Different instruments and parts require different materials for cleaning and regular care.

The **Seca scale 877** should be stored at normal indoor temperatures and protected against humidity or wetness. If it has been transported under hot conditions, it should be put in a cool place for 15 minutes before using it. The scales should be handled with care under all circumstances.

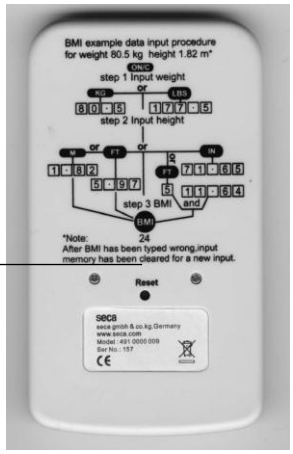
Important: Replace the batteries every 4 months (before any indication to replace the batteries is given). This is because batteries reaching the end of their lifetime can generate measurement errors that can remain undetected for several weeks. Please keep a log book of battery replacement dates so that it is clear when the batteries should next be replaced.

The **Seca stadiometers 242/264** are robust if handled with care. Keep the stadiometer clean using domestic cleaning products. Under no circumstances use abrasive or acid cleaners, spirits, benzene, or such like for cleaning as these substances can damage the high quality surface and coding.

On the **Seca stadiometer 242,** care should be taken not to accidentally press the ZERO button on the head stop or the display unit. This can cause the channel to switch and will lead to ----- being displayed. If this happens, please consult the manufacturer's manual for instructions on how to reset the channel.

Important: Replace the batteries every 4 months (before any indication to replace the batteries is given). This is because batteries reaching the end of their lifetime can generate measurement errors that can remain undetected for several weeks. Please keep a log book of battery replacement dates so that it is clear when the batteries should next be replaced.

The **BMI calculator** does not need any maintenance, however, if the calculator does not start, please press the RESET button on the back using the tip of a pencil.



Reset button

Measurements

General Notes on Measuring Adult Anthropometry

1. Height and weight of mothers in the FGLS study are taken at study entry by one measurer. Thereafter, weight alone is taken at each follow-up visit because height will not change. For the fathers of the babies in the FGLS, height is also taken once. All measurements are recorded on the corresponding form (Maternal Study Entry, Pregnancy Follow-up).
2. In INTERGROWTH-21ST mothers are weighed twice by the same measurer. The woman wears minimal, light clothing. If it is not possible for her to remove heavier clothing, each country should develop a list of typical clothing weights and subtract the weight of the clothing from the total weight.
3. For all women taking part in NCSS, height will be taken once before discharge from hospital and recorded in the Pregnancy and Delivery Form. Pre-pregnancy weight is to be obtained from the medical records.
4. All adult measurements are taken in the ultrasound clinic or in the delivery/postpartum room.
5. Height is recorded **as it appears on the display** to one decimal place. For example, if the display reads 165.8cm, write 165.8cm on the form; do not round up to 166cm.

The general operational procedures for obtaining the measurements are as follows:

1. After introducing yourself to the subject, briefly explain the procedures that you are about to undertake. During the measurements, the measurer should maintain his or her composure and assume comfortable positions for taking the measurements. Prepare the scale according to instructions. The scale should be placed on a perfectly horizontal, flat and hard surface in a way that the display is clearly visible. The surface of the scale should be clean. Indoor temperature should not exceed 40°C and there should be enough light in the room. The stadiometer should be fixed to the wall.
2. Ask the subject to remove any heavy objects/clothing and take off shoes. Each site develops a list of typical adult clothing weights (e.g. T-shirts, trousers, etc.) which is recorded in the data collection forms.
3. Before ending the anthropometry session, check the form for completeness.

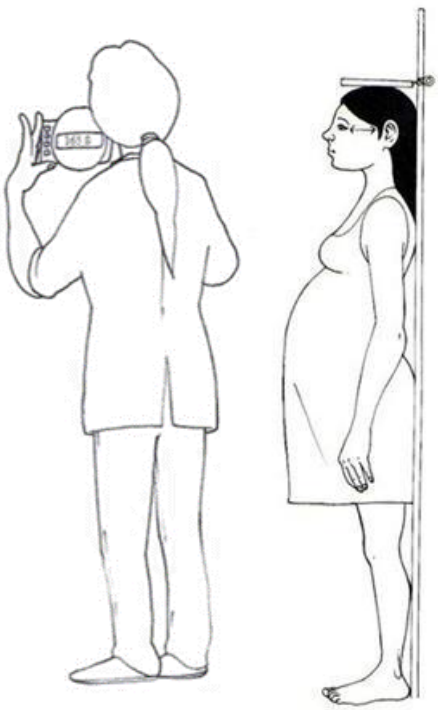
Measurement Technique

Measurements are taken as described below. A checklist at the end of each section gives a summary of the main points to remember whilst taking a measurement.

Height (for all mothers in FGLS and NCSS and fathers in FGLS)

1. Ask the subject to remove their shoes and any headwear or hair ornaments. Measure the thickness of any irremovable braids/corn rows with a small plastic ruler and deduct this from the total height at the end.
2. Turn the stadiometer on. "----" is displayed initially.
3. Raise the head piece far enough up so that the subject can stand under the headboard comfortably. **If the subject is much taller than the measurer, stand on a chair or stool to correctly position the subject.**
4. Ask the subject to stand with their back to the measuring rod, with feet slightly apart, the trunk balanced over the waist, knees straight, arms and shoulders relaxed.

If using the Seca Stadiometer 462, remember to hold the brake button down when moving the head stop.



In contact with the measuring rod:

Head

Shoulders

Buttocks

Calves

Heels

Note: The illustration shows the Seca Stadiometer 242. As mentioned on page 31, the 264 model is slightly different.

5. Ask the subject to look straight ahead and hold his/her head in a Frankfort horizontal plane.

6. Now slide the head stop down until it touches the top of the head.
7. Ask the subject to take a deep breath; this straightens the spine and gives a consistent measurement.
8. Read off the measurement from the digital display and record on the appropriate part of the form, as it appears on the display i.e. to one decimal place.

Weight (for all mothers in FGLS, every follow-up visit)

1. The woman should wear minimal, light clothing. If it is not possible for her to remove heavy clothing, please refer to the list of typical weights of adult clothing developed by each centre (Annex 2) and remember to subtract this summed value from the total weight before recording the value on the form.
2. Ask the mother to remove any heavy objects and take off her shoes.
3. Ensure the scale is on a perfectly flat surface with no obstructions.
4. Turn the scale on by gently pressing a foot on the surface of the scale. The word SECA should appear, followed by 88:8888. When the value 0.0 appears, the scale is ready for use.

5. Ask the mother to stand on the scale, placing her feet on the footmarks pasted on the scale, and remain still until the weight appears.
6. Read and record the weight in the appropriate section of the form.
7. Please take the weight measurement twice and record on the form as it appears on the display, i.e. to one decimal place.

BMI

To calculate the BMI:

1. Activate the calculator by pressing ON/C
2. Press KG and then enter the weight of the woman in kilograms.
3. Press M and then enter the height of the woman in metres. **Please note that height is entered in metres not centimetres. To convert height in centimetres from the forms to metres, divide the value by 100. For example, if the height in centimetres is 160, the height in metres is 1.6.**
4. Press the green BMI button.

Example, if the weight is 80.5kg, and height is 1.82 metres, then:

1. Press KG
2. Enter 80.5
3. Press M
4. Enter 1.82
5. Press BMI
6. The calculated BMI should be 24.3

Adult Anthropometry Checklist

Height

1. Remove shoes and hair ornaments
2. Subject stands with their back to measuring rod, feet slightly apart, trunk balanced over the waist, knees straight, arms and shoulders relaxed.
3. Position head
4. Take deep breath in and stand tall
5. Headboard touches top of head
6. Record height as it appears on the display

Weight:

1. Subject wears minimal, light clothing
2. Remove shoes and heavy objects
3. Zero scale
4. Subject stands centrally on scale
5. Read subject's weight
6. If the weight of heavy clothing needs to be subtracted, refer to the list of approximate weights (Annex 2)

Part III: Quality Control in the Study

Quality Control

Measurer performance during the study is monitored in several ways:

(1) For infant measurements, each of the two anthropometrists will measure the infant once. **The *maximum allowable differences* for acceptable precision for length is 7mm, for head circumference 5mm, and for weight 50g**, based on the precision of the SECA scale. If the difference between two measurements exceeds pre-set maximum values, the measurements are repeated. Measurers have to check their measurements on the spot and compare with the maximum allowable differences. If one or more of the three measurements deviates between observers by more than the maximum allowable difference, those measurements should be repeated by both observers.

(2) Questionnaires are delivered as quickly as possible to the local coordination centre, preferably once per day, and no less frequent than every 3 days. The local research coordinator or data manager checks the questionnaires for completeness and consistency on the same day.

(3) Data entry is performed locally (using the INTERGROWTH-21st standardized online data entry software - www.intergrowth21.org.uk - with built-in range and consistency checks) and does not lag behind data collection by more than a few days. If recorded values are out of the allowed range, they will be flagged and this gives rise to checks for recording possible data entry errors and raising queries if necessary.

The data manager personally checks all flagged values for the following:

a. consistency between the 2 measurers (i.e. measurements of two measurers within maximum allowed difference)
b. consistency with other anthropometric indicators of the infant (e.g., to check if this is just a ‘big’ baby in the NCSS)
c. consistency with previous measurements of same infant (for the PPFS)
d. that there is no data entry error

(4) Every three months during the study, standardization sessions are held to ensure the measurers are following the recommended techniques to monitor their reliability (precision & accuracy), and to take corrective measures if required. Only two measurements will be involved: length and head circumference. The measurers repeat measurements on a minimum of 10 infants. The repeated measurements are independent, i.e. each measurer measures all 10 infants and then measures them all in a second round, recording the results on a separate form. These test-retest data will be entered into a customised spreadsheet to calculate reliability statistics. Depending on the number of measurers at a site, one or two days is required for the quarterly standardization sessions. It is recommended to use as the 'gold standard', the overall mean of all measurers on each child, because is difficult to have a single measurer as the 'gold standard' for all different measurements. If a site cannot conduct these quarterly standardization sessions as described above, an alternative solution based on the same principles should be submitted by the local PI to the Anthropometry Group of the study for approval. After each standardization session, the summary results together with the raw data are to be sent to the CU (Oxford) for compilation of the master data set.

Prevention of measurement errors is of crucial importance, especially during these large studies. Errors occur due to demotivation, work overload, fatigue. If the quarterly standardisation protocols reveal that an anthropometrist repeatedly differs, it is recommended that retraining occurs to correct the problem. If this is not successful, the person in question should be replaced.

Standardization Sessions

The standardization sessions are carried out in newborn wards or well baby clinics targeting infants younger than 3 months. Ten newborns/infants minimum are required for the session (the number for the initial standardization is 20).

The measurers work in pairs. For each measurer, the first and second measurements of each infant are separate (in time and on paper) to ensure independence. Moreover, each measurer takes readings independent of his or her team-mate. Each child has 2 recording forms (Series 1 and Series 2) for each measurer taking each set of measurements (Annex 1).

The session coordinator fills out an appropriate number of Series 1 and Series 2 forms for each infant to be measured. The measurers pick up the appropriate series forms for each infant and fill in their names before taking the measurements. When a team completes measurements on a baby, they return the forms to the coordinator so that she or he keeps track of who has measured which babies. *Each measurer should take the first series of measurements on all babies before beginning the second series*. (This reduces recall of first round values when taking second series measurements). Each measurer records measurements independent of his or her partner. The assisting measurer should really help the lead measurer by checking all aspects of positioning that are necessary to obtain accurate readings.

Data Analysis

The test-retest data are entered into the data table (Annex 3) in order to transfer them into the MGRS Excel spreadsheet that automatically computes the reliability statistics of interest for the study's purposes. Detailed descriptions of these statistics and how they are calculated and interpreted are presented below (see Assessing precision and Assessing accuracy). The spreadsheet is designed to handle a minimum of 10 subjects for each measurement. Missing values are admissible but they should be kept to a minimum, otherwise the computations fail. Reliability statistics are processed separately for each measurement (length and head circumference). The 'results' panels should be labelled accordingly when processing the output.

Assessing Precision

These statistics are automatically calculated in the MGRS spreadsheet. The steps for calculating them are presented here to help understand the results obtained from the spreadsheet analysis. A detailed example of the manual calculation with real height data is presented in Annex 1 of the WHO (1983) publication entitled *Measuring Change in Nutritional Status*. Reliability of anthropometric measurements in the MGRS has been published (WHO Multicentre Growth Reference Study Group, 2006)

Several measurers, including an expert, taking duplicate measurements on several subjects are needed to assess precision. These duplicates are called measure_1 and measure_2 in the following sections. It is important that the first and second measurements of each infant by a given measurer are separated in time and on paper (see Organization of standardization sessions). It is assumed that the infant measured does not change between measurements in any way that would affect the results. The information required for assessing precision is presented in Table 4.

Technical Error of Measurement

A measurer's TEM is calculated as the square root of the sum of squared differences between duplicates, divided by 2 times the number of subjects measured (Malina, 1973).

The steps outlined below are followed to compute TEM:

First step: For each measurer, compute the difference between each pair of measurements on each subject (i.e. measure_1 minus measure_2) and record the result in a new column, d. Square each difference and record the result in a separate column, d^2.

Second step: Sum the squared differences in column d^2 for each measurer to obtain Σd^2.

Third step: Divide the sum of squared differences (Σd^2) by twice the number of children (2N) measured by that measurer. The square root of the result from this division is that measurer's technical error of measurement (TEM). It has the same units as the units in which the measurements were taken, and is inversely proportional to precision.

$TEM = \sqrt{(\Sigma d^2 \div 2N)}$

The F-test for Precision

The TEM of the gold standard and the measurer can be compared using an F-test (Mueller & Martorell, 1988). This test requires the computation of an F-statistic, which is a ratio of two groups' variances. In the present case, the test "group" (numerator) is the set of duplicate measurements taken by the measurer, and the comparison "group" (denominator) is the set of duplicate measurements by the gold standard, whether this is the expert or the overall mean.

Expert as gold standard

To compute the statistic for the F-test, the sum of squared differences (Σd^2) between the measurements taken by the measurer is divided by the sum of squared differences between the measurements taken by the expert.

$$\text{F ratio} = \Sigma d^2_{\text{Measurer}} \div \Sigma d^2_{\text{Expert}}$$

The F-statistic thus obtained has numerator and denominator degrees of freedom equivalent to the number of subjects measured by the measurer and the expert, respectively. Therefore,

in the quarterly standardization session where 10 children are measured, the critical value for a significant F-statistic at $p<0.05$ is 2.97. A ratio this large or larger could be obtained by chance in 5 out of 100 cases**. In other words, if the F-ratio is 2.97 or greater, it is unlikely that the variability in the measurer's measurements is due to chance alone. Such a measurer needs further training to master the measurement technique to be able to reproduce his or her own measurements.**

Overall mean as gold standard

As mentioned previously, the overall mean of all measurers serves as the gold standard during the quarterly standardization sessions in each site (see Organization of standardization sessions). For each subject measured twice by multiple measurers, there is a mean of all measure_1's and another mean of all measure_2's. We shall call them mean_1 and mean_2; the difference between mean_1 and mean_2 for each subject, $Đ$*;* and the squared difference, $Đ^2$. The sum of squared differences between mean_1 and mean_2 ($\Sigma Đ^2$) is important for calculating the F-statistic for precision, and, as will be shown later, for calculating the F-statistic for bias as well.

The overall mean is used as the gold standard for precision, and mean_1 and mean_2 are used in the same way as the expert's measure_1 and measure_2 in the previous scheme (see 'Expert as gold standard' under Assessing precision). To compute the F-statistic for each measurer, his or her Σd^2 is divided by $\Sigma Đ^2$. Using the overall mean as the gold standard makes it possible to evaluate also the expert's performance against the overall mean. The interpretation is the same as under the scenario where the expert was the gold standard.

Sign Test

The sign test for precision aims to identify within-measurer tendencies in the differences between the first and second duplicate measurements (WHO, 1983). If the second measurements are systematically higher or systematically lower than the first, it is a sign of what is known as "measurement effect". As the measurement session progresses, the measurer's performance can change in a way that systematically overestimates or underestimates previous measurements.

Assessing Accuracy

As indicated in Table 6, the assessment of accuracy involves examining the means of the measurements taken by the gold standard (the expert or the overall mean) and the measurers to detect bias: that is, whether a given measurer overestimates or underestimates measurements (WHO, 1983). The preliminary step is to calculate -for the gold standard and each measurer- the mean of each duplicate set of measurements on each subject, and the grand mean of all measurements on the subject.

Expert as Gold Standard

For each subject, compute the difference between the measurer's and the expert's mean value and record this in a separate column, let us call it đ, for each measurer. Square each difference and record the result in a separate column, $đ^2$. Sum up the differences in each of the two columns to obtain Σđ and $Σđ^2$, respectively.

Average bias

To estimate the measurer's average bias, divide the sum of differences in means (Σđ) by the number of subjects measured, i.e.

$$\text{average bias} = Σđ \div N.$$

If average bias is zero (0), the measurer's estimates of means are equivalent to the expert's. If the estimate carries a negative or positive sign compared with the expert, the measurer tends to under- or overestimate measurements, respectively.

F-test of bias

Assessment of each measurer's accuracy in comparison with the gold standard is done using an F-test (WHO, 1983). The F-ratio of measurer bias compared with the expert uses the $Σđ^2$ of the measurer as the numerator, and the $Σd^2$ of the expert (computed for assessing precision, see Table 5) as the denominator.

$$\text{F-ratio} = Σđ^2_{\text{Measurer}} \div Σd^2_{\text{Expert}}$$

In effect, the numerator is the variation of the measurer's from the expert's estimates of means, while the denominator is the variation within the expert's duplicate measurements. The resulting F-statistic is understood and interpreted in the same way as the F-statistic for precision (see 'Expert as gold standard' under Assessing precision).

Sign test

The sign test checks whether poor accuracy is due to systematic or occasional bias (WHO, 1983). Average bias for a given measurer could be zero (0) when the sum of overestimated means is equivalent to the sum of underestimated means. However, average bias could also be zero (0) if one large overestimation is equal to the absolute value of several underestimations. The sign test of bias shows up such imbalances using counts of the sign (negative or positive) of the differences between the measurer's and the expert's means. If the proportion of one sign is significantly larger than the other, the sign test will be statistically significant.

Overall Mean as Gold Standard

The preliminary step in assessing accuracy involves calculating the grand mean of all measurers' measurements of, say, length on a given subject. In addition, we will use the mean_1, mean_2, Đ, $Đ^2$ and $\Sigma Đ^2$ values obtained when assessing precision (Table 5).

For each measurer, subtract their estimate of a given subject's mean from the same subject's grand mean, and record this in a separate column. Let us call this column ð to distinguish it from đ, the difference between the measurer's and the expert's mean (see 'Expert as Gold Standard' under Assessing Accuracy). Square each of these differences (ð) and record the results in another column, $ð^2$. Obtain the sums of the values in each of the two columns, i.e. $\Sigma ð$ and $\Sigma ð^2$.

Average bias

To estimate average bias for the measurer, divide the sum of differences from the grand mean by the number of subjects measured, i.e.

$$\text{average bias} = \Sigma ð \div N.$$

F-test of bias

The F-test of measurer bias, based on the overall mean, uses the measurer's $\Sigma ð^2$ in the numerator, the denominator is $\Sigma Đ^2$, and the sum of squared differences between mean_1 and mean_2. (Notice that this is the same denominator used in the F-test of the measurer's TEM

in comparison with the overall mean - see 'Overall Mean as Gold Standard' under Assessing Precision).

$$\text{F-ratio} = \Sigma\delta^2_{\text{Measurer}} \div \Sigma Đ^2_{\text{Overall}}$$

The resulting F-statistic is understood and interpreted in the standard way.

Sign test

The sign test of bias follows the same principle where the expert serves as the gold standard. As for precision, the overall mean is an estimate of the expert's bias.

Interpretation of TEM and Bias

The quarterly standardization sessions are to monitor measurer performance so that possible corrective action can be taken quickly. TEM and average bias results should be plotted to show each measurer's performance over time. Those who deviate from the high reliability standards required in INTERGROWTH-21st need retraining, a task carried out by the local lead anthropometrist in each site.

Statistical output on its own may not give a reliable picture of a measurer's performance because the number of children measured is small. **The rule-of-thumb in anthropometry is that the acceptable measurer TEM should be no more than 2 times the expert's TEM**. The measurers' performance at the initial standardization can be evaluated on this basis. From the quarterly standardization sessions, it will be possible to calculate the average of all measurers' TEM's and use this to monitor precision within the site over time and compare performance across sites. When assessing the group's average TEM from one standardization to the next, account should be taken of any special circumstances of the specific standardization session (e.g., many agitated infants).

Average bias results show immediately whether the measurer is under- or overestimating a certain measurement. The lead anthropometrist should attempt to identify the systematic fault that causes measurer's biased measurements, e.g. he or she does not sufficiently stretch out infants' legs when measuring length, thus systematically underestimating this measurement. Remedial training is given by the local lead anthropometrist or international expert if present at the site.

Table 5: Variables used for assessing precision

Subject	Expert				Measurer 1				Measurer 2				Overall			
	meas_1	meas_2	d	d^2	meas_1	meas_2	d	d^2	meas_1	meas_2	d	d^2	mean_1	mean_2	Đ	$Đ^2$
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
N=10				$\sum d^2$				$\sum d^2$				$\sum d^2$				$\sum Đ^2$

Table 6: Variables used for assessing accuracy

	Expert as Gold Standard							**Overall mean as Gold Standard**									
	Expert	Measurer 1			Measurer 2			Grand mean	Overall (Same as in Table 5)				Measurer 1			Measurer 2		
Subject	mean	mean	đ	$đ^2$	mean	đ	$đ^2$		mean_1	mean_2	Đ	$Đ^2$	mean	ð	$ð^2$	mean	ð	$ð^2$
1																		
2																		
3																		
….																		
7																		
8																		
9																		
10																		
N=10			∑đ	$∑đ^2$		∑đ	$∑đ^2$					$∑Đ^2$		∑ð	$∑ð^2$		∑ð	$∑ð^2$

References and Acknowledgements

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All line drawings in this manual were designed and produced by Stewart Chromik.

Annex 1: Sample anthropometry standardization forms

FIRST MEASUREMENT SERIES
(Head Circumference and Length)

SER 1

SESSION NUMBER ☐☐

CHILD'S NAME _____

CHILD NUMBER ☐☐

MEASURER'S NAME ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

HEAD CIRCUMFERENCE (cm) ☐☐ . ☐

LENGTH (cm) ☐☐ . ☐

SECOND MEASUREMENT SERIES
(Head Circumference and length)

SER 2

SESSION NUMBER ☐☐

CHILD'S NAME _____

CHILD NUMBER ☐☐

MEASURER'S NAME ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

HEAD CIRCUMFERENCE (cm) ☐☐ . ☐

LENGTH (cm) ☐☐ . ☐

Annex 2. Sample Weights of Women's Clothing.

No.	Item of clothing	Weight (g)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

Annex 3. Test-retest Data Tables for Site Standardisation Sessions

Date: / /	**Standardisation Session – Length**											
	Supervisor		**Observer A**		**Observer B**		**Observer C**		**Observer D**		**Observer E**	
Baby No.	LNTH 1	LNTH2	LNTH1	LNTH2	LNTH1	LNTH2	LNTH1	LNTH2	LNTH1	LNTH2	LNTH1	LNTH2
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												

Date: / /	**Standardisation Session - Head circumference**											
	Supervisor		**Observer A**		**Observer B**		**Observer C**		**Observer D**		**Observer E**	
Baby No.	HC1	HC2	HC1	HC2	HC1	HC2	HC1	HC2	HC1	HC2	HC1	HC2
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												