Extracting data on children's growth trajectories from growth charts in low-resource settings: A demonstration from the Manhiça district, Mozambique

Abstract

Objective: We aimed to identify an efficient method for enriching our understanding of children's growth in data-poor settings by generating growth trajectory data from the World Health Organization 'Road to Health' cards (RTHCs) which are widely used during routine health visits.

Design: Using photographs taken of the RTHC by fieldworkers during population-based data collection, we extracted weight and age data electronically using freely available, open-source software (Graph Grabber). We validated these against the weight and age data that had also been hand-written by healthcare workers on the RTHCs. A graphical comparison of digitized and manually transcribed weight-for-age growth curves was computed using Bland Altman Analysis. Finally, to demonstrate use of the data, we examined the growth trajectories and compared them with the WHO growth standard.

Setting: Data were collected in Manhiça district, Mozambique, as part of the Child Health and Mortality Prevention Surveillance (CHAMPS) network project between 2016 and 2020.

Participants: The study included all children who died before their 5th birthday in the study area whose families were able to provide a RTHC (n=89).

Results: The data extraction process was time-efficient, and required minimal supervision. Graph Grabber accurately captured the coordinates of the individual weight-for-age charts and there was strong agreement between the graphs and manually transcribed values from the RTHCs. Among the 89 cards, 52 had legible data and at least 2 observations marked, which is necessary for plotting a line. Where the age and weight digitization differed from the hand-written information, the reason was that the healthcare worker had made errors in plotting the data. In using the data to examine weight-for-age trajectories, we found that 28% and 18% of the girls and boys were underweight (< -2 SD) at 6 months of age, respectively.

Conclusion: Data extraction software can be used to characterize and study growth patterns efficiently, using anthropometric measures taken during children's routine clinic visits.

Introduction

Growth is a critical indicator of child health.[1-5] Normal growth is defined as increases in height, weight, and head circumference following established age- and sex-specific standards.[1] Growth monitoring of infants and young children is an essential element of primary health care, allowing early identification of both growth faltering and excess weight gain.[2,5] Growth that is either too slow or too rapid may be the first indication of ill health, and can indicate chronic diseases, genetic disorders, or parasitic, viral or bacterial infections. According to the Child Health and Mortality Prevention Surveillance (CHAMPS) network project, approximately 25% of infant and child deaths have malnutrition implicated as the underlying cause of death.[6,7] Abnormalities in growth may also signal abuse or neglect.[8] Age-appropriate nutritional interventions can promote growth and reduce malnutrition.[5] Therefore, growth monitoring of children provides an opportunity for preventive and curative health care to reduce malnutrition and associated morbidity and mortality.[4]

Graphical representations of growth trajectories by age are commonly used for growth monitoring. In many countries, graphical representations of growth trajectories are recorded on patient-held records, often in the World Health Organization (WHO)-designed "Road to Health" cards (RTHC).[9,10] These graphical representations are marked to plot a child's growth relative to WHO growth standards expected for under-five children raised in optimal conditions.[11,12]

Growth monitoring data collected in clinical settings and captured in RTHCs are intended to detect growth faltering and serve as an educational and motivational tool for parents.[13] However, they may additionally offer an efficient source of data for population-based research on growth and nutrition. Such data are needed to understand growth patterns of children, differences across populations, changes over time, and reasons for growth faltering, morbidity and mortality. If data can be made available for cross-sectional and longitudinal research of growth, they would substantially reduce the financial and logistical costs currently needed for study-based anthropometric surveillance measurements. Some countries have already adopted pooling individual growth data for surveillance purposes, for example, the Canadian Pediatric Nutrition Surveillance System.[14] In low and middle-income countries (LMICs), there have not been efforts to synthesize clinical records from individual children to study population growth patterns. The objective of this study is to demonstrate the extraction and use of data from growth charts to generate estimates of children's growth trajectories. We report on the steps for data capture and extraction, the accuracy of the data extraction process, and the potential for using this approach to study growth trajectories for population-based research. We use data from RTHCs collected as part of a larger study of child health in Manhiça, a rural district of southern Mozambique. To test the potential of using the digitized data, we demonstrate the growth patterns of children who died before the age of 5 years.

Road to Health Cards

The World Health Organization has designed "Road to Health" cards or booklets to be used during routine care for children under the age of five years to monitor children's growth and identify.[9,10] Data are marked in writing and in graphs to plot the child's weight to identify growth faltering.[11,12] Graphical representations are marked to plot a child's growth relative to WHO growth standards for under-five children raised in optimal conditions.[11,12] These records are also intended to serve as an educational and motivational tool for parents.[13] **Figure 1** shows an example of the RTHC currently used in Mozambique.

These cards or booklets are used in many countries and are kept by parents at their homes, to be brought along to the clinic whenever the child goes for a well-baby visit or for care needs. The cards are to be filled in by the nurse or other health care provider upon measuring the child during routine clinic visits including well-baby visits. They include sections for recording birthdate, age, sex, birthweight, immunizations, and measures of mid-upper arm circumference, head circumference, weight, and height at each routine well-baby visit, directly measured and noted by clinical staff. According to guidelines for health workers, weight should be recorded using standard protocols to avoid measurement errors.[18] After measuring the child, the health workers mark using a dot or star in the box corresponding to the age of the child in months. The dot or star within a column is supposed to be adjusted to reflect the time when the measurement was taken:[19] If the child is measured early in the month, this dot should be closer to the left side of that column; if the child was measured 2 weeks into the month, the indication should be in the middle; and if the child is measured late into the month, the dot or star should be towards the far-right side of the column. The health worker also handwrites numeric weight and age information.

Study setting and data

Mozambique is located in Southeastern Africa, with a population of nearly 28 million.[9] The country has among the highest prevalence of chronic malnutrition in sub-Saharan Africa, having remained relatively unchanged over the past 25 years. According to the 2021 Global Nutrition Report, 42.3% of children under 5 years of age were stunted and 4.4% were wasted.[15] In Mozambique, RTHCs, known locally as *Cartão de Saúde da Criança* or informally as "*cartão amarelo*" or "*ficha amarela*", i.e "yellow card", are filled in during routine visits to the health center from birth until 59 months.

Photographs of the RTHC were taken in the district of Manhiça by fieldworkers of the Manhiça Health Research Center (*Centro de Investigação em Saúde de Manhiça*, CISM) during their activities within the CHAMPS network project[16]. The district of Manhiça is a rural setting of southern Mozambique, located 80 kilometers North of the country's capital. The photos of growth charts were taken between 2016 and 2020 using android tablets and converted to either .jpg or .pdf files as part of a comprehensive post-mortem analysis conducted for children who died before the age of 5 years.

Thus, all children who had died before the age of 5 years during the study period were eligible for inclusion in this analysis if their families were willing to participate in the post-mortem study and were able to provide a RTHC, resulting in 89 cards.

Of the 89 children for whom families were able to provide RTHCs, 37 were excluded from the analysis: 19 did not contain no growth information, either because the child died before their first measurement or because the nurse failed to record the information on the card. Six cards had only one data point, either because the child died before a second measurement could be taken or the growth data were not appropriately charted. Eight cards had weight handwritten but not plotted against age. Four of the RTHCs were illegible. Thus, the data extraction, described below, was conducted for 52 cards.

Methods for data extraction

All cards were anonymized prior to data extraction. Each photographed RTHC was digitized using Graph Grabber 2.0.2 (https://www.quintessa.org/), an easy-to-learn, freely available, open-source software tool available for the Windows operating system, that enables the extraction of data coordinates from images containing graphs. Data were extracted from each growth chart with Graph Grabber, as summarized in **Figure 2**. Data points are extracted by drawing along the line of a graph and having the software automatically extract the data points. First, the researcher doing data extraction uploads the photograph of each RTHC. Next, the researcher carefully selects the X-axis (age in months) and Y-axis (weight in kilograms) manually. For the software to precisely estimate the coordinates of the growth curve in each RTHC, the researcher must ensure that the axes were drawn accurately and the limits (minimum, maximum, and interval values for each axis) were specified. After careful selection of the axes and their limits, the data extractor uses a point-and-click method to select the coordinates on the uploaded weight-for-age chart. This process generates a data series for each X, Y coordinate (weight, age) for each chart. That is, the digitization process provides age and weight data of each child for every month that weight-for-age data were plotted on the RTHC. The data series for each chart is exported and saved as an Excel file. The data are transferred into a master spreadsheet with variables for weight and age. Weight-for-age digitization can also be automatically completed using the software's prototype curve detection functionality, but we found the point and click method to be more precise.

The software keeps a history of data extractions and the researcher conducting data extraction can save every completed process in a Global Geodynamics Project (GGP) data file. These project files contain the project name, x- and y-axis intervals, and the data series of each RTHC. To monitor data quality, one team member used this file to check the accuracy of the extraction process completed by the primary extractor for each file. If needed, this file can be saved mid-way into the extraction process so data extractors can stop and continue the digitization process anytime later without starting afresh. The data extraction process of age and weight for each RTHC takes on average 12 minutes, varying from a minimum of 3 minutes to a maximum of 20 minutes, according to the number of data points.

Using the health workers' handwritten numeric weight and age information, also present on the card, we manually transcribed this information into the spreadsheet for each file to compare with the digitally extracted data for validation. For the purpose of this exercise, we treated the manually transcribed data as the gold standard. Because manually transcribed data can also contain errors, a more conservative approach would be to examine patterns of correspondence between the two methods.

As an alternative method, we explored using a fully automated digitization process. However, we found this process to be subject to measurement errors as it requires the extractor to center the cursor on the curve and adjust the threshold based on the thickness of the growth curve in the RTHC.

This process involved drawing a mask over the growth curve to enable Graph Grabber estimate all X, Y (age, weight) coordinates on the curve. Furthermore, the threshold of the mask should be adjusted to account for the width of the curve; if the curves are faint, which is true for growth trajectory curves on RTHCs, then a lower threshold should be used. However, mask points should only be used if the mask is accurate and care was taken to center the cursor around the curve. Also, this automated extraction process generates more X, Y (age, weight) coordinates than what is on the actual RTHC, and these coordinates do not perfectly fit those on the RTHC. Although the software provides options for adjusting, moving, and deleting individual points using the "select" tool in the View Toolbar, we find this process to be more time consuming and subject to many errors.

Methods of data analysis

The excel file containing the data series for each digitized RTHC was imported and analyzed in SAS version 9.4 (**SAS** Institute, Inc). We quantified the agreement between the manually transcribed weight and age data and the digitized age and weight data using Bland Altman Analysis. For weight, the average of the digitized and manually transcribed weight for every month of assessment were computed for each child and this average was plotted against the difference of the two measurements. This is presented in a scatter plot, where the Y-axis shows the difference between the two weight measurements (Digitized weight – manually transcribed weight) and the X-axis shows the average of the two measures ((Digitized weight + manually transcribed weight/2). To illustrate whether there is a significant systematic difference between the digitized and manually transcribed weight, we calculated the bias, estimated as the mean difference (d), the standard deviation of the differences (s), and constructed a 95% confidence limit of agreement around the mean difference (*d)*. This limit was defined as the mean difference (d) ±1.96* the standard deviation of the differences (s). These measures are shown in the scatter plots using horizontal lines. We also verified the normality of the distribution of the differences using a histogram. This process was repeated for assessing the agreement between digitized and manually transcribed age.

A graphical comparison of digitized and manually transcribed weight-for-age growth curves was computed in SAS. These curves were constructed using scatter plots, with age on the x-axis and weight on the y-axis, exactly how they are depicted on RTHCs. We used non-parametric smoothing to connect the weight-for-age coordinates to visualize the growth trajectories. For ease of interpretation and comparison, we plotted both curves (digitized and manually transcribed) in one figure for each child and used similar axes scale across panels.

SAS was used to analyze the individual trajectory for each child and the average growth trajectory of all children who had at least two measurements, using both digitized and manually transcribed data. The average growth trajectory was computed using a two-step process. First, we estimated the mean weight for each month from birth until 24 months; because children were not measured at the same time, we calculated the mean weight for each month using only the children whose weights were captured in that month of their life. For example, the average weight in the first month was computed as the sum of the weights of all children whose weight measurements were captured in the RTHC in their first month of life divided by the number of children. Hence, those whose weight was not captured in a given month did not contribute to the mean weight estimation for that month. Second, we plotted these age-specific mean weights and applied the non-parametric smoothing similar to those used to generate individual growth trajectories.

To understand how the growth of children who die before their fifth birthday compares to that of children living in optimal conditions, we compared the individual growth trajectories (weight-for-age) of the children in the study to the WHO growth standards of 2006[12] using WHO Anthro software.[17]

Results

Of the 89 children for whom families were able to provide RTHCs, 37 cards were excluded from the analysis: 19 were excluded because data had not been entered by health workers, perhaps because the child had died very soon after birth, before the information could be recorded. Six cards had only one data point, either because the child died before a second measurement could be taken or the growth data were not appropriately charted. Eight cards had weight handwritten but not plotted against age. Four of the RTHCs were illegible.

Analyses were conducted on 52 RTHCs that had at least two measurement points, the minimum number of measurements needed to create a growth trajectory. For the 52 children included in this analysis, weight-for-age data was collected for a total of 415 months. Among these, the median number of measurements was 7.5 months, and the minimum and maximum duration of follow up was 2 and 16 months, respectively.

The primary challenge we identified in the data extraction process is inconsistency in organizing and formatting of the images. Photos were saved in several file types, sometimes with each panel as a different file; there were also inconsistent naming conventions.

Accuracy of digitized and manually-transcribed data

The Bland Altman method recommends that, to establish agreement between two quantitative measures, 95% of the data points should lie between $\pm$ 2 standard deviations of the mean difference and the line of equality (Bias) should fall within this interval. The results met these two criteria and, in fact, over 95%% of data points fell within this range, suggesting very strong agreement between the manually transcribed data and those. For age digitization, the 95% confidence interval of the mean difference was wider and slightly farther from zero than for weight.

The Bland Altman plots in figures 3 and 4 show the degree of similarity between the digitized and manually transcribed weight and age data, respectively. The mean of the difference between the manually transcribed and digitized weights was 0.03 Kg (95% CI: -0.23 to 0.31, figure 3). This translates to a median percentage difference of 0.49 percent (IQR: -0.3 to 1.49). On average, the digitized weight data were systematically slightly lower than the manually transcribed. But the small IQR hovers around zero and suggests that the digitized and manually transcribed weight were comparable for the majority of the children. Figure 4 shows the difference between manually transcribed and digitized age. The mean of the difference between the manually transcribed and digitized age was 0.02 months (95% CI: -0.72 to 0.76). The median measurement error (IQR) associated with age digitization was -0.03 percent (-3.61 to 4.06).

We examined whether there are differences in clinical or research findings between the digitized and manually transcribed data. Figure 5 shows that these are nearly indistinguishable when describing the weight-for-age trajectories for 16 randomly-selected children.

Individual and average growth trajectories of children

Figure 6 shows the individual weight-for-age trajectories (in grey) of the 52 children and the average weight-for-age trajectory (in red) using the digitized weight-for-age data. We compared the digitized growth trajectories to the WHO 2006 growth standard for girls (figure 7a) and for boys (figure 7b). Among the girls (n=18), 83% fell below the WHO weight-for-age z-score (WAZ) average of 0; the others fell between 0 – 1 Standard Deviations (SD) above the WHO standard for normal weight (figure 7a). The WHO recommendation for normal WFA is ± 2 SD. At 6 months of age, 28% of the 18 girls had a WFA Z-score at or below – 2 SD of the WHO recommendations while the rest had normal weight for their age. Of the 5 girls who were underweight at 6 months, 4 of them remained underweight until they died. The fifth was severely underweight for the majority of the first year of life, then experienced steady, upward growth pattern until 15 months, reaching the normal weight-for-age, but again became underweight at 18 months of age and experienced growth failure until dying at 20.7 months. Half of the girls experienced a sharp decline in growth in the last two months before death. Among boys (n=34), 18% were underweight (< -2 SD) at 6 months of age and 79% had a weight-for-age z-score below the WHO average (0 SD) until death. On average, individual growth patterns of the boys followed an upward trajectory, as expected in normal child growth, for the first 6 months of life. Thereafter, individual growth became more variable, with over 80% of the boys transitioning irregularly between gaining and losing weight.

Discussion

Population-based data are needed to understand growth patterns of children in low-resource settings, to characterize differences across population groups, evaluate changes occurring after a policy intervention or a health emergency, and identify reasons for growth faltering and for morbidity and mortality. To date, in many low-income settings, we rely on anthropometric measurements taken as part of research studies, but such data are costly and logistically challenging, so they are often taken on small samples and at single points in time. We propose a cost-effective method to make anthropometric data available for research and policy evaluations by collecting these from the widely used "Road to Health" cards issued to children at birth in many countries. Pictures of these cards can be taken during population-based data collection such as the Demographic and Health Surveys (DHS), Health and Demographic Surveillance Systems (HDSS), and national censuses, which are regularly fielded across sub-Saharan Africa and Asia. Because the cards capture data recorded at multiple health clinics, they can provide longitudinal data on children's growth even in DHS data, which are cross-sectional.

We demonstrated that a supervised graph digitization tool such as Graph Grabber can be used to extract growth trajectory data from individual growth charts. We found that the digitized growth trajectories were similar to those obtained using manually transcribed data from the RTHCs and that the measurement error associated with data extraction was minimal. Thus, retrospective primary or secondary data generated through digitizing of clinical growth charts can also be used to examine child growth patterns at the population level. This study demonstrates the effectiveness of using digitization of pictures to extract anthropometric data from RTHCs. This method is efficient, relying on already ongoing work of health workers, and leverages existing health services data.

Using the Bland Altman method, we found that there was a high agreement between digitized and manually extracted data on weight and age. The slightly higher variability in digitized age between the data extracted from plotting and hand-written information on the form originates primarily from the health workers' recording of the information in the RTHCs. Some health workers placed the dot at either end of the column, not paying attention to the time of the month when the data were collected. These errors of misplacement of dots could be corrected or adjusted using the dates that are written in the cards for each visit, thus conferring more accurately timing of the measurement. To do this, one will need the date of consultation for each measurement, which, some, but not all cards, have recorded.

Several studies in low- and middle-income countries have demonstrated that monitoring growth trajectories, especially when paired with growth promotion programs and nutrition counseling, is effective in improving child health.[20] Measuring growth trajectories is challenging in both clinical and field settings.[9,21-23] The errors encountered during anthropometric assessments can be mitigated through the training of field workers and nurses and the use of calibrated equipment and standardized protocols. Health workers should be well versed on how to capture anthropometric data using standardized methods and tools, record and plot them, and interpret these measurements for caregivers. Inadequate training has been identified as a primary reason for the failure of growth monitoring programs. In a review of 18 growth monitoring programs in countries such as India, Jamaica, and Nigeria, researchers found that the time spent on training significantly affected program performance: 3 days was spent on training in the least performing programs, while those that achieved their targets spent as much as 8 weeks on training.[24]

This proof-of-concept study has some limitations and directions for future studies. The RTHC used were from deceased children, whose growth trajectories are generally not typical. Future studies should apply the method introduced here to extract data of a representative sample of children from an HDSS. This study demonstrated that the method of extracting information from RTHC is accurate and efficient, and time demands are not overly burdensome. Thus, population-based studies can efficiently apply these methods to larger samples. For example, a larger study of all children in a community could be used to describe growth patterns and to identify the socio-demographic risk factors for growth faltering. A larger study using information from the RTHC of deceased children could be conducted to identify how long before death significant differences in growth start to appear. This information would help us identify the windows of opportunity for intervention and early indication of danger.

A limitation that should be explored further is the availability and maintenance of RTHCs by children's parents and caregivers. Some families do not visit health facilities at all. Some families do visit, but may not receive the card from the clinic; some may lose their card and, even if they receive a new one, the information from the first would be lost; cards may get crumpled; many families bury the card with the child if the child dies; some families may refuse to show the cards during data collection. In our study, 21% of participating families did not have a card or it was blank; for 20% of those that did provide a card, it was in such bad shape that it could not be read. Another limitation of this method is the quality of the measurements conducted at health facilities. Some clinic staff may forget to give the family a card, may fail to fill in the card or may have illegible handwriting, or may measure the child incorrectly. Indeed, 20% of cards used in this analysis had some information missing and 6% had some illegible information. We could not assess the errors on the cards. This limitation can be explored in a future study by measuring a sample of children shortly after they were measured in clinics; study measures using highly trained staff and accurate equipment can indicate the external validity of the clinical measures recorded on the RTHC. While these possible sources of error can lead to noise in the data and missing information, we do not expect these errors to bias the direction of results.

The RTHCs only captures weight-for-age data which is used for underweight assessment. Underweight reflects a child's weight relative to their age and can be vital in detecting rapid changes in health and nutritional status during infancy. However, this indicator has been criticized for overestimating the undernutrition burden among older children,[25,26] and indicators that captures long term growth performance such as stunting and wasting are more widely adopted.[27] Some countries have adopted an expanded Road to Health Booklet (RTHBs), developed in 2010, which includes additional anthropometric measurements: length-for-age, weight-for-age, weight-for-length, mid upper arm circumference, and head circumference, as well as providing information about infant and young child feeding practices and preventative measures against common childhood infections and diseases. [28] Information is provided in the booklet for parents and can also be used by health workers for nutrition counseling during visits.

We found that the data extraction process was affected by the quality of the pictures taken by data collectors. Some photos were captured in a dark environment, had low contrast, or had the shadow of the data collector affecting visibility; others were captured with small number of pixels or were taken in a tilted position. We recommend training data collection teams to take pictures with a flash, to ensure clarity, and to keep the card straight when photographing. Teams could be equipped with a white cloth or paper on which to align the RTHC before taking the photo. Because the primary challenge we identified in the data extraction process is inconsistency in organizing and formatting of the images, we recommend saving each RTHC as one single JPG file. The file should be labeled with consistent file names reflecting the child's anonymized unique identifier and date.

The method we presented involves human-supervised digitization of the RTHC. There are several open-source tools available, such as DigitizeIt, WebPlotDigitizer, and Eugauge Digitizer. We found Graph Grabber to be the most user-friendly. Another possible comparison to be explored further would be a fully automated digitization process. However, we found this process to be time-consuming and introducing errors that then have to be resolved by the researcher. Hence, we utilized the manual extraction function in digitizing the RTHCs. This process was time-efficient and involved manually setting the boundaries for the X and Y axes and using a point and click method to select every coordinate in a given card.

Conclusion

Due to the logistics and financial constraints of collecting longitudinal anthropometric data, there are limited data on growth trajectories of children in areas of high childhood mortality. Capturing data that are already being collected during routine health visits is feasible and can generate vast amounts of data of both healthy and unhealthy children to inform programs, health policy, and nutritional assessments.

Figures

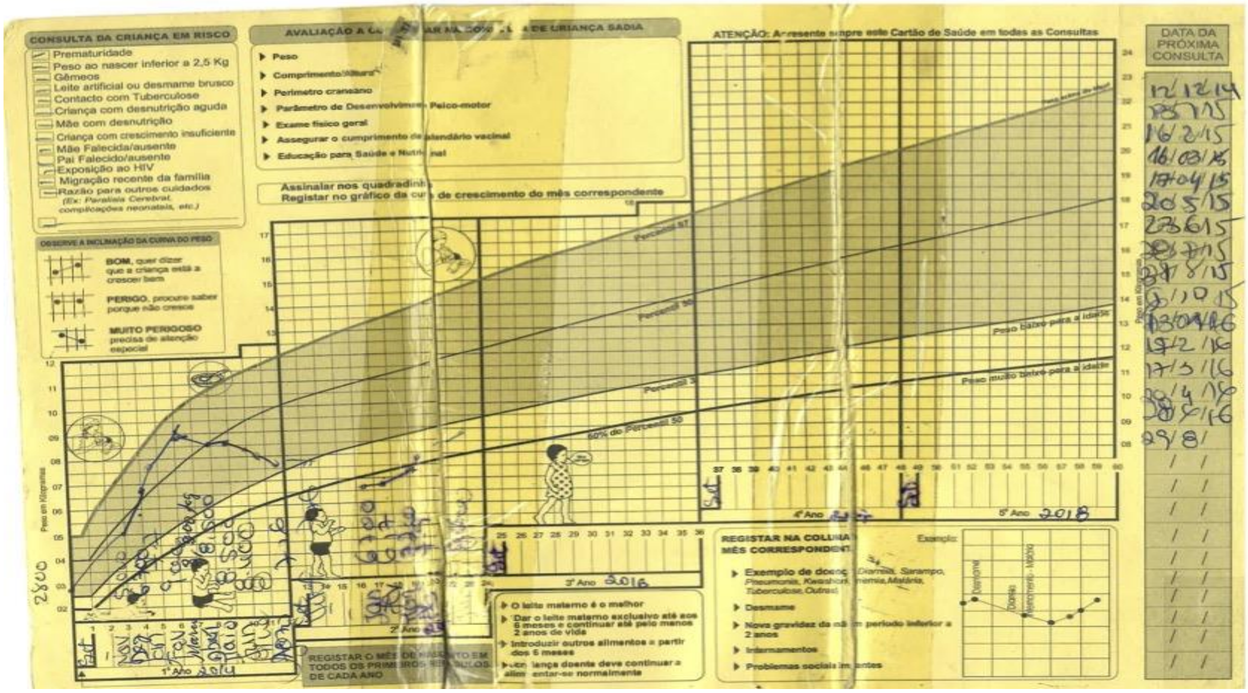


Figure 1: Example of Road to Health Card used in Mozambique (Source: CHAMPS fieldworker, 2020).

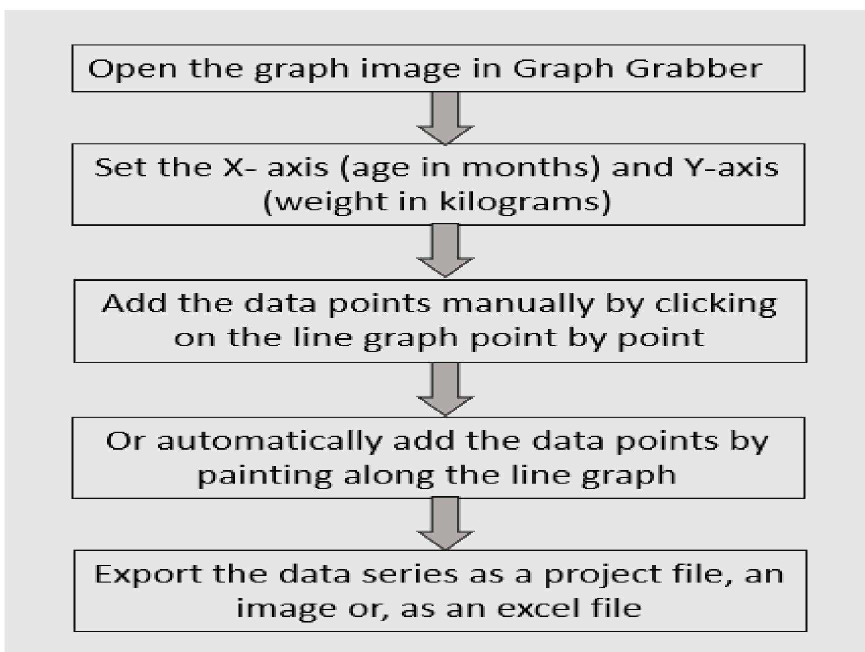
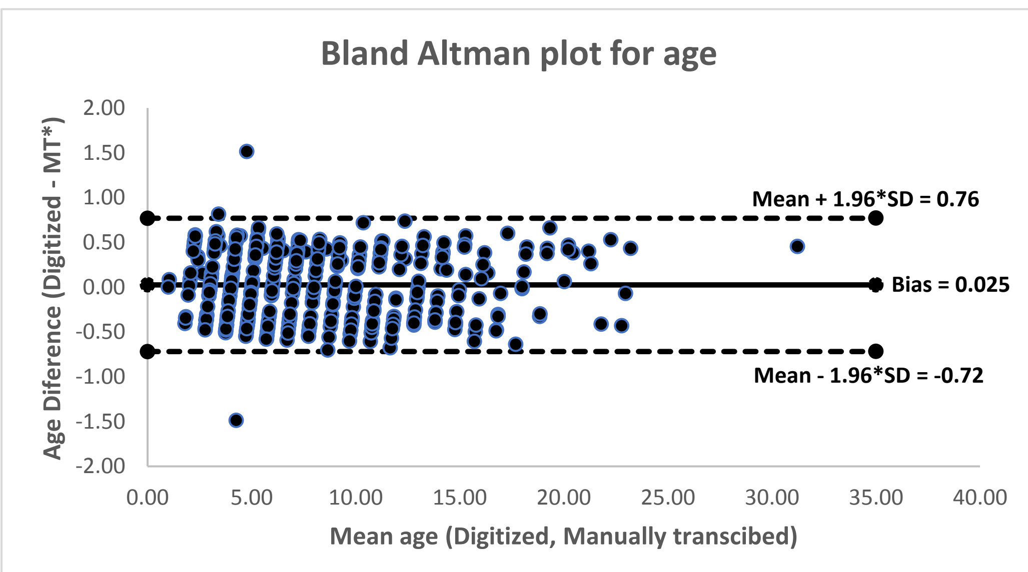


Figure 2: Summary of the data extraction process using Graph Grabber

*MT: manually transcribed

Figure 3: ***Bland Altman Analysis for weight comparing*** digitized and manually transcribed weight, n= Σ (datapoints per child) = 415.



*MT: manually transcribed

Figure 4: ***Bland Altman Analysis for age, comparing*** digitized and manually transcribed age, n= Σ (datapoints per child) = 415.

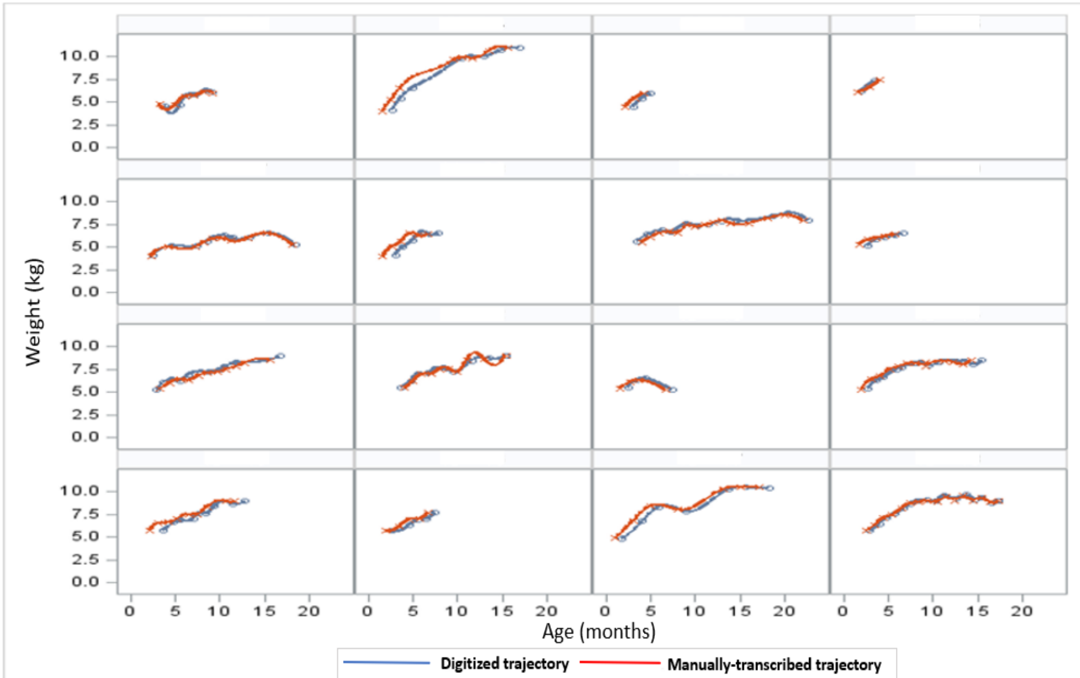


Figure 5: Growth trajectories of a sub-sample of 16 children using digitized and manually-transcribed data. Each graph box represents one child's data. All trajectories are available upon request.

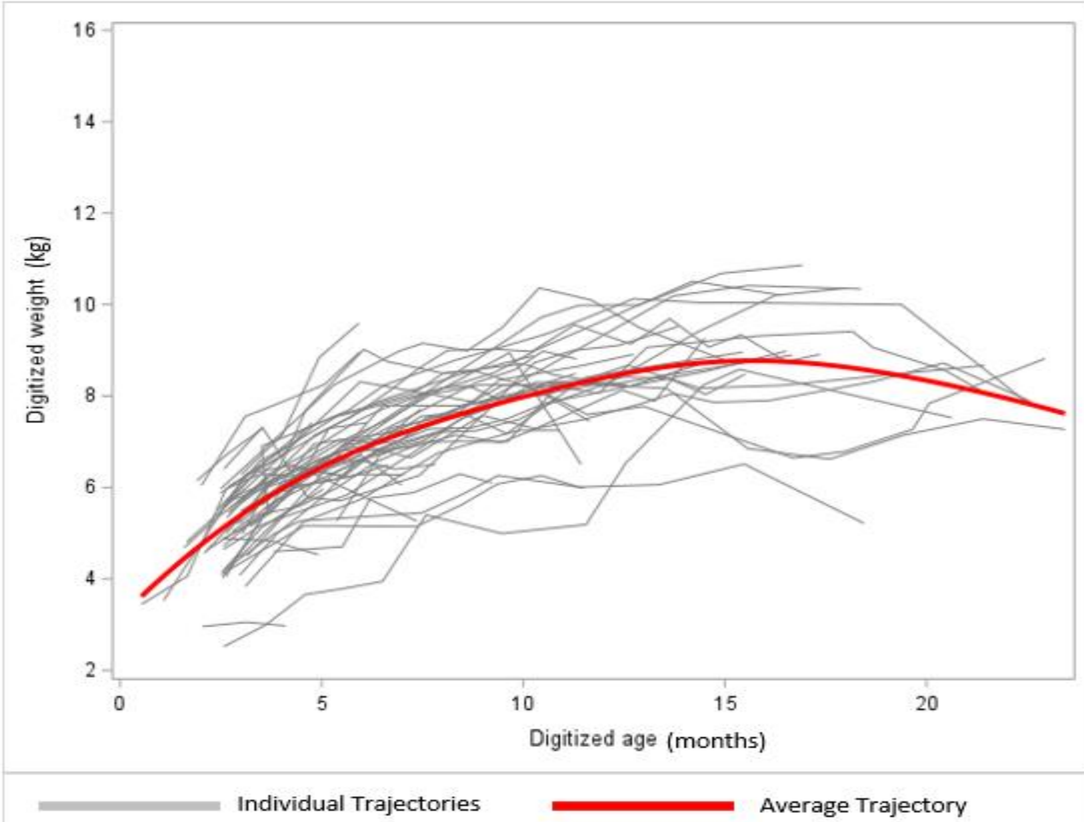


Figure 6: Individual and average growth trajectory of boys and girls from birth until 24 months of age using digitized weight-for-age data (n_{female} = 18, n_{male} = 34).

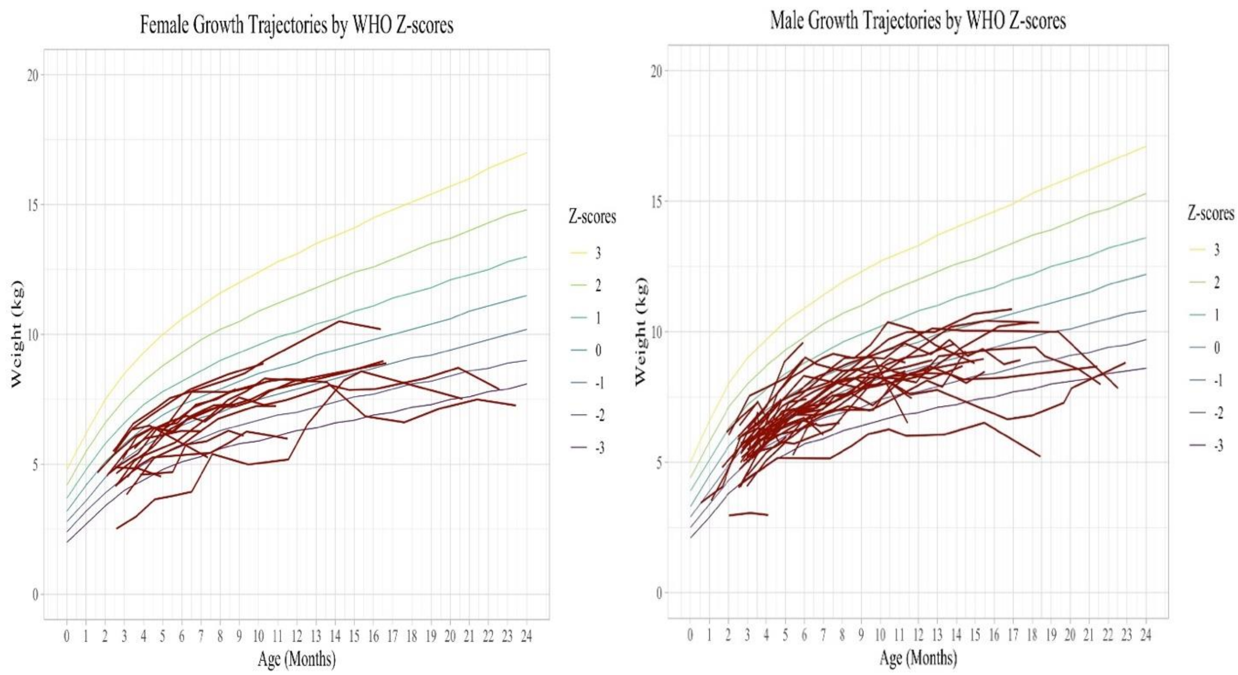


Figure 7: Weight-for-age distributions of female 7a) and male (7b) deceased children in Mozambique compared to the WHO weight-for-age standard in z-scores. Z-scores of ± 2 SD represent the cut-offs for healthy weight based on the 2006 WHO reference data. (n_{female} = 18, n_{male} = 34).

References

1 Tanner, J. M. 1 Normal growth and techniques of growth assessment. *Clinics in endocrinology and metabolism* **15**, 411-451 (1986).

2 Lipman, T. *et al.* A multicentre randomised controlled trial of an intervention to improve the accuracy of linear growth measurement. *Archives of disease in childhood* **89**, 342-346 (2004).

3 Cameron, N. Growth patterns in adverse environments. *American Journal of Human Biology* **19**, 615-621 (2007).

4 Johnson, W. *et al.* The reliability of routine anthropometric data collected by health workers: a cross-sectional study. *International journal of nursing studies* **46**, 310-316 (2009).

5 Ashworth, A., Shrimpton, R. & Jamil, K. Growth monitoring and promotion: review of evidence of impact. *Maternal & child nutrition* **4**, 86-117 (2008).

6 Breiman, R. F. *et al.* Postmortem investigations and identification of multiple causes of child deaths: An analysis of findings from the Child Health and Mortality Prevention Surveillance (CHAMPS) network. *PLoS medicine* **18**, e1003814 (2021).

7 Madewell, Z. J. *et al.* Prioritizing Health Care Strategies to Reduce Childhood Mortality. *JAMA Network Open* **5**, e2237689-e2237689 (2022).

8 Natale, V. & Rajagopalan, A. Worldwide variation in human growth and the World Health Organization growth standards: a systematic review. *BMJ open* **4**, e003735 (2014).

9 Tarwa, C. & De Villiers, F. The use of the Road to Health Card in monitoring child health. *South African Family Practice* **49**, 15-15d (2007).

10 Kitenge, G. & Govender, I. Nurses' monitoring of the Road to Health Chart at primary healthcare level in Makhado, Limpopo province. *South African Family Practice* **55**, 275-280 (2013).

11 Group, W. M. G. R. S. & de Onis, M. Assessment of differences in linear growth among populations in the WHO Multicentre Growth Reference Study. *Acta Paediatrica* **95**, 56-65 (2006).

12 Group, W. M. G. R. S. & de Onis, M. WHO Child Growth Standards based on length/height, weight and age. *Acta paediatrica* **95**, 76-85 (2006).

13 Lotfi, M. Growth Monitoring: A Brief Literature Review of Current Knowledge. *Food and Nutrition Bulletin* **10**, 1-8, doi:10.1177/156482658801000414 (1988).

14 Promoting optimal monitoring of child growth in Canada: Using the new World Health Organization growth charts - Executive Summary. *Paediatr Child Health* **15**, 77-83, doi:10.1093/pch/15.2.77 (2010).

15 *2021 Global Nutrition Report: The state of global nutrition. Bristol, UK: Development Initiatives.*, <https://globalnutritionreport.org/reports/2021-global-nutrition-report/> (

16 Salzberg, N. T. *et al.* Mortality Surveillance Methods to Identify and Characterize Deaths in Child Health and Mortality Prevention Surveillance Network Sites. *Clin Infect Dis* **69**, S262-s273, doi:10.1093/cid/ciz599 (2019).

17 W.H.O. *WHO Anthro Survey Analyser and other tools*, <https://www.who.int/tools/child-growth-standards/software> (

18 Himes, J. H. Challenges of accurately measuring and using BMI and other indicators of obesity in children. *Pediatrics* **124 Suppl 1**, S3-22, doi:10.1542/peds.2008-3586D (2009).

19 (1986)., W. H. O. *Guidelines for training community health workers in nutrition, 2nd ed*, <https://apps.who.int/iris/handle/10665/37922> (
20 Ashworth, A., Shrimpton, R. & Jamil, K. Growth monitoring and promotion: review of evidence of impact. *Matern Child Nutr* **4 Suppl 1**, 86-117, doi:10.1111/j.1740-8709.2007.00125.x (2008).
21 Gupta, P. M. *et al.* Improving assessment of child growth in a pediatric hospital setting. *BMC pediatrics* **20**, 1-10 (2020).
22 Naidoo, H., Avenant, T. & Goga, A. Completeness of the Road-to-Health Booklet and Road-to-Health Card: Results of cross-sectional surveillance at a provincial tertiary hospital. *Southern African Journal of HIV Medicine* **19** (2018).
23 Wright, C. & Mutoro, A. Accuracy of growth chart use in monitoring and assessing under-nutrition in Kenya. *Archives of Disease in Childhood* **97**, A46-A46 (2012).
24 Ashworth, A., Shrimpton, R. & Jamil, K. Growth monitoring and promotion: review of evidence of impact. *Matern Child Nutr* **4 Suppl 1**, 86-117, doi:10.1111/j.1740-8709.2007.00125.x (2008).
25 Wang, Y., Moreno, L. A., Caballero, B. & Cole, T. J. Limitations of the current world health organization growth references for children and adolescents. *Food Nutr Bull* **27**, S175-188, doi:10.1177/15648265060274s502 (2006).
26 de Onis, M. & Yip, R. The WHO growth chart: historical considerations and current scientific issues. *Bibl Nutr Dieta*, 74-89, doi:10.1159/000425433 (1996).
27 Klaver, W. Underweight or stunting as an indicator of the MDG on poverty and hunger. *41 (2010)* (2010).
28 Naidoo, H., Avenant, T. & Goga, A. Completeness of the Road-to-Health Booklet and Road-to-Health Card: Results of cross-sectional surveillance at a provincial tertiary hospital. *South Afr J HIV Med* **19**, 765, doi:10.4102/sajhivmed.v19i1.765 (2018).