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Elizabeth Christie Rhodes Date

Examination of the Double Burden of Malnutrition in Malawi:

Implications for Nutrition Surveillance

By

Elizabeth Christie Rhodes
Doctor of Philosophy

Nutrition and Health Sciences

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A.B., Brown University, 2006

S.M., Harvard T. H. Chan School of Public Health, 2011

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An abstract of
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Abstract

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The nutrition transition is advancing in low- and middle-income countries (LMICs), contributing to a rise in overweight and obesity on top of ongoing problems of undernutrition. The co-existence of under- and overnutrition, termed the 'double burden of malnutrition', has been documented in every region of the world, even in the poorest countries in sub-Saharan Africa like Malawi. However, due to limited nutrition surveillance, many LMICs lack up-to-date information about the prevalence and trends in overweight and obesity and conditions of undernutrition, especially micronutrient deficiencies. Furthermore, little is known about the co-occurrence of overweight and micronutrient deficiencies within the same individual. This dissertation investigated the double burden of malnutrition at the population and individual levels using data from serial nationally representative, cross-sectional Malawi Micronutrient Surveys conducted in 2001, 2009, and 2015-16. Malawi offered an opportunity to conduct this research, given that it is one of the few LMICs that has routinely collected data to assess micronutrient status. Taking advantage of the potential to learn from Malawi's experience collecting national nutrition data, we also evaluated the implementation process of the 2015-16 Malawi Micronutrient Survey using qualitative research methods. Main findings showed that: (1) from 2001 through 2015-16, there were declines in the prevalence of anemia and vitamin A deficiency, and while overweight and obesity prevalence did not change, nearly 15% of women were overweight or obese in 2015-16; (2) more than one in ten women had co-occurring overweight and micronutrient deficiencies; and (3) there was strong interest within the Government of Malawi to conduct the 2015-16 Malawi Micronutrient Survey, but the implementation process involved serious challenges, such as complex field logistics and high time investment. This dissertation work adds to the growing body of literature on the double burden of malnutrition and makes an important contribution by providing evidence on the challenges of collecting national nutrition data. Altogether, the findings highlight the need for enhancing nutrition surveillance systems to monitor all forms of under- and overnutrition as LMICs undergo the nutrition transition, with special attention to developing population-based survey models that can be implemented effectively and efficiently.

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Chapter 1: Introduction

The co-existence of under- and overnutrition, termed the 'double burden of malnutrition', represents an enormous global health challenge (1). The double burden of malnutrition has been documented at the population, household, and individual levels in every region of the world, even in the poorest countries in sub-Saharan African. Given the scale of the problem (2), and the adverse consequences of malnutrition for individuals and developing economies (3), the United Nations has prioritized addressing the double burden of malnutrition as part of its global health agenda. The United Nations Sustainable Development Goal 2, 'End Hunger', seeks to end all forms of malnutrition by 2030 (1). The United Nations General Assembly recently initiated a Decade of Action on Nutrition spanning from 2016 to 2025 with the aim to strengthen action to eliminate all forms of malnutrition globally (1).

The double burden of malnutrition among women of reproductive age deserves particular attention. Undernutrition in women includes underweight, anemia, and micronutrient deficiencies, and overnutrition encompasses issues of overweight and obesity and diet-related non-communicable diseases (1). Women who are undernourished face an increased risk of complications during pregnancy, and overweight and obesity during pregnancy increases risk of gestational diabetes and pre-eclampsia (4). Overweight and obesity also are strong risk factors for diabetes, cardiovascular disease, and other diet-related non-communicable diseases (5). Furthermore, proper nutrition before and during pregnancy is essential for breaking the intergenerational cycle of malnutrition (3). Maternal underweight is a risk factor for delivery of small-for-gestational-age and low birth weight babies, and maternal overweight is associated with pre-term birth, stillbirth, birth defects such as heart defects and neural tube defects in infants, and difficulties breastfeeding (3, 6-8). There is also evidence suggesting that maternal obesity influences children's risk of obesity, heart disease, stroke, and type 2 diabetes (9). Maternal vitamin A deficiency can cause night blindness (3). Meanwhile, anemia and iron deficiency are major contributors to maternal deaths, and anemia during pregnancy increases risk for adverse birth outcomes, such as preterm birth, low birth weight, and perinatal and neonatal mortality (3, 10).

In view of the negative effects of under- and overnutrition for women and their children, concerted efforts are needed to tackle the double burden of malnutrition among women in low- and middle-income countries. Up-to-date information about prevalence and trends in all forms of malnutrition at the population level, as well the co-occurrence of overweight and micronutrient deficiencies at the individual level, is crucial both to measure the double burden of malnutrition and to inform policy making and effective targeting of health resources. To produce this information, routine collection of high-quality, national nutrition data are required. However, nutrition surveillance in low- and middle-income countries often only includes collection of data to assess body mass index and anemia, resulting in a severe lack of micronutrient status data in these settings (11).

Motivated by this recognition, the overarching goal of this dissertation is to investigate the double burden of malnutrition in women and evaluate a survey model for collecting national data on under- and overnutrition. Malawi offers an exceptional opportunity to conduct this research, given that it is one of the few low- and middle-income countries that has routinely collected nationally-representative biomarker data for key micronutrients, along with body mass index and hemoglobin. Stand-alone Malawi Micronutrient Surveys were conducted in 2001 and 2009, and in 2015-16, the Malawi Micronutrient Survey was conducted in coordination with the 2015-16 Malawi Demographic and Health Survey. The specific aims of this dissertation are:

Aim 1: To evaluate the implementation process of the 2015-16 Malawi Demographic and Health Survey and Malawi Micronutrient Survey with a focus on three phases: preparation, data collection, and data analysis and dissemination.

Aim 2: To examine trends in the prevalence of underweight, overweight and obesity, anemia, and deficiencies in iron and vitamin A among non-pregnant women of reproductive age in Malawi from 2001 through 2015-2016.

Aim 3: To assess the prevalence of two characterizations of the individual-level double burden of malnutrition (i.e., co-occurring overweight and anemia, co-occurring overweight and micronutrient

deficiencies) among non-pregnant women of reproductive age in Malawi and understand how the prevalence varies across urban and rural areas.

In Chapter 2, I provide background for this research, with a focus on reviewing the literature on the co-existence of under- and overnutrition in low- and middle-income countries. The detailed methodology of this dissertation is described in Chapter 3. Chapters 4, 5, and 6 are the heart of the dissertation, focusing on Aims 1, 2, and 3, respectively. Each of these three chapters is structured in the form of a scientific manuscript, with a brief background, description of methods, presentation of results, and discussion and conclusions. In Chapter 7, I present a summary of the main research findings and discuss the implications for nutrition surveillance, as well as future research directions.

Overall, this dissertation research may be useful to health practitioners and policy makers in Malawi, particularly those implementing the Government of Malawi's 2018-2022 National Multi-Sector Nutrition Strategic Plan (12). The findings also may be useful to other low- and middle-income countries looking to increase the availability of nutrition data and measure the double burden of malnutrition to set priority actions and accelerate progress towards achieving Sustainable Development Goal 2 (End hunger, achieve food security and improved nutrition and promote sustainable agriculture). From a scientific perspective, this body of work may motivate future investigation to improve nutrition surveillance in low- and middle-income countries.

Chapter 2: Background

Nutrition transition

The nutrition transition is thought to contribute to the shift from predominant issues of undernutrition to overweight, obesity, and diet-related non-communicable diseases (NCDs) in low- and middle-income countries (LMICs) (13-15). The concept of the nutrition transition refers to broad shifts in dietary and physical activity patterns (14). As the nutrition transition progresses, traditional diets characterized by whole foods such as whole grains and pulses and low intakes of animal-source foods,

salt, and sugars are replaced by energy-dense, nutrient poor diets high in refined carbohydrates, high fat intake, processed foods and sugar-sweetened beverages (16-18). There are also reductions in physical activity and increases in sedentary time associated with low energy expenditure (15, 19). Together, increased consumption of energy-dense foods and reduced energy expenditure drive increases in overweight and obesity (14, 15). Underlying drivers of this nutrition transition include macrolevel factors such as urbanization and economic growth and associated increases in per capita income (14, 19). LMICs undergoing the nutrition transition are experiencing rising levels of overweight and obesity, even while undernutrition remains a widespread problem (13, 20-22).

Defining the double burden of malnutrition

The concept of the double burden of malnutrition (DBM) was introduced into the global nutrition narrative at the 1992 International Conference on Nutrition (23). With recognition that most countries faced problems of under- and overnutrition, the DBM was described as a "new paradigm" and aimed to motivate a shift from a sole focus on undernutrition to a focus on problems of both under- and overnutrition (23). The DBM has been defined as the co-existence of undernutrition such as micronutrient deficiencies and overweight and obesity (23). Expanded definitions that include NCDs also have been used (1, 2, 24). For example, in a recent policy brief, the World Health Organization characterized the DBM as the co-existence of undernutrition along with overweight, obesity, or diet-related NCDs (1).

The DBM occurs within populations, households, individuals and across the life-course (1, 25). At the population level, undernutrition and overweight, obesity, or NCDs can coexist in the same community, region, or country (1, 2, 26). The DBM can be observed within households, whereby one household member is undernourished, and another is overweight or obese or has a NCD (for example, a stunted child with an overweight mother) (1, 13, 27, 28). Under- and overnutrition also occurs within the same individual simultaneously (for example, co-occurring overweight and anemia or micronutrient deficiencies) or temporally separated (for example, an overweight adult who was stunted in early childhood) (1, 27).

Rivera et al. have described the complexity of identifying and defining the DBM (29). A key challenge is that conclusions about the magnitude of the problem can differ according to the level at which the DBM is assessed. In Brazil, for example, the individual-level DBM of co-occurring overweight and anemia in children under five was 1.2%, which would lead to a conclusion that the DBM does not exist (29). However, at the population level, the prevalence of anemia among Brazilian children under five was 25.5% and the prevalence of overweight and obesity was 7.3%, indicating that there is a DBM (29). Finally, no international cut-off points have been established to determine the occurrence of the DBM at the population, household, or individual levels (29).

Population level double burden of malnutrition

The co-existence of underweight and overweight at the population level has been widely reported in the literature, with many studies evaluating levels and trends in weight status among women. From 1975 to 2014, global age-standardized prevalence of underweight (BMI <18.5 kg/m^2) in adult women declined from 14.6% to 9.7% (30). Compared to the reductions in underweight over these past four decades, the increase in global obesity prevalence was greater (30). Worldwide, age-standardized prevalence of obesity in women increased between 1975 and 2014 from 6.4% to 14.9% (30). The global prevalence of overweight in women also has increased substantially. A systematic analysis found that overweight prevalence in women worldwide increased from 29.8% in 1980 to 38.0% in 2013 (31). The rise in overweight and obesity has affected high-income and LMICs alike, with levels of overweight and obesity in many LMICs nearing the levels documented in high-income countries (32). In particular, overweight and obesity are highly prevalent in LMICs in the Middle East and North Africa and in Latin America and the Caribbean (32).

The striking distinction in LMICs is that the obesity epidemic is unfolding on top of persistent levels of undernutrition, particularly in the poorest regions (17, 30). For example, underweight remains common in LMICs in south Asia and central and east Africa, despite some declines in the past four decades (30). As of 2014, underweight prevalence in women was 24% in south Asian countries and

higher than 12% in central and east African countries (30). Nonetheless, evidence shows that the burden of overweight among women exceeds that of underweight in most LMICs. In an analysis of nationally representative data collected between 1992 and 2000 in 36 LMICs, Mendez et al. found prevalence of overweight in women was higher than underweight prevalence in more than half of the countries surveyed (33). While overweight prevalence historically has been higher in urban areas relative to rural areas, urban-rural differences in overweight are diminishing in many LMICs (4, 17, 32, 34). Popkin & Slining documented similar levels of overweight among women in urban and rural areas in all regions, except for South Asia and sub-Saharan Africa (32). In that same study, annual increases in overweight were greater in rural areas than urban areas in all regions, except sub-Saharan Africa (32). These findings are aligned with the results of an analysis using Demographic and Health Survey data from 32 sub-Saharan African countries, which found urban women to have a higher likelihood of overweight and obesity compared to their rural counterparts (35). In rural areas of many sub-Saharan African countries, as well East Asian and South Asian countries, underweight remains more prevalent than overweight (4).

While underweight and overweight are well studied conditions of malnutrition, less is known about the levels and trends in micronutrient deficiencies in women owing to the lack of routine collection of data on micronutrient status. For example, the lack of availability of data on serum zinc concentrations in LMICs has prompted a reliance on indicators of zinc deficiency risk, such as the prevalence of usual intakes of dietary zinc falling below the Estimated Average Requirement (36). A 2017 study found that of 82 countries implementing vitamin A interventions two-thirds did not have data on vitamin A status or had data that were older than 10 years or more (37). Data on iron status also are not widely available, making assessment of iron deficiency in LMICs challenging (38). Currently, the World Health Organization Micronutrients Database in the Vitamin and Mineral Nutrition Information System, which is charged with assessing the micronutrient status of populations, does not include indicators of iron status (39). Instead, anemia is often assessed in population-based surveys and commonly used as a proxy for iron status. However, scientific evidence unequivocally shows that anemia is not a good predictor of iron

deficiency (38, 40). Moreover, many factors contribute to the development of anemia, of which iron deficiency is one (11, 41). Given these data gaps, there have recently been calls to include routine collection of micronutrient status data in nutrition surveillance systems in LMICs (11, 37, 42).

Individual level double burden of malnutrition

The co-occurrence of overweight and anemia or micronutrient deficiencies at the individual level in women is relatively underexplored in the literature on the DBM. Much of the existing evidence on this topic is based on cross-sectional studies. For example, a series of studies were published in 2014, which documented the co-occurrence of overweight and anemia among women in seven Latin American countries (27, 43-49). According to the findings, there was substantial variation in the prevalence of the individual-level DBM even in countries within the same region. Brazil had the highest prevalence of co-occurring overweight and anemia, with 13.6% of women experiencing this DBM (44). Guatemala, Ecuador, and Mexico had similar levels of co-occurring overweight and anemia with an estimated prevalence of 11.7%, 8.9%, and 7.5%, respectively (43, 47, 48). The lowest level was observed in Colombia, where only 3.4% of women had co-occurring overweight and anemia (45). Compared to Latin America, evidence on the individual-level DBM in women in sub-Saharan Africa is largely lacking (50). Jones et al. conducted one of the few studies of the individual-level DBM in women in this region using Demographic and Health Surveys for 30 sub-Saharan African countries (50). Results showed that the odds of co-occurring overweight and anemia were higher among women in periurban and urban areas than women in rural areas (periurban, OR: 1.18 [95% CI: 1.05, 1.33]; urban, OR: 1.43; [95% CI: 1.27, 1.61]) (50). Notably, this was one of the few studies that has examined the distribution of the individual-level double burden within a country. In South Asia, one cross-sectional study was conducted in India and found that the prevalence of co-occurring overweight and anemia was 9% among women (24).

Since these studies are based on cross-sectional data, they offer little insight into the factors involved in the development of the individual-level DBM. It is often hypothesized that the individual-level DBM may arise from diets comprised of foods associated with the nutrition transition that are

energy-dense and micronutrient poor (13, 50, 51). However, studies have not specifically evaluated this hypothesis. Furthermore, the majority of previous studies that have examined the individual-level DBM have relied on anemia as a proxy for micronutrient deficiencies, due to a lack of availability of micronutrient status data (24, 27, 50-52). One of the few exceptions was a study conducted in Vietnam, which only presented data on overweight with single micronutrient deficiencies, such as iron deficiency and zinc deficiency. While these findings revealed that overweight and single micronutrient deficiencies co-occur among women in Vietnam, the extent to which overweight co-occurs with multiple micronutrient deficiencies in Vietnamese women remains unclear. Thus, there is a need to expand on this work and gain a better understanding of co-occurring overweight and micronutrient deficiencies in women.

Research needs

Research needs addressed by this dissertation include the following:

1. Existing national health and nutrition surveys in LMICs do not collect sufficient data to monitor all forms of malnutrition. While weight status and anemia are assessed routinely (4, 11), the collection of micronutrient status data to assess deficiencies in key micronutrients are rare. Research is needed to identify effective, efficient, and sustainable strategies for collecting national data on all forms of malnutrition, including micronutrient deficiencies.
2. Up-to-date information on trends in women's nutritional status is needed to understand the evolving nutrition situation in LMICs undergoing the nutrition transition and to inform policy making.
3. Little research has examined the individual-level DBM in women. Research is needed to assess the national prevalence of the individual-level DBM, as well as how the prevalence varies across urban and rural areas.

Chapter 3: Methodological Approach

This dissertation used mixed-methods. Qualitative research methods were suitable for exploring perceptions of the implementation process of the 2015-16 Malawi Demographic and Health Survey (MDHS) and Malawi Micronutrient Survey (MNS) among key stakeholders (Aim 1). Quantitative research methods were required to assess trends in women's nutritional status (Aim 2), as well as to assess the prevalence of the individual-level double burden of malnutrition among women (Aim 3). I present data analysis methods specific to each aim in the relevant chapters (Chapters 4 – 6). Here, I present additional details to provide a fuller understanding of the methods used in this dissertation.

Extended qualitative research methods

Participant recruitment

Purposive sampling was used to select individuals who conducted the 2015-16 MDHS and MNS, including individuals from the Government of Malawi and international agencies. This sampling method ensured that we captured the perspectives of a diversity of individuals, namely those working at different levels (national, international) and carrying out a variety of roles (financial support, technical assistance, planning and logistics, data collection, data management, data analysis, reporting and dissemination). Individual email requests for participation were sent and, if a response was not received within several weeks, follow-up attempts were made to contact potential participants by email at least three additional times.

MDHS and MNS field team supervisors also were recruited given their experience with day-to-day issues of data collection in the field. They could provide further insight into field related issues that may not be discussed in detail by Government and international agency staff, such as challenges with communication between MDHS and MNS field staff, strategies for mobilizing communities prior to data collection, and the process of obtaining consent from respondents to participate in the MDHS and MNS. A local member of the evaluation team contacted field team supervisors by phone and invited them to participate.

Of the 26 individuals recruited for participation in this evaluation, 24 agreed to participate. We determined that a sample size of 24 would be adequate after consideration of multiple parameters known to influence saturation, including: purpose of evaluation, saturation goal and focus, data quality, population, and sampling strategy (53). Specifically, we took into account that the purpose of the evaluation was to capture themes and our goal was to achieve saturation in core codes (not in all data), indicating a smaller sample would be required for saturation (53). Since one interviewer did not have prior experience conducting qualitative research and one interviewer was an experienced interviewer, we anticipated a combination of "thin" and "thick" data. Also, we considered that we had a heterogenous population, a fixed sample, and an interest in not only reaching code saturation (i.e., the point at which we have "heard it all") but also meaning saturation (i.e., the point at which we "understand it all"), all of which suggested that a larger sample would be needed to achieve saturation (53). Thus, we determined that an intermediate to large sample size would be needed, and a sample size of 24 met that need.

Data collection

We conducted semi-structured, in-depth interviews to understand the views and experiences of stakeholders in implementing the MDHS and MNS. Interviews were a suitable data collection method since we were interested in individuals' perspectives (54). In addition, we sought to explore topics that individuals may be unwilling to discuss openly and in detail in a group setting, such as disadvantages of an integrated survey model, communication issues with partners, and challenges faced during data collection (54). Face-to-face interviews were conducted whenever logistically feasible. However, due to wide geographic variation in where individuals were located (Malawi; Washington, DC; Maryland; Georgia) and the prohibitively high cost of travel, some interviews were conducted by telephone. We used a semi-structured interview guide that included a section on each of the three phases of the MDHS and MNS: preparation; data collection; and data analysis, reporting, and dissemination (Appendix A). All questions on the guide were open-ended and included probes that allowed for exploring issues in greater depth and detail. The interviews were scheduled to last approximately 45 minutes as to not over-burden

stakeholders with limited time. Thus, the guide was designed with this time limit in mind. However, more than half of interviews lasted approximately one hour, with some lasting longer as time allowed.

Interviews were conducted in English, the official language of Malawi. Interviews were digitally recorded and transcribed verbatim. Approximately three quarters of the interviews were transcribed using Express Scribe Transcription software, which allows the speed of the recordings to be slowed down to facilitate transcription. About one quarter of the interviews were transcribed by Landmark Associates, a transcription company with experience transcribing interviews for academic research. Each transcript completed by Landmark Associates was reviewed in full, which involved listening to the digital interview recording, checking the accuracy of the transcript, and revising the transcript as needed. Two interviews were not recorded due to an error with the recorder, but extensive notes were taken immediately after the interviews and included as part of the data for analysis.

The training for interviewers covered the following topics: role of the interviewer, best practices for qualitative interviewing (for example, asking open-ended and non-leading questions, remaining neutral, developing rapport, using active listening, and probing), and maintaining confidentiality and anonymity. The training also included a question-by-question review of the entire interview guide and instruction on how to use the interview guide flexibly. After interviewers completed the first several interviews, the digital interview recordings were reviewed to identify ways interviewers could improve their interviewing skills, such as probing more and using the interview guide flexibly. Then, phone and in-person sessions were held to provide re-training. Review of the digital interview recordings continued throughout data collection and re-training and technical assistance was provided as needed to help ensure data quality.

Data analysis

Textual data were analyzed using thematic analysis. Using one-third of the data (or 9 interviews), deductive and inductive strategies were employed to identify issues, or ‘codes’, in the data and develop a codebook (54). MAXQDA12 was used to code the data and thick descriptions of codes were developed. Structured comparisons of issues were carried out to gain a deeper understanding of the issues (54). For

example, data were compared by agency (for example, CDC versus USAID), stakeholder type (Government versus international agency versus field staff), and field team (MDHS versus MNS). Next, codes were grouped into categories and then organized into themes. Lastly, relationships between the codes were explored and a conceptual diagram was developed to depict the themes and how they related to each other (55).

Malawi Micronutrient Survey data

The data used for the quantitative analyses in this dissertation came from three cross-sectional surveys: (1) 2001 MNS; (2) 2009 MNS; and (3) 2015-16 MNS.

2001 and 2009 Malawi Micronutrient Surveys

The 2001 and 2009 MNS's were conducted as stand-alone surveys and followed a similar methodology. The surveys were designed to provide nationally representative data, as well as regionally representative data for the three regions of Malawi: Northern, Central, and Southern regions (56, 57).

The 2001 MNS employed a two-stage cluster design with stratification by region. A probability proportional to population size sampling procedure was used to select 30 clusters per region, totaling 90 clusters nationally. Clusters were enumeration areas used in data collection for the Malawi Census. In each cluster, all households were listed. Using the household listing, 18 households were randomly selected per cluster. In each selected household, every other woman aged 15 to 45 years was selected for participation in the survey. Additional details of the 2001 MNS methodology have been presented elsewhere (57).

The 2009 MNS also employed a stratified two-stage cluster sampling design. In the first stage, 40 clusters in each stratum (or region) were randomly selected using probability proportional to population size. In the second stage, all households in each cluster were listed. From the list of households, 15 households were randomly selected from each cluster. Within each selected household, all women aged

15 to 49 years were invited to participate in the survey. Detailed methodology of the 2009 MNS has been presented elsewhere (56).

2015-2016 Malawi Micronutrient Survey

The 2015-16 MNS was conducted in coordination with the 2015-16 MDHS. The MDHS was a cross-sectional survey that employed a two-stage cluster sampling design. The sampling frame was a complete list of all standard enumeration areas created for the 2008 Malawi Population Housing Census. In the first stage of sampling, clusters (i.e., census standard enumeration areas) were selected using a probability proportional to population size sampling procedure. In the second stage, an updated household listing in each selected cluster was created. From this household listing, a fixed number of 30 households in each urban cluster and 33 households in each rural cluster were selected with an equal probability systematic selection. In total, 850 clusters were selected to participate in the survey. Women of reproductive age 15 to 49 years were eligible to be interviewed if they were either permanent residents of the selected households or visitors who stayed in the selected households the night before the survey. In a random subsample of one-third of these households in each cluster, men aged 15 to 45 were eligible to be interviewed and tested for HIV, and women and preschool children under 5 years were eligible for anthropometry measurement, anemia testing, and HIV testing.

The 2015-16 MNS sample was a subsample of the MDHS, which was selected to provide estimates of key indicators for the country and for each region (North, Central, South). The MNS sample was comprised of 105 clusters (35 clusters per region) randomly selected from the 850 MDHS clusters. Within each of the 105 clusters selected, households that participated in HIV testing (10 in each urban cluster, 11 in each rural cluster) were excluded from participation in the MNS. All remaining households (20 in each urban cluster, 22 in each rural cluster) were included in the MNS sample. Women aged 15 to 49 from 9 households randomly selected from all households were selected to participate. All selected women had participated in the MDHS. Additional details of the methodology of the 2015-16 MDHS and MNS have been presented elsewhere (58, 59).

Indicators for vitamin A deficiency and iron deficiency

In Chapters 5 and 6, details of the measures and indicators used in quantitative analyses are described. Two indicators require further explanation: retinol binding protein (RBP) and ferritin. In the 2015-16 MNS, retinol was measured in a subsample of preschool children, school-aged children, and women. Because the ratio of RBP: retinol is not always 1:1, we used linear regression to estimate population-specific cut-offs for RBP that correspond to the retinol cut-off for vitamin A deficiency of <0.7 µmol/L. Specifically, linear regression models were used for each subgroup (preschool children, school-aged children, women) and for all these subgroups combined to generate equations with RBP as the exposure variable and retinol as the outcome. Next, we solved for RBP, setting retinol equal to 0.7 µmol/L. Details of this approach are presented in Table 2.1. Based on this work, it was decided that RBP <0.46 µmol/L was an appropriate cut-off equivalent to retinol <0.7 µmol/L in the 2015-16 MNS. A similar approach was used to derive cut-offs for RBP for the MNS 2009 (56).

Ferritin was adjusted for inflammation using a regression-correction approach (38). Inflammation was measured by concentrations of C-reactive protein (CRP), a measure of acute inflammation, and α1-acid glycoprotein (AGP), a measure of chronic inflammation (38). The regression-correction approach uses linear regression to adjust the serum ferritin concentration by CRP and AGP concentrations on a continuous scale (38). This regression-correction approach is important because ferritin is an acute phase protein, and serum ferritin levels rise during inflammation (38, 60, 61). As such, inflammation affects serum ferritin concentrations, resulting in inaccurate prevalence estimates of iron deficiency in a population (38, 61). Adjusting for inflammation increases the estimated prevalence of iron deficiency. Prevalence estimates of inflammation-corrected iron deficiency are believed to be more accurate (38). The recommendation to adjust serum ferritin for inflammation has been adopted by the World Health Organization and will be released in 2018.

Table 2.1: Regression equations to calibrate retinol binding protein to retinol

Group (sample size)	**Equation**	**Retinol binding protein cut-off calculated**
Preschool children only (n=76)	0.7 = 0.3788 + 0.7549*RBP	0.4255
School aged children only (n=91)	0.7 = 0.2747 + 0.9291*RBP	0.4578
Women of reproductive age only (n=91)	0.7 = 0.2747 + 0.9291*RBP	0.4578
Entire group (n=260)	0.7 = 0.2914 + 0.8817*RBP	0.4634

Multiple imputation methods

For Aim 2, multiple imputation methods were used to address missing data, which were greater than 10% in the 2001 and 2009 MNS data sets. Specifically, complete anthropometric and micronutrient status data were available for 74% of women (n=335/450) in the 2001 MNS data set. Data from the 2009 MNS were available in two separate data sets, one with anthropometric data and one with data on anemia, iron status, and vitamin A status. With regards to anthropometric data, 86% of women (n=533/623) had complete data. Data on anemia and micronutrient deficiencies only were available for a subsample of women, and of these women, 89% (n=438/492) had complete data. In the 2015-16 MNS data set, missing data was not a significant issue, as 95% of women (n=703/737) had complete anthropometric and micronutrient status data. However, to maintain consistency in the methodology used across data sets, imputation methods also were used to impute missing values in the 2015-16 data set.

Multiple imputation is computationally intensive (62) and using this method involved three main steps (63). First, the multiple imputation procedure in SAS statistical software (PROC MI) was used to impute missing values (63, 64). For each of the four MNS data sets, 50 imputed data sets were created given the extent of missing data (63). In the imputation procedure, all socio-demographic variables (age in years, wealth, education level, residence) and anthropometric and biomarker variables were included (63). Because multiple imputation procedures assume data are normally distributed, bias can be introduced if non-normally distributed variables are included in the multiple imputation procedure (62).

Thus, log transformations were used to deal with non-normally distributed variables (62). Prior to analysis, these variables were back-transformed.

Second, standard procedures, such as PROC SURVEYFREQ, PROC SURVEYMEANS, and PROC SURVEYLOGISTIC, were used to analyze each of the 50 completed data sets for 2001 and output the results (63). Third, PROC MIANALYZE was used to input the results of the 50 separate analyses for 2001 and apply multiple imputation formulae to generate parameter estimates, standard errors, confidence intervals, and test statistics for the descriptive statistics or model parameters (63). These two steps were repeated for the 2009 anthropometric data set, 2009 anemia and micronutrients data set, and the 2015-16 data set.

Chapter 4: Integrating Micronutrient Status Assessment into the 2015-2016 Malawi Demographic and Health Survey: A Qualitative Evaluation

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Abstract

The demand for national-level micronutrient status data continues to grow, yet little is known about the implementation of different models for collecting micronutrient status. We conducted an evaluation of the process of linking the 2015-2016 Malawi Demographic and Health Survey (MDHS) and 2015-2016 Malawi Micronutrient Survey (MNS). We conducted 24 in-depth interviews with stakeholders from the Malawi Government, international agencies, and data collection teams. Interview questions explored perceptions of what worked and what was challenging during three phases of implementation: preparation; data collection; and data analysis, report writing, and dissemination. Data were analyzed using thematic analysis. Results showed there was a strong interest amongst stakeholders in Malawi to integrate the MDHS and MNS. Perceived benefits of such an approach included potential cost-savings and lower respondent burden. However, stakeholders did not view the linkage of the surveys to be a fully integrated approach. The lack of full integration produced challenges, such as stakeholder buy-in and complicated field logistics. Two main barriers to integrating the surveys emerged. First, the MDHS and MNS were originally designed as stand-alone surveys, and planning for each survey was at an advanced stage once the Government sought to integrate the surveys. Second, the MNS could not be incorporated as a module within the MDHS core questionnaire given the complexity of the MNS data collection and short timeframe for planning. These findings can inform decisions about the implementation of the next MNS and may be applicable to other countries that are conducting micronutrient status surveys.

Introduction

The demand for high quality and timely national-level nutrition data continues to grow. Recent Global Nutrition Reports called for a "data revolution" to increase the availability of national-level data (42). As low- and middle-income countries (LMICs) intensify action to address malnutrition, there is increasing interest in closing data gaps and obtaining data to inform policy decisions, target programs and resources, and track progress (65-67). Data on micronutrient status and coverage of micronutrient interventions are lacking in many LMICs (37, 65, 68). These data are important since nutrition programming often includes both nutrition-specific (e.g., micronutrient supplementation) and nutrition-sensitive (e.g., agriculture and food security) interventions to improve micronutrient status (69, 70).

To date, the predominant approach for assessing population micronutrient status has been to conduct a stand-alone national micronutrient status survey. Cambodia pioneered linking micronutrient status data collection with the 2014 Cambodia Demographic and Health Survey (DHS) by having field teams collect micronutrient status data among a subsample of households one to three months following the DHS (71). In 2015, Malawi undertook a similar approach. The 2015-2016 Malawi Micronutrient Survey (MNS) was administered to a subsample of households surveyed by the 2015-2016 Malawi Demographic and Health Survey (MDHS) (58). MNS field teams visited the subsample of households after the MDHS collected data (58).

We conducted an evaluation of the process of linking the MDHS and MNS. Our objective was to understand the experiences of key stakeholders throughout implementation of the surveys. Specifically, we explored what worked and what were the challenges during three phases: (1) preparation; (2) data collection; and (3) data analysis, reporting, and dissemination.

Key messages

- As interest in nationally-representative micronutrient status data increases and capacity to collect these data expands, best practices are needed to guide the design and implementation of micronutrient status surveys.
- Generating additional evidence on strengths and limitations of different survey models to obtain national micronutrient status data, including integrated approaches, is needed.
- It is important to consider the characteristics of the national survey in which micronutrient status assessment is to be integrated, as national surveys vary in size, complexity, and level of standardization.
- It is useful to start planning and coordinating early when integrating micronutrient status assessment into a national health survey.

Methods

Context

DHS surveys are nationally-representative household surveys that serve as a primary data source for population and health indicators in LMICs (72). The DHS Program has provided technical assistance to more than 300 surveys in over 90 countries (73). The DHS Program, funded by the United States Agency for International Development (USAID) and coordinated by ICF, works with participating countries and donors to conduct DHS surveys (72). The 2015-2016 MDHS was the fifth DHS survey conducted by the Government of Malawi and the first to attempt to integrate a micronutrient status survey. Many partners contributed to this effort: USAID, ICF, Centers for Disease Control and Prevention (CDC), United Nations Children's Fund (UNICEF), Irish Aid, World Bank, Emory University, UN Women, UNFPA, and the Malawi National AIDS Commission (58).

Informed by data from two previous MNS conducted in 2001 and 2009, the Government recognized micronutrient malnutrition as a major public health problem. The Government had identified data gaps and implemented nutrition interventions that they wanted to evaluate (e.g., targeted

micronutrient supplementation, nutrition education, and food fortification of staple foods). The MNS was designed to collect anthropometry and biologic specimens (venous blood and urine) to estimate the prevalence of anemia and micronutrient deficiencies (iron, vitamin A, iodine, zinc, vitamin B12, folate), inflammation, infection (malaria, urinary schistosomiasis), and inherited blood disorders. The MNS also was designed to estimate prevalence of households with adequately iodized salt, vitamin A fortified oil, and sugar by analyzing food samples; prevalence of household hunger; and coverage of social protection programs and key nutrition interventions (58). Survey population groups included preschool-aged children (6-59 months), school-aged children (5-14 years), women of reproductive age (15-49 years), and men (20-55 years) (58). Three other national surveys were scheduled for 2015 and 2016, and Government staff capacity would have been overextended by a concurrent stand-alone MNS. Hence, the Government endorsed combining the MNS with another survey, and ultimately determined that MDHS offered the best platform based on design, logistics, and estimated costs.

It was determined that the MNS would collect data in approximately 12 percent of MDHS clusters (58). The operational design involved linking the MDHS and MNS at three points. The first point occurred after finishing MDHS data collection in a cluster selected for MNS data collection when each field team would meet to go through a 'handover' process. MDHS field teams filled out sections of the MNS paper questionnaires with identification information for eligible individuals (names, ages, household label with a unique barcode, identification number) and handed these over to MNS field teams in each cluster. MNS field teams then used this information to proceed with data collection (58). Second, once all MDHS and MNS data collection was complete, the datasets were linked. Third, joint dissemination of results was planned. MDHS collected data electronically and MNS collected data on paper questionnaires. Details of the design and sampling methods of the MDHS and the linkage with MNS have been presented elsewhere (58, 59).

Participant recruitment

We used a purposive sampling strategy to recruit individuals from Government and international technical assistance and donor agencies with experience in all phases of the MDHS and MNS

implementation process. In addition, we recruited MDHS and MNS field team supervisors to provide supplementary data on the day-to-day issues encountered at the field level, which may not be identified in detail by Government and international agency staff (e.g., communication issues between MDHS and MNS field staff, community mobilization strategies, respondent consent process). We sent individual email requests for participation to Government and international agency staff and followed up at least three times where needed. We contacted field team members by phone and invited them to participate.

Our overall sample size was 24, which was sufficient to reach saturation across our sample as well as within the three stakeholder groups (Government, international agency, and field staff). We reached both code saturation (the point at which the range of thematic issues have been identified) and meaning saturation (the point at which a rich understanding of issues has been developed) (53). Within each stakeholder group, we recruited a sufficient number of participants to reach saturation on issues raised (Government, n=7; international agencies, n=10; field staff, n=7) (53, 74).

Data collection

We conducted 24 semi-structured, in-depth interviews to capture participants' experiences of MDHS and MNS implementation (74). Since we were interested in topics that participants may be unwilling to discuss openly in a group setting (e.g., challenges during preparation), individual interviews were the most suitable data collection method (54). We conducted interviews face-to-face whenever possible. Some interviews were conducted by telephone due to wide geographic variation in participants' locations and prohibitive cost of travel. Telephone interviews have been found to produce similar results compared to face-to-face interviews (75). The National Health Sciences Research Committee in Malawi granted ethical approval for the MDHS and MNS surveys. The project was also reviewed by the institutional review board of Emory University and was deemed nonhuman subjects research.

We used a semi-structured interview guide. The guide used for interviews with Government and international agency participants included a section on each implementation phase (preparation; data collection; and data analysis, reporting, and dissemination), while the guide for interviews with field staff only included the questions related to their contributions to the data collection phase. We asked open-

ended questions with follow-up probes to explore topics in depth and obtain detailed information. We used an inductive process of data collection to identify issues emerging from early data collection to refine questions and probes in subsequent interviews, thereby going deeper into each topic as data collection progressed (54). For example, because support for linking the MDHS and MNS from a high-level Government staff member emerged as important in initial interviews, we refined the interview guide for subsequent interviews to include a question about support from high-level Government staff. While we used this inductive process, all participants were asked the same key questions in the respective guides with only slight refinements in subsequent interviews to allow the interviewer to go deeper into issues identified as relevant by participants in early interviews.

Two interviewers were trained on best practices for qualitative interviewing, maintaining confidentiality, and the interview guide, and received re-training and technical assistance throughout data collection (54). Interviewers were involved in the MDHS and MNS in various capacities (e.g., logistics, technical assistance). All interviews were conducted in English, digitally recorded, and transcribed verbatim. Two interviews were not recorded due to recorder error; detailed notes were taken and included in the data. Textual data was managed in MAXQDA12.

Data analysis

We analyzed data using thematic analysis. We applied deductive and inductive strategies to identify issues, or 'codes', in the data, developed a codebook, and used MAXQDA12 software to code the data. We developed thick descriptions of codes and conducted structured comparisons of issues by various strata such as type of participant, agency (e.g., CDC versus USAID), and field team (MDHS versus MNS) (54). Next, we grouped codes into categories, which then became the sub-themes that were further organized into main themes. Finally, we explored links between codes and developed a conceptual diagram that depicts main themes and their relationships (55). To validate our analyses, we used two strategies. We reread data after drafting results and developing our conceptual diagram (Figure 4.2) to check that our findings were strongly grounded in the data (54). We also used the concept-indicator

model, which involved checking that there were codes that collectively represented the themes identified (76).

Results

We identified factors that influenced the operational design of the MDHS and MNS. Results also showed three main themes regarding what worked and what was challenging during implementation of the MDHS and MNS: (1) stakeholder buy-in; (2) management structure of the surveys; and (3) nutrition indicators and data quality. We describe each theme, presenting the varying perspectives among participants.

Rationale for the MDHS and MNS Operational Design

When a decision was made by the Government to attempt to integrate the MDHS and MNS, MDHS and MNS partners initiated coordination efforts, starting with a series of meetings to develop an operational design. When they came together, they decided the most feasible approach was to link the MDHS and MNS. Two key factors influenced this decision. First, once the Government decided to attempt to integrate the surveys, MDHS and MNS partners had already worked separately to plan and develop protocols for the respective surveys as stand-alone surveys. Thus, the planning and protocol development for each survey was at an advanced stage. A common sentiment among Government and international agency participants was that they would have preferred communication and coordination among MDHS and MNS partners to have started earlier, with one participant positing that planning together earlier might have allowed for a different operational design. Second, there was not enough time to incorporate MNS as a module within the MDHS core questionnaire given the size of the MNS questionnaire and number of biomarkers, complexity of specimen collection and processing, and cold chain requirements.

Stakeholder buy-in

Nearly every participant discussed some aspect of stakeholder buy-in for the MDHS and MNS. Eight influences on buy-in emerged (Table 4.1). Most Government participants believed there was strong

Government buy-in, mainly because a high-level Government staff member championed the effort to link the surveys and Government personnel convinced others with doubts that it was feasible. Several participants suggested the MDHS was a good platform for the MNS due to its design and collection of population and health data, but not all participants agreed. Many participants viewed buy-in from international technical assistance agencies as a major challenge, with some participants describing it as one of the greatest challenges. In particular, participants frequently discussed the difficulties in gaining support from The DHS Program staff. Perceived barriers to buy-in faced by The DHS Program staff included The DHS Program not having oversight of the MNS data collection and thus having limited knowledge of the MNS data quality, and the costs for The DHS Program (e.g., high investment in coordination). A common view was that those involved primarily in the MNS had more to gain from coordinating with the MDHS, such as leveraging MDHS infrastructure (e.g., sampling frame and household listing). A few international agency participants felt a sense of shared goals to link the MDHS and MNS was never fully achieved among all partners. Differential field staff allowances between MDHS and MNS field staff were reported to be additional barriers to perceiving the MDHS and MNS as one survey.

Survey management structure

The theme of survey management structure relates to the way in which the MDHS and MNS partners were organized. There were two Government Principal Investigators (PIs) – one from the National Statistical Office (NSO) who was responsible for the MDHS and coordination with the MNS, and one from the Community Health Sciences Unit (CHSU) who was responsible for the MNS. The Department of Nutrition, HIV and AIDS (DNHA) was a key Government partner focused on the MNS. USAID and ICF provided technical assistance for the MDHS, while CDC and Emory University provided technical assistance for the MNS. UNICEF provided support by procuring all MNS supplies. The overarching perception was that challenges related to this structure were the most significant among all

implementation challenges. We identified four sub-themes: structure to facilitate coordination; logistical interdependence between the MDHS and MNS; human resource investment; and decision-making.

Structure to facilitate coordination

The survey management structure required coordination between MDHS and MNS partners to plan and execute the surveys. There were two separate Steering Committees – one for MDHS and one for MNS. Some committee members overlapped between the two Steering Committees. The MDHS Steering Committee met at key decision points along the survey process, and the MNS Steering Committee met approximately every two weeks. There was consensus among Government and international agency participants that the Steering Committees were critical for enabling regular communication, with some participants finding that the Steering Committees promoted accountability by serving as a forum for following-up on tasks. Additionally, a few international agency participants perceived the Memorandum of Understanding between MDHS and MNS partners to define roles and outline a clear work plan to be useful. Some participants also highlighted the important role of the MNS Survey Coordinator. They observed that the MNS Survey Coordinator also worked on the MDHS and was up-to-date on MDHS activities, enabling effective coordination of the surveys.

Logistical interdependence between the MDHS and MNS

Government and international agency participants discussed ways in which the survey management structure of the MDHS and MNS, along with the operational design of linking the surveys, created logistical interdependence between the MDHS and MNS. Figure 4.1 depicts the tasks required to complete the MDHS and MNS, showing which tasks had to be completed before moving on to the next tasks and where delays in tasks occurred and, in turn, created scheduling issues or inefficiencies during implementation.

Almost all participants highlighted the delay in delivery of MNS supplies as a major challenge, with some participants pointing it out as one of the most significant challenges encountered during the

implementation of the MDHS and MNS. Many participants described the cascade of delays for the MNS that resulted from the delay in supply procurement, namely the training for field teams, pilot, and start of data collection. Also, because MNS field teams were following MDHS field teams, the MDHS field teams had to adjust their itinerary for data collection, which also incurred additional fieldwork costs for the MDHS. Specifically, MDHS field teams had to delay data collection in the subsample of clusters selected for inclusion in the MNS until the MNS field teams were ready to start data collection, which required changing the order of clusters visited. One Government participant summed it up this way: "Some materials and shipments for the MNS came late…and that actually threw the whole plan out of kilter." This obstacle was particularly stressful for participants from the Government and CDC who were trying to move as quickly as possible to ensure the MNS teams could align with the MDHS. They also recognized the immense strain and additional workload the delay in MNS supplies caused the MDHS. A few Government participants applauded the coordination between the MDHS and MNS partners to overcome the obstacle of delayed supplies and logistical complexities for the MNS teams to follow the MDHS teams. Some participants believed that if the delivery of MNS supplies had not been delayed, then the challenge of aligning the timelines of the surveys would have been significantly lessened.

Most participants described the difficulties in ensuring the pace between the MDHS and MNS field teams were in sync. Pacing was viewed by many Government and international agency participants as a highly complex process, with one participant likening it to a "complicated puzzle" and another questioning whether it was too sophisticated to implement well. Some of the pacing challenges were due to the change in the MDHS itinerary, resulting in the sequence of clusters not being as well matched to the movement of the MNS field teams as originally planned. Also, the surveys moved at different speeds. Thus, in some instances, the MDHS teams were delayed (e.g., due to running out of fuel, or tablets not functioning properly), which resulted in MNS teams having to wait. In other cases, the MNS teams were delayed, requiring the MDHS teams to wait. Several participants from the Government and international agencies pointed out that this waiting time reduced the efficiency of both the MDHS and MNS teams.

Furthermore, a few Government participants raised the issue of potential cost implications related to the MDHS teams having to go back to districts they had completed to collect data in MNS clusters. Most MDHS and MNS field staff highlighted pacing as a challenge, with over half describing feelings of pressure to match the pace of the other team.

Many participants discussed the difficulties of the handover process between MDHS and MNS teams, attributing these difficulties to two related issues. First, the teams attended separate trainings, and thus did not practice the handover process together. Once data collection began, not all MDHS team leads fully understood the correct way to fill out MNS questionnaires with eligibility information. Second, because there was no pilot of the handover process, the MDHS electronic program that generated information on eligibility was not field tested and a program error was not detected until data collection began. Participants also observed that since MDHS teams used an electronic program and MNS teams used paper-based forms, transferring eligibility information was difficult. Many participants would have preferred a joint training, pilot of the handover process, and electronic data collection for both teams.

The MNS Survey Coordinator and others strove to foster a shared purpose among MDHS and MNS field teams to facilitate effective coordination. One Government participant recalled: “We were trying as much as possible to create that relationships, that strong bond between the teams so that they could understand that we can’t do without the other. We [MDHS] can’t do without MNS and MNS can’t do without MDHS.” Participants generally viewed the coordination between MDHS and MNS teams to have worked very well, with many participants mentioning regular communication as a key facilitator.

Human resource investment

The predominant perception among Government and international agency participants was that MDHS and MNS implementation was resource intensive. Specifically, The DHS Program staff stressed the high time investment required from their staff to work with the MNS, frequently noting that the additional work associated with coordinating with the MNS was not adequately budgeted. One participant

with The DHS Program said, “The amount of time that DHS staff spent on integration-related work was pretty significant…On a spectrum from one to ten, ten spending a lot more time, one being low, Malawi was definitely nine or ten compared to other countries.” Several CDC participants echoed this point, highlighting that The DHS Program staff devoted substantial time to coordination on top of their MDHS specific responsibilities.

Decision-making

The sub-theme of decision-making relates to the chain of responsibility for making decisions about protocols and funds. Government and international agency participants reported difficulties in mobilizing funds quickly and receiving approval for protocol changes. For example, when MNS needed to purchase sugar to replace sugar samples collected from households, the purchase request had to be approved by those managing each survey, including the MNS PI and MDHS PI. One participant reported that this process was particularly difficult since those managing the MDHS often were unaware of the needs of the MNS. Other participants felt confused over who controlled the budget. Many participants believed having one management team could have improved decision-making processes.

Nutrition indicators and data quality

The theme of nutrition indicators and data quality is comprised of three sub-themes: duplication of nutrition indicators; community mobilization and response rates; and knowledge of MNS data quality.

Government and international agency participants pointed out that both the MDHS and MNS collected anthropometry and anemia. This duplication in data collection was perceived to be inefficient and an example of how the surveys were not fully integrated, as a fully integrated survey would collect these indicators once. Additionally, there were some marked differences in the results, which may have been due to differences in data collection methods used or the MNS sample being a small subsample of the MDHS, but which made data interpretation and utilization difficult at the country level (58, 59).

Some participants highlighted the advantage of having the MDHS field teams inform communities that MNS field teams were coming and gaining consent for participation in the MNS. Since MDHS teams had built rapport with traditional authorities, MNS teams did not have to spend much additional time on community mobilization. Participants reported that entering communities went smoothly for MNS teams and perceived the MNS consenting process to be more efficient.

For The DHS Program staff, a critical issue was that they did not have oversight over the MNS field work and knowledge of MNS data quality. This issue is particularly concerning since The DHS Program hosts the MNS data and report on their website. Additionally, they receive inquiries about MNS data from data users, and rather than handling them internally, they needed to forward them to CDC technical advisors for input. Several participants noted that had the surveys been truly integrated this would not have been an issue, as The DHS Program would have full oversight over data quality.

Lack of full integration

Overall, participants perceived many implementation challenges (including stakeholder buy-in, survey management structure, and issues regarding duplication in nutrition indicators and knowledge of MNS data quality) to be related to the lack of integration between the MDHS and MNS (Figure 4.2). Some participants explained that while the goal was to integrate the surveys, operationally the surveys seemed like two separate surveys. One international participant described it this way:

> "We kind of throw around the term 'integration', and people at different levels in Malawi wanted it. But I think what happened wasn't integration in the truest sense of the word. So, people would say, in country, "We want this to be integrated. This needs to be integrated." But I sense that there was quite a bit of disappointment that the trainings, for example, weren't joint trainings. So, I don't think what happened was exactly how people intended it to be. So, it was more of a compromised method and everybody kind of accepted it and did the best they

could with it, versus it being truly the approach that perhaps the country envisioned having."

While the lack of integration and its associated challenges were concerning for all participants, international agency participants voiced the deepest concern. Government participants readily acknowledged problems with the MDHS and MNS design, but ultimately were pleased that implementation challenges were overcome, and the country completed the surveys. They described feelings of pride and happiness that their goal of conducting the MDHS and MNS together was achieved. As one Government participant put it, "This opportunity [to conduct the MDHS and MNS] was a good opportunity that we had as a country, and we have to be very proud of it…For now, we are celebrating because we have all these things coming out despite the challenges, despite everything that we had, and despite being a learning ground. So, that's very great."

Most participants proposed that many implementation challenges would be avoided if the surveys were fully integrated. They offered an array of examples for ways to increase integration, such as having one Government agency managing the operations and budget, a lead technical assistance agency providing oversight, one supply procurement process, and joint training for MDHS and MNS field teams.

Discussion

For countries seeking to collect nationally-representative micronutrient status data, there are a variety of survey approaches. In Malawi, there was a strong Government interest to integrate micronutrient status assessment into a planned MDHS. Government participants described a range of perceived benefits from such an approach with MDHS, such as cost-savings, lower respondent burden, and a combined MDHS and MNS dataset. They also recognized the surveys were not fully integrated, as well as the related implementation challenges, and articulated a preference for full integration of the surveys. Nonetheless, they expressed great satisfaction that the MDHS and MNS was completed. Simultaneously, most international agency participants described MDHS and MNS implementation as highly complex and arduous, while recognizing the perceived advantages of linking the surveys from the

Government's perspective. It is worth noting that Malawi was one of the first countries to endeavor to integrate a national micronutrient status survey with a DHS. As with any new approach, there was a learning curve and unanticipated issues that arose. Nevertheless, the lack of full integration between surveys generated serious challenges throughout each survey phase.

The findings from Malawi provide a case example of the interest in integrated survey models, while also underscoring the broader need for identifying integrated survey designs that are efficient and satisfactory to all stakeholders. Furthermore, our results bring to light six key lessons that may be useful to consider when designing and implementing integrated survey models:

- Plan for integration early in the survey design phase: Planning and protocol development for the MDHS and MNS as stand-alone surveys were already at an advanced stage once the decision was made to attempt to integrate them. Joint planning among all partners early in the survey design phase may be a key factor for success in developing a more fully integrated survey design.
- Allow adequate time for integration planning: A major barrier to fully integrating the MDHS and MNS was insufficient time for planning, especially given the complexity of MNS and nature of DHS surveys. DHS surveys typically are planned more than one year in advance and are very large and standardized, as they collect extensive demographic and health data and have large sample sizes. As such, adequate time may be needed to accomplish critical planning tasks and activities, such as: gaining stakeholder support for integration; negotiating an affordable, feasible, and acceptable integrated design; and planning logistics.
- Consider costs and benefits of survey integration for all partners: Gaining support for the MDHS and MNS was challenging, in part, because not all partners benefited equally. To promote stakeholder buy-in for an integrated survey approach, it may be beneficial to identify benefits for all partners and find ways to reduce or compensate for additional costs associated with integration (e.g., budgeting staff time for integration-related activities).

- Create one survey management team: A significant challenge during MDHS and MNS implementation was the existence of two management teams. Having one survey management team may prevent coordination issues, streamline decision-making processes, and consolidate oversight and quality assurance activities.
- Allow ample lead time for procuring supplies: If the delivery of MNS supplies had not been delayed, then challenges with aligning the MDHS and MNS data collection timelines might have been minimized. Allowing sufficient time for supply procurement may be particularly important when integrating micronutrient assessment into another survey, since there may be little flexibility for delaying the entire survey due to delayed supplies for one component.
- Consider the characteristics of the survey in which micronutrient status assessment is to be integrated: National surveys vary in size, complexity, and level of standardization. In Malawi, integration was difficult, in part, because the MDHS was highly standardized and large, with its own complex logistics and data collection protocols. Understanding survey characteristics might provide insight into the level of difficult and time required for integration.

Our evaluation has several limitations. One challenge was determining timing of interviews, as MDHS and MNS implementation spanned over three years. We balanced the need to conduct interviews when participants could accurately recall their experiences and provide detailed responses, while also being able to discuss the full scope of their work from preparation to dissemination. We opted to stagger interviews (e.g., field staff who were only involved in data collection were interviewed soon after data collection ended). Also, while the cost of the MDHS and MNS was perceived to be an important issue among participants, a cost analysis was outside of the scope of this evaluation. However, we were able to explore perceptions of different dimensions of cost, such as time and money.

It is important to note that interviewers were involved in implementing the surveys, and thus, interviewers had met or worked with some of the participants who they interviewed. Participants potentially limited their responses due to perceived hierarchy or discomfort with sharing honest opinions with someone they knew. However, we emphasized confidentiality in their views and stressed our interest

in hearing honest opinions. We practiced reflexivity, which involved conscious self-reflection to acknowledge any potential influence on the evaluation due to familiarity or involvement, particularly during data collection and interpretation of findings (54, 77). Further, individuals from The DHS Program were not part of the evaluation team. The findings presented here are, therefore, not the result of a joint evaluation process with all partners. Notably, our sample did include individuals from The DHS Program to capture their perspectives. Several authors were interviewed for this evaluation given their roles as key personnel in the implementation of the MNS. However, these authors were not involved in data analysis or interpretation, which was conducted by the lead author independently of those interviewed.

The major strength of this evaluation is its contribution to the small evidence base on micronutrient status survey implementation. Additionally, we captured a diversity of perspectives by sampling participants across multiple stakeholder groups. We also explored implementation issues in-depth by using qualitative interviews and employing an inductive data collection process.

Conclusion

This evaluation makes an important contribution by exploring the experience of linking a micronutrient status survey with a DHS survey in Malawi. The findings can inform decisions about the design and implementation of the next MNS specified in the 2018-2022 National Multi-Sector Nutrition Strategic Plan (12). The results also may be useful to other LMICs that are considering incorporating micronutrient status assessment into national surveys. Altogether, our findings point to the need for more attention on methodologies that could be used to close nutrition data gaps. It is our hope that this paper stimulates implementation research, including rigorous process evaluations and cost analyses, on approaches for collecting nationally-representative micronutrient status data in different settings.

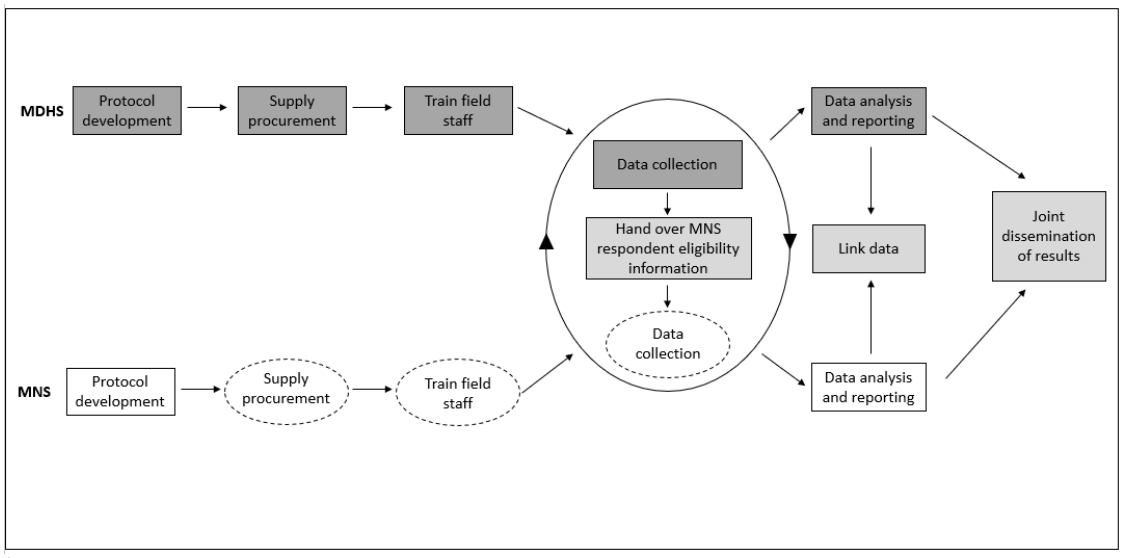
Chapter 4 Tables and Figures

Table 4.1: Influences on stakeholder buy-in for MDHS and MNS

Influences	**Illustrative example**
Champion	Some Government participants stressed that having a high-level champion for the MDHS and MNS within the Government was critical. They described the vital role the Commissioner of Statistics played in building consensus around linking the MDHS and MNS across Government agencies.
Belief in feasibility	There were divergent views on the feasibility of combining MDHS and MNS among Government staff initially – some Government staff believed linking the MDHS and MNS was feasible, while others were not as confident in the approach. Government participants who were initially unsure about the feasibility attributed their hesitation to the lack of examples of the approach from which to learn and no precedent for the approach in Malawi. Ultimately, they were convinced it was feasible by other Government staff and accepted the plan to move forward with linking the MHDS and MNS.
Interest in micronutrient biomarker and program data	Views on the importance of the micronutrient status data collected by MNS affected buy-in for Government participants, as well as participants from international agencies. On the one hand, some participants, including those primarily involved in MNS as well as others, described a strong interest in MNS results (e.g., to provide up-to-date data on the nutrition situation in Malawi and to support the case for investment in nutrition interventions). For these participants, they were open to, and in some cases advocated for, linking the MDHS and MNS. On the other hand, one international agency participant reported that the justification for the number of micronutrient biomarkers included in the MNS was unclear and questioned whether nutrition was a priority topic for The DHS Program, particularly given the number of requests routinely received for including other health topics.
Perceived costs and benefits	Some participants described the perceived value of linking the MDHS and MNS that accrued to partners as important for buy-in. For many participants, an overarching perception was that there were a variety of advantages. Government participants generally believed that conducting the MNS and MDHS jointly would save money and increase efficiency for Government staff supporting both surveys. Some Government participants also viewed it as an opportunity for the Government to ensure the sustainability of the MNS, given that MDHS is conducted approximately every five years. Many participants believed that conducting MDHS and MNS together would reduce respondent burden. Participants who were primarily involved in MNS also described benefits. For example, linking the MDHS and MNS datasets expands opportunities for further analyses, as the combined MDHS and MNS dataset includes nutrition data along with MDHS data on a wide range of topics. Also, given that MDHS is a widely used resource among policy makers and academics, disseminating MNS results with MDHS results could increase attention on nutrition indicators. Additionally, the MNS could leverage the infrastructure of the MDHS, including the sampling frame and household listing. However, many international agency and Government participants mentioned

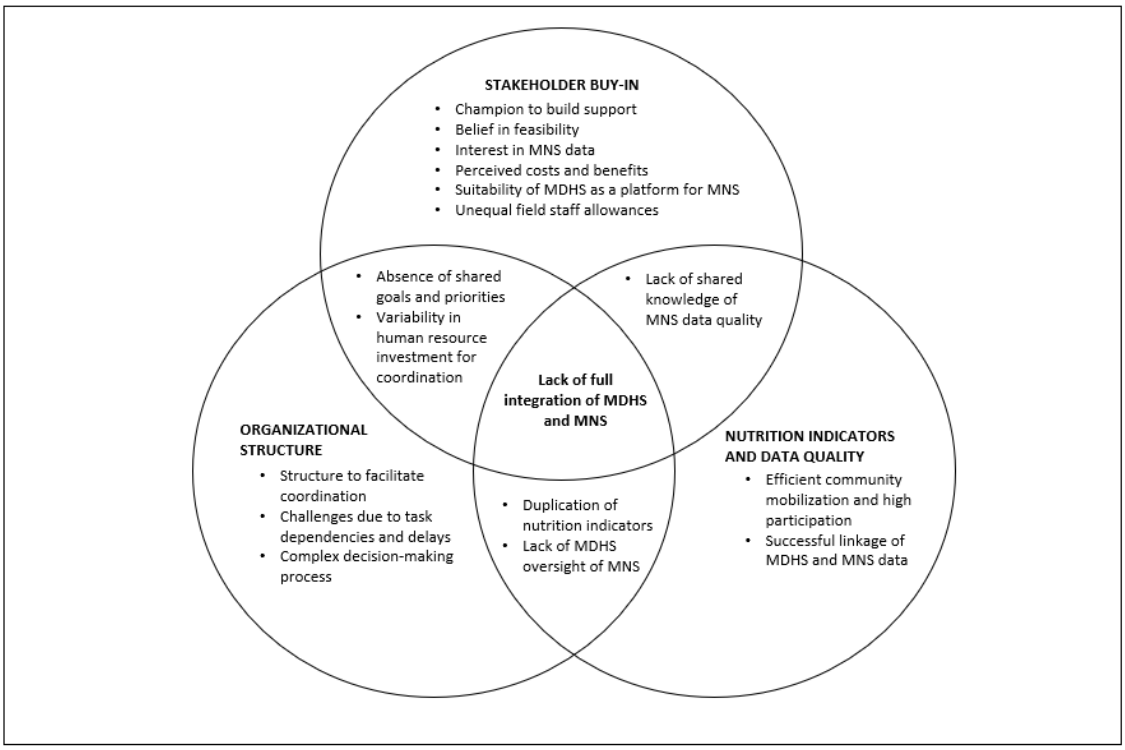
	that there were no perceived benefits to MDHS and, in fact, there were substantial costs given the additional effort required for linking the two surveys.
Suitability of MDHS as a platform for micronutrient status data	Several participants discussed the suitability of MDHS as a platform for including a broad suite of micronutrient status data. Most participants who discussed the issue of suitability viewed MDHS as an optimal platform, given the existing MDHS infrastructure to collect nationally representative data on a range of demographic and health topics. However, one international agency participant who viewed DHS as a social science survey did not believe the large variety of micronutrient biomarkers collected by MNS was suitable for MDHS.
Knowledge of MNS data quality	The survey management structure meant that The DHS Program provided technical assistance for the MDHS, while the CDC provided technical assistance for the MNS. Among those from The DHS Program, a major concern was the lack of oversight of the MNS planning and field work, as they were unable to speak to the quality of the MNS data as a result. This was viewed as highly problematic given that they host the MNS report on their website and receive inquiries from data users about MNS data. Per a request from ICF, CDC assumed the task of fielding all MNS data inquiries. One participant noted that individuals from CDC shared concern that The DHS Program did not participate in any data quality checks for the MNS.
Partners' priorities	Several international participants observed that there was not a sense of shared goals to complete the MDHS and MNS. Instead, they perceived that those primarily involved in the MDHS prioritized MDHS tasks and those primarily involved in the MNS prioritized MNS tasks. One participant attributed this to the survey management structure, which necessitated that some people take responsibility for the MDHS and others take responsibility for MNS. One international participant described it this way: "My feeling was that people felt like they either had primary allegiance to the MDHS or to the MNS. And though, while most people wanted both to occur, there was this sense of priority. Everybody had their priority."
Field staff allowances	Field staff frequently described dissatisfaction with the difference in the allowance amounts received by MDHS and MNS field staff, with many noting that they would have preferred to receive equal allowances. The different allowance amounts were reported to make it harder for the MDHS and MNS field staff to view themselves as part of one survey.

Figure 4.1: Tasks and task dependencies of the 2015-2016 Malawi Demographic and Health Survey and 2015-2016 Malawi Micronutrient Survey[1]



[1]Circled dash-lined tasks show where delays occurred and, in turn, created scheduling issues or inefficiencies.

Figure 4.2: Key domains of implementation issues of the 2015-2016 Malawi Demographic and Health Survey and 2015-2016 Malawi Micronutrient Survey[1]



[1] MDHS refers to the 2015-2016 Malawi Demographic and Health Survey. MNS refers to the 2015-2016 Malawi Micronutrient Survey.

Chapter 5: Recent Trends in Under- and Overweight, Anemia, and Micronutrient Deficiencies among Women in Malawi

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Abstract

Background: Malawi is one of the few low- and middle-income countries that has routinely collected nationally-representative data on micronutrient status in addition to data on body mass index (BMI) and anemia, and thus provides an opportunity for evaluating national trends in multiple forms of malnutrition among women in a low-resource setting.

Objective: We examined trends in the national prevalence of underweight, overweight and obesity, anemia, iron deficiency, and vitamin A deficiency among non-pregnant women aged 15-45 years in Malawi from 2001 to 2015-2016.

Methods: We used data from three cross-sectional, nationally-representative Malawi Micronutrient Surveys (MNS's) conducted in 2001, 2009, and 2015-16. For each survey year, we estimated the weighted prevalence of underweight (BMI <18.5 kg/m^2), overweight (BMI 25.0-29.9 kg/m^2), obesity ($\geq$ 30 kg/m^2), anemia (altitude-adjusted hemoglobin <12.0 g/dL), iron deficiency (unadjusted sTfR >8.3 mg/L or inflammation-adjusted ferritin <15 μg/L), and vitamin A deficiency (retinol or retinol-calibrated retinol binding protein < 0.7 μmol/L). To test for linear

trends, we used logistic regression models to estimate the log odds of each condition of malnutrition as a function of time, controlling for age.

Results: From 2001 through 2015-16, the prevalence of underweight in women increased (2001: 7.5% [95% CI: 4.6, 10.4], 2009: 5.2% [95% CI: 2.9, 7.4], 2015-16: 9.8% [95% CI: 7.6, 12.0], p=0.01), and the prevalence of overweight or obesity did not change (2001: 9.6% [95% CI: 6.9, 12.2], 2009: 14.4% [95% CI: 10.6, 18.2], 2015-16: 13.4% [95% CI: 9.9, 16.9], p=0.70). Anemia prevalence significantly decreased over time (2001: 27.0% [95% CI: 22.1, 31.8], 2009: 36.9% [95% CI: 32.2, 41.5], 2015-16: 22.4% [95% CI: 18.5, 26.3], p<.0001). The prevalence of iron deficiency using the sTfr definition did not change (2001: 31.5% [95% CI: 26.3, 36.7], 2009: 27.1% [95% CI: 22.8, 31.5], 2015-16: 24.8% [95% CI: 20.8, 28.7], p=0.44). Between 2009 and 2015-16, the prevalence of iron deficiency using the ferritin definition also did not change (2009: 15.3% [95% CI: 12.0, 18.7], 2015-16: 15.7% [95% CI: 12.3, 19.0], p=0.97). The prevalence of vitamin A deficiency decreased substantially from 2001 through 2015-16 (2001: 58.6% [95% CI: 52.2, 65.1], 2009: 1.4% [95% CI: 0.6, 2.3], 2015-16: 0.3% [95% CI: -0.1, 0.8], p<.0001).

Conclusions: Problems of undernutrition among women in Malawi persist, and in the case of underweight, may be worsening. At the same time, more than one in ten women are overweight or obese. These findings can inform policy making in Malawi, especially as the country strives toward achieving Sustainable Development Goal 2 to end all forms of malnutrition.

Introduction

Increasingly, low- and middle-income countries are facing a double burden of malnutrition, characterized by the co-existence of undernutrition and overweight, obesity, and diet-related non-communicable diseases (NCDs) (1). Addressing this double burden of malnutrition represents an enormous public health challenge and has become a focus of the United Nations global health agenda. In 2015, the United Nations set a target to end all forms of malnutrition by 2030, as part of Sustainable Development Goal 2, ‘End Hunger’ (1). In 2016, the

United Nations General Assembly launched a Decade of Action on Nutrition spanning from 2016 to 2025, which seeks to strengthen action around eliminating all forms of malnutrition globally (1). As low- and middle-income countries seek to address the double burden of malnutrition, an important first step for countries is to understand national trends in conditions of under- and overnutrition in order to assess progress, set national priorities for nutrition programming, and target health resources effectively.

Malawi is one of the few low- and middle-income countries that offers an opportunity for evaluating national trends in multiple forms of undernutrition and overweight and obesity among women in a low-resource setting. Malawi is unique in its routine collection of nationally-representative data on micronutrient status in addition to data on weight status and anemia. Malawi Micronutrient Surveys (MNS's) were conducted in 2001, 2009, and 2015-16 (58). Furthermore, evaluating trends in women's nutritional status is timely given recent action by the Government of Malawi. The Government established a Food and Nutrition Security Policy in 2005 and implemented a National Nutrition Policy and Strategic Plan between 2007 and 2015, with women identified as a key target group for programming (12). In addition, as part of the 2003-2008 National Plan of Action for the Prevention and Control of Micronutrient Malnutrition, the Government implemented interventions to reduce micronutrient deficiencies in women, such as dietary diversification programming and iron supplementation (78). The Government also has prioritized reducing vitamin A deficiency through mandatory fortification of sugar and centrally milled wheat and maize flours with vitamin A. Most recently, the Government of Malawi's 2018-2022 National Multi-Sector Nutrition Strategic Plan was established to renew its commitment to addressing malnutrition (12). Objectives of this Plan include improving women's nutritional status by promoting women's empowerment, implementing iron-folate supplementation programs, and increasing access to services for prevention of nutrition-related NCDs (12). Evaluating trends in the nutritional status of Malawian women can assist in assessing progress to date and inform nutrition programs and policy decisions going forward. Increasing urbanization

and steady economic development in Malawi provide further impetus for evaluating recent trends, as these macrolevel changes are related to shifts in dietary intake and physical activity, which may drive increases in overweight and obesity (17, 19).

The objective of this study was to examine national trends in the prevalence of underweight, overweight and obesity, anemia and iron deficiency anemia, iron deficiency, and vitamin A deficiency and insufficiency among non-pregnant women of reproductive age in Malawi from 2001 through 2015-2016. We are assessing these forms of malnutrition because they were the targets of nutrition initiatives in Malawi between 2001 and 2015-16, and are currently a focus of interventions being implemented as part of the 2018-2022 National Multi-Sector Nutrition Strategic Plan (12).

Methods

Data sources and study population

We used data from three Malawi Micronutrient Surveys (MNS's) conducted in 2001, 2009, and 2015-16. 2001 is the first year when MNS data were available, and 2015-16 provided the most recently available MNS data. Details of the methodology of the MNS's have been presented elsewhere (58). In brief, all MNS's were designed to be nationally representative and employed a two-stage cluster sampling design. Also, all MNS's collected anthropometric and micronutrient status data. Response rates for participation among women were 74% in 2001, 94% in 2009, and 90% in 2015-2016. Analyses were limited to women aged 15-45 because 45 was the upper age limit in the 2001 MNS. Thus, we excluded 32 and 45 women aged 46-49 in 2009 and 2015-16, respectively. We also excluded pregnant women (2001, n=70; 2009, n=77; 2015-2016, n=34), and women for whom pregnancy status was not known (2001, n=9; 2009, n=23; 2015-2016, n=14).

Biologically implausible BMI values (beyond 5 standard deviations from reference means; 2001: n=4, 2009: n=2, 2015-16: n=3) were set to missing. Complete anthropometric and

micronutrient status data were available for 74% of women (n=335/450) in 2001 and 95% of women (n=703/737) in 2015-2016. In 2009, 86% of women (n=533/623) had complete anthropometric data. Data on iron and vitamin A status only were available for a subsample of women in 2009, and of these women, 89% (n=438/492) had complete data on iron and vitamin A status. These data on iron and vitamin A status for 2009 were in a separate data set than the data set containing anthropometric data for 2009.

The multiple imputation procedure in SAS statistical software (PROC MI) was used to impute missing data (63, 64). For each of the four MNS data sets, 50 imputed datasets were created. In the imputation procedure, we included all socio-demographic variables (age, wealth, education level, residence) and anthropometric and biomarker variables (63), except for when imputing values missing in the 2009 micronutrients data set since not all socio-demographic variables were available in the data set. To deal with non-normally distributed variables, we used log transformations (62). These variables were back-transformed before analysis.

Measures of nutritional status

Anthropometry measurement methodology did not differ across the 2001, 2009, and 2015 MNS's. A digital floor scale (SECA brand) was used to measure weight to the nearest 0.1 kilogram (kg), and a wooden stadiometer (ShorrBoard® brand) was used to measure height to the nearest 0.1 centimeter. We used body mass index (BMI) to classify women into four weight categories, using the WHO cutoff points: underweight (< 18.5 kg/m^2), normal (18.5 – 24.9 kg/m^2), overweight (25.0 – 29.9 kg/m^2), and obese ($\geq$ 30.0 kg/m^2) (79).

In the 2001 and 2009 MNS's the HemoCue 201 model was used to measure anemia, and in the 2015-16 MNS anemia was measured using the HemoCue 301 model. In 2001 and 2009, whole blood for measuring hemoglobin concentrations was collected from a capillary finger stick, compared to venous blood in 2015-16. Anemia among non-pregnant women was defined as hemoglobin concentrations adjusted for altitude < 12.0 g/dL. Iron deficiency was defined two

ways. In the 2001, 2009, and 2015-16 MNS's, iron deficiency was defined as serum soluble transferrin receptor (sTfR) not adjusted for inflammation > 8.3 mg/L for results that were obtained using the In-house sandwich ELISA assay from the VitMin Laboratory (80). In the 2009 and 2015-16 MNS's, data on serum ferritin and biomarkers for inflammation (CRP and AGP) were available. Thus, for 2009 and 2015-16, we also examined iron deficiency defined as serum ferritin adjusted for inflammation < 15 μg/L (81). Ferritin is an acute phase protein, and serum ferritin levels increase during inflammation (38, 60, 61). Thus, inflammation can affect serum ferritin concentrations and result in inaccurate prevalence estimates of iron deficiency in a population (38, 61). Using a regression-correction approach, we adjusted for inflammation as measured by concentrations of C-reactive protein (CRP), a measure of acute inflammation, and α1-acid glycoprotein (AGP), a measure of chronic inflammation (38). The regression-correction approach uses linear regression to adjust the serum ferritin concentration by CRP and AGP concentrations on a continuous scale (38). Adjusting for inflammation results in an increase in the estimated prevalence of iron deficiency defined using ferritin concentrations (38). It is thought that prevalence estimates of inflammation-corrected iron deficiency are more accurate (38). Serum ferritin concentrations reflect iron stores (61), and sTfR levels are an indicator of the balance between cellular iron requirements and iron supply (60). According to the World Health Organization, ferritin is the preferred indicator of iron status, but sTfR also can be used (60). In addition, iron deficiency anemia was defined two ways. It was defined as iron deficiency (using sTfR) plus anemia in each survey year, and as iron deficiency (using inflammation-corrected ferritin) plus anemia in 2009 and 2015-16.

For 2001, vitamin A deficiency was defined as serum retinol < 0.7 μmol/L. For 2009 and 2015-2016, retinol binding protein (RBP) was measured, as a proxy for retinol, in all participants, and retinol was measured in a subsample of participants. Given that the ratio of RBP:retinol is not always 1:1, we used linear regression to estimate population-specific cut-offs for RBP that correspond to retinol cut-offs for vitamin A deficiency (82). For 2009, vitamin A deficiency was

defined as serum RBP < 0.78 µmol/L (78). For 2015-16, vitamin A deficiency was defined as serum RBP < 0.46 µmol/L (58). RBP concentrations were not adjusted for inflammation, given that the correlations between RBP and CRP and AGP in women have been found to be too weak to justify an inflammation-adjustment approach (83). In sub-analyses, we evaluated trends in the prevalence of vitamin A insufficiency in women. For 2001, vitamin A insufficiency was defined as retinol $\geq$ 0.7 to < 1.05 µmol/L. For 2009, vitamin A insufficiency was defined as serum RBP $\geq$ 0.78 to < 1.14 µmol/L. For 2015-16, vitamin A insufficiency was defined as serum RBP $\geq$ 0.46 to < 0.86 µmol/L.

Statistical analysis

For each survey year, we obtained point estimates and 95% CIs for the prevalence of underweight, overweight, obesity, overweight or obesity, anemia, iron deficiency anemia, iron deficiency, vitamin A deficiency, and vitamin A insufficiency. To characterize changes in each condition of malnutrition over time, we used logistic regression models to test for linear trends. We estimated the log odds of each condition of malnutrition as a function of time, with time treated as a continuous predictor. Because the observed time points for this analysis are unequally spaced, values that take this into account were used to represent each survey year (i.e., 2001 was recoded as 1, 2009 was recoded as 9, and 2015-2016 was recoded as 15.5). All logistic regression models included age as a categorical covariate to control for changes in the underlying age distributions over time. If the p-value for the time variable was < 0.05, then we concluded that there was evidence of a linear change. If the associated beta for the significant linear time variable was negative, we determined there was evidence of a linear decrease; if the associated beta was positive, we concluded there was evidence of a linear increase. Variables for residence, education, and socio-economic status were not included in the logistic regression models as covariates, due to these variables not being available in the 2009 data set containing micronutrient status data. We conducted similar analyses for socio-demographic variables residence, education,

and age. We did not evaluate change over time in socioeconomic status, because this variable was measured in the same manner across survey years.

In addition, we conducted a complete case analysis in which we generated point estimates and 95% CIs for all conditions of malnutrition using data from the sample of women with no missing values. Also, using the imputed data sets, we generated age-standardized prevalence estimates and 95% CIs for all malnutrition conditions. These estimates were age standardized by the direct method to the 2008 Malawi Census population using the following age ranges and weights: 15-29 years, weight, 0.6328; 30-39 years, weight, 0.2352; 30-49 years, weight, 0.1321. For all analyses, we used survey weights to account for unequal probabilities of selection and accounted for the stratified, clustered design of the surveys. Data were analyzed using SAS 9.4 (SAS Institute, Inc, Cary, North Carolina).

Results

Table 5.1 presents demographic characteristics of non-pregnant Malawian women aged 15 to 45 years by survey year. Across survey years, a greater proportion of women resided in rural areas compared to urban areas. The proportion of women with a secondary education or more was 13.5%, 19.1%, and 20.9% in 2001, 2009, and 2015-16 respectively. The mean age was 27.4, 27.9, and 27.3 in 2001, 2009, and 2015-16, respectively. No changes in these demographic characteristics were found from 2001 through 2015-16. More than one third of women were categorized as having low socioeconomic status in 2001, 2009, and 2015-16, though comparability is limited due to socioeconomic status not being measured consistently across survey years.

Nationally-representative prevalence estimates for indicators of under- and overnutrition in 2001, 2009, and 2015-16 are presented in Table 5.2. The prevalence of underweight in women significantly increased from 7.5% (95% CI: 4.6, 10.4) in 2001 to 9.8% (95% CI: 7.6, 12.0) in 2015-16 ($p=0.0135$ for trend). Overweight prevalence in women did not change from 2001 (7.9%

[95% CI: 5.3, 10.5]) through 2015-16 (10.5% [95% CI: 7.3, 13.6]). The prevalence of obesity in women also did not change from 2001 (1.7% [95% CI: 0.3, 3.0]) through 2015-16 (2.9% [95% CI: 1.3, 4.5]). Similarly, the increase in the prevalence of overweight or obesity in women was not statistically significant (2001: 9.6% [95% CI: 6.9, 12.2], 2015-16: 13.4% [95% CI: 9.9, 16.9], p=0.70).

Anemia prevalence in women significantly decreased from 27% (95% CI: 22.1, 31.8) in 2001 to 22.4% (95% CI: 18.5, 26.3) in 2015-16 (p <.0001 for trend). However, the prevalence of iron deficiency anemia, using the sTfR definition for iron deficiency, did not change from 2001 (11.4% [95% CI: 8.0, 14.9]) through 2015-2016 (9.8% [95% CI: 7.3, 12.3]). The prevalence of iron deficiency using the sTfR definition in women was 31.5% (95% CI: 26.3, 36.7) in 2001 and 24.8% (95% CI: 20.8, 28.7) in 2015-16, but the decrease in prevalence was not statistically significant. Similarly, the prevalence of iron deficiency anemia, using the inflammation-corrected ferritin definition for iron deficiency, did not change between 2009 (7.1% [95% CI: 4.9, 9.3]) and 2015-16 (8.1% [95% CI: 5.5, 10.6]). Iron deficiency using the inflammation-corrected ferritin definition also did not change from 2009 (15.3% [95% CI: 12.0, 18.7]) to 2015-16 (15.7% [95% CI: 12.3, 19.0]). The prevalence of vitamin A deficiency decreased substantially from 58.6% (95% CI: 52.2, 65.1) in 2001 to 0.3% (95% CI: -0.1, 0.8) in 2015-16 (p <.0001 for trend). There also was a statistically significant decreasing trend in vitamin A insufficiency prevalence from 2001 (32.5% [95% CI: 27.4, 37.6]) through 2015-16 (5.3% [95% CI: 3.1, 7.4]) (p <.0001 for trend). The weighted prevalence estimates of conditions of malnutrition generated using multiple imputation were similar to results based on a complete case analysis, as well as age-standardized results (Supplemental Tables 5.1 and 5.2).

Discussion

The decreasing trend in the prevalence of anemia, vitamin A deficiency, and vitamin A insufficiency from 2001 through 2015-16 illustrates that Malawi is making progress on reducing

forms of undernutrition. On the other hand, the prevalence of iron deficiency anemia and iron deficiency did not change. With regards to weight status, a positive finding of our analysis was that overweight and obesity prevalence did not change. However, we found that the problem of underweight may be worsening.

The finding that the prevalence of overweight and obesity did not change among women in Malawi differs from global trends, as well as trends documented in other low- and middle-income countries. Globally, age-standardized obesity prevalence in women increased from 6.4% in 1975 to 14.9% 2014. According to the results of a systematic analysis, overweight prevalence in women worldwide increased from 29.8% to 38.0% between 1980 and 2013 (31). A study using data from nationally representative surveys conducted in 33 low- and middle-income countries found that overweight prevalence was increasing in the majority of countries (4). Of note, however, is that it is difficult to make direct comparisons across studies given the different time periods evaluated. However, given that evidence consistently shows that the prevalence of overweight and obesity has been increasing in all regions (3), it is notable that Malawi has not experienced a rise in overweight and obesity. It is possible that national estimates masked subnational trends, such as trends according to urban-rural residence, particularly given that Malawi is largely rural and the proportion of women residing in rural areas in our sample was substantially greater than the proportion of women in urban areas.

Notably, we found a significant increase in underweight prevalence in women. This finding is not directly comparable to previous studies, since previous studies evaluated trends in underweight prevalence across urban and rural areas, while we assessed national trends. However, a previous study that assessed the annualized change in underweight prevalence in women residing in urban areas found that Malawi experienced a “flip”, whereby underweight prevalence decreased in the 1990s to early 2000s but increased more recently (4). Widespread food insecurity may be one factor underlying this trend in underweight prevalence. In 2015-16, over 60% of households in Malawi experienced moderate to severe household hunger (58), which

may result in reduced diet quantity and inadequate total calories, thereby increasing women's risk of underweight (84). The increase in underweight prevalence observed in Malawi differs from global trends, though comparability is limited by the fact that different time periods were assessed in studies of global trends. Between 1975 and 2014, global age-standardized underweight prevalence in women decreased from 14.6% to 9.7% (30). Moreover, in South Asia, where underweight prevalence was 24% in 2014 and the highest in the world, age-standardized underweight prevalence declined from 1975 to 2014 (30). There is some evidence that the prevalence of underweight has recently increased among women residing in rural areas in China, Mexico, Cameroon, and Tanzania, and among women in urban areas in Bolivia (4).

Results related to micronutrient status were overall positive, in particular significant improvements in the prevalence of anemia. The reduction in anemia prevalence observed in Malawi are aligned with global trends. From 1995 to 2011, global prevalence of anemia in non-pregnant women decreased from 33% to 29% (85). Across low- and middle-income countries, there is substantial variation in anemia prevalence, with the prevalence of anemia in women reaching as high as 61% in Benin and less than 20% in Honduras (86). A study that analyzed data from nationally representative Demographic and Health Surveys from 32 low- and middle-income countries found that in a third of countries half or more women had anemia (86). Thus, the finding that less than a quarter of Malawian women had anemia and anemia prevalence was declining bodes well for Malawi, especially given that Africa has the highest prevalence of anemia (86). However, a notable finding was that improvements in anemia may not be the result of changes in iron status, since the prevalence of iron deficiency anemia and the prevalence of iron deficiency did not concurrently decrease. Because vitamin A deficiency and insufficiency is associated with anemia (41), it is possible that the declines in anemia were related to improvements in vitamin A status. The burden of infection, such as HIV and malaria, does not appear to explain the decline in the prevalence of anemia, given that both the prevalence of malaria and HIV prevalence in women appears to have remained relatively stable over the last

fifteen years (57-59). Research is needed to investigate the determinants of anemia among Malawian women, including nutritional and non-nutritional factors such as malaria, HIV, and chronic disease (86), which may shed light on the reasons for the decrease in anemia prevalence. Data collected from the 2015-16 could be used to assess anemia determinants (58).

Our finding that the prevalence of vitamin A deficiency and vitamin A insufficiency decreased over time was not surprising, given that the Malawi Government has focused substantial effort and resources toward improving vitamin A status in the population. Mandatory fortification of sugar and centrally milled wheat and maize flours with vitamin A in Malawi may have played a role, though the greatest reductions in vitamin A deficiency and insufficiency were seen between 2001 and 2009 and fortification may not have been implemented at scale during that time (87). For example, trial fortification of sugar began in parts of the country in 2009, but it wasn't until 2012 that the only sugar producer at the time began to routinely fortify sugar voluntarily (87). Also, sugar fortification became mandatory only recently in 2015 (87). Fortification of vegetable oil with vitamin A also may have contributed to improvements in vitamin A status, though fortification of oil was not mandatory until 2016 (87). In 2015-16, 74% of households in Malawi had sugar and 77% had oil, but only 24% of sugar and 6% of oil were labelled as fortified (58). That same year less than 12% of households had adequately fortified oil in 2015-16; however, 58% of households had adequately fortified sugar (58). Analyses of the coverage of fortified foods over time may shed light on the contribution of fortification to improvements in vitamin A status. Future research on the quantity and frequency of women's consumption of these fortified foods also would be useful for gaining a better understanding of the role of food fortification. The role of dietary intake of vitamin A on women's vitamin A status is underexplored in Malawi. An analysis of household expenditure data showed that consumption of vitamin A in Malawi decreased nationwide primarily due to reduced consumption of green leafy vegetables (88), but these results cannot be used to make conclusions about women's dietary intake. Thus, research is needed to explore factors associated with vitamin A status, such

as presence of fortified sugar or oil in the household and dietary intake of vitamin A rich foods. A positive deviance analysis to explore why the level of vitamin A deficiency in Malawian women was lower than levels found in other low- and middle-income countries would be useful for informing strategies to improve vitamin A in other contexts. Furthermore, given the low prevalence of vitamin A deficiency and insufficiency in Malawian women and programs and policies to improve vitamin A status, future studies to evaluate potential vitamin A toxicity in Malawian women are warranted.

There are limitations to our analysis. First, data from the 2001 and 2009 MNS's had substantial missing data on demographic characteristics and nutritional indicators. However, we used multiple imputation to address the problem of missing data and improve the validity of our results (62). Second, data on all socio-demographic characteristics were not available in the 2009 data set with anemia and micronutrient status data. Thus, it was not possible to control for socio-demographic variables in our analyses beyond age. A related limitation was that we could not explore the potential influence of these demographic characteristics on changes in nutritional status over time. Third, there were differences in the indicators included in the 2001, 2009, and 2015-16 MNS, as well as some variation in methods for data collection, measurement, and laboratory analyses. The HemoCue 201 model was used to measure hemoglobin in the 2001 and 2009 MNS's, while the HemoCue 301 model was used in the 2015-16 MNS. Some studies have shown that these models may not produce the same results, but the differences are minimal and the evidence is mixed (89). It is also important to note that capillary blood samples were used to measure hemoglobin in 2001 and 2009, compared to venous blood samples in 2015-16. Whitehead et al. found that the difference in hemoglobin results in capillary blood samples were slightly higher than in venous blood samples, but concluded that the difference was too small to be of relevance from a clinical perspective (89). A separate study found no significant difference in hemoglobin results between venous and capillary blood samples (89). Another limitation was that ferritin was measured in 2009 and 2015-16 only, hindering our ability to evaluate trends in

iron deficiency and iron deficiency anemia using the ferritin definition throughout the entire study period. However, sTfR was available for each survey year, which allowed for assessment of trends in iron deficiency and iron deficiency anemia using the sTfR definition from 2001 through 2015-16. Our findings that there were no significant declines in iron deficiency and iron deficiency anemia were consistent across both indicators of iron status. There were also differences in the indicators of vitamin A status, with serum retinol measured in 2001 and RBP measured in 2009 and 2015-16. Because retinol was measured in a subsample of participants in 2009 and 2015-16, we were able to estimate population-specific cut-offs for RBP that correspond to retinol cut-offs for vitamin A deficiency and insufficiency (82). Finally, we examined national trends in women's nutritional status, which may obscure trends at subnational levels (4, 90). Analyses are needed to understand how trends in women's nutritional status vary across urban and rural areas in order to inform program planning and targeting of health resources. Moreover, future studies should evaluate trends in the prevalence of overweight and obesity among subpopulations of women of reproductive age, such as younger women aged 15 to 19 and older women, given the influence of age and parity on weight status (91-95). However, information on national trends in women's nutritional status provided by this study is readily usable by policy makers in Malawi.

The present study has several strengths. We analyzed nationally representative data based on samples of non-pregnant women of reproductive age collected from three MNS's, including the most recent data from the 2015-16 MNS. This allowed for the investigation of trends in women's nutritional status over time using the most recent data available. A major strength of this analysis was that it assessed trends in anemia and micronutrient deficiencies and insufficiencies based on biomarker data. In addition, because inflammation affects serum ferritin concentrations, we used a regression-correction approach to adjust serum ferritin for inflammation as measured by CRP and AGP concentrations (38). This approach has been shown to ameliorate the confounding effects of inflammation on prevalence estimates of iron deficiency when serum

ferritin is used as an indicator of iron status (38). Also, prevalence estimates of underweight, overweight, and obesity were based on BMI values calculated using directly measured weight and height.

In conclusion, this study provides the most up-to-date and comprehensive information on trends in the prevalence of conditions of under- and overnutrition among women in Malawi. Since micronutrient status data are not routinely collected in low- and middle-income countries, this is one of the few studies to assess trends in micronutrient deficiencies in a low-resource setting. Our findings can inform policy making in Malawi, especially as the country strives toward achieving Sustainable Development Goal 2 to end all forms of malnutrition. Malawi is well positioned to make progress in reducing undernutrition with its renewed commitment through the 2018-2022 National Multi-Sector Nutrition Strategic Plan (12). Furthermore, Malawi has set out to address overweight and obesity as part of this Plan (12). In doing so, Malawi has an opportunity to prevent the rise in overweight and obesity prevalence seen in other sub-Saharan African countries and low- and middle-income countries worldwide (4, 15, 96, 97).

Chapter 5 Tables

Table 5.1: Demographic characteristics of non-pregnant women aged 15-45 in Malawi, by survey year

	MNS 2001	MNS 2009	MNS 2015-16	P for trend[1]	Nature of trend from 2001 through 2015-16[2]
n	450	623	737		
Residence (%)					
Urban	14.1 (6.2, 22.0)	15.5 (10.1, 20.8)	9.2 (2.8, 15.6)	0.26	→
Rural	85.9 (77.5, 94.2)	84.5 (78.4, 90.7)	90.8 (82.4, 99.2)	Reference	Reference
Education (%)					
< Secondary	86.5 (80.6, 92.4)	80.9 (76.4, 85.3)	79.1 (72.1, 86.1)	0.64	→
≥ Secondary	13.5 (8.3, 18.7)	19.1 (15.6, 22.7)	20.9 (16.0, 25.8)	Reference	
Socioeconomic status (%)[3]					
Low	52.9 (45.8, 60.0)	37.1 (32.7, 41.5)	38.3 (32.1, 44.6)	-	-
Medium	37.1 (31.2, 43.1)	29.1 (25.0, 33.1)	37.8 (32.6, 43.0)	-	-
High	10.0 (6.3, 13.7)	33.8 (28.1, 39.5)	23.9 (18.3, 29.5)	-	-
Age (years)	27.4 (26.4, 28.3)	27.9 (27.2, 28.6)	27.3 (26.6, 27.9)	0.17	→

Data are percent or mean and 95% CIs

[1] Calculated using logistic regression models with the time point of each survey modeled as a continuous predictor

[2] ↗, increasing; ↘, decreasing; → did not change.

[3] In 2001, socioeconomic status was measured using a socioeconomic status index, which was created using data on household assets, water source, sanitation, house construction, and type of fuel used by the household (57). In 2009, a composite index of socioeconomic status similar to the index used in 2001 was created using household level data (78). In 2015-16, a wealth index was calculated using data on a household's ownership of assets, materials used for housing construction, and types of water access and sanitation facilities (59). Due to differences in the measurement of socioeconomic status across survey years, change over time was not evaluated for this variable.

Table 5.2: Weighted prevalence of conditions of under- and overnutrition among non-pregnant women aged 15-45 in Malawi

	MNS 2001	MNS 2009	MNS 2015-16	P for trend[1]	Nature of trend from 2001 through 2015-16[2]
Weight status					
n	450	623	737		
Underweight[3]	7.5 (4.6, 10.4)	5.2 (2.9, 7.4)	9.8 (7.6, 12.0)	0.01	↗
Overweight[4]	7.9 (5.3, 10.5)	12.8 (9.1, 16.5)	10.5 (7.3, 13.6)	0.36	→
Obese[5]	1.7 (0.3, 3.0)	1.6 (0.6, 2.7)	2.9 (1.3, 4.5)	0.19	→
Total overweight or obese	9.6 (6.9, 12.2)	14.4 (10.6, 18.2)	13.4 (9.9, 16.9)	0.70	→
Anemia					
n	450	492	737		
Anemia[6]	27.0 (22.1, 31.8)	36.9 (32.2, 41.5)	22.4 (18.5, 26.3)	<.0001	↘
Iron deficiency anemia (sTfR)[7]	11.4 (8.0, 14.9)	10.9 (7.8, 14.1)	9.8 (7.3, 12.3)	0.59	→
Iron deficiency anemia (inflammation-corrected ferritin)[8]	-	7.1 (4.9, 9.3)	8.1 (5.5, 10.6)	0.75	→
Micronutrient deficiencies and insufficiencies					
n	450	492	737		
Iron deficiency (sTfR)[9]	31.5 (26.3, 36.7)	27.1 (22.8, 31.5)	24.8 (20.8, 28.7)	0.44	→
Iron deficiency (inflammation-adjusted ferritin)[10]	-	15.3 (12.0, 18.7)	15.7 (12.3, 19.0)	0.97	→
Vitamin A deficiency[11]	58.6 (52.2, 65.1)	1.4 (0.6, 2.3)	0.3 (-0.1, 0.8)	<.0001	↘
Vitamin A insufficiency[12]	32.5 (27.4, 37.6)	9.5 (7.0, 11.9)	5.3 (3.1, 7.4)	<.0001	↘

Data are percent and 95% CIs.

[1] Calculated using logistic regression models with the time point of each survey modeled as a continuous predictor and age included as a covariate.

[2] ↗, increasing; ↘, decreasing; → did not change.

[3] Underweight defined as BMI < 18.5 kg/m^2.
[4] Overweight defined as BMI 25.0-29.9 kg/m^2.
[5] Obese defined as $\geq$ 30.0 kg/m^2.
[6] Anemia defined as hemoglobin adjusted for altitude < 12.0 g/dL in non-pregnant women.
[7] Iron deficiency anemia was defined as iron deficiency (using sTfR) and anemia.
[8] Iron deficiency anemia was defined as iron deficiency (using inflammation-adjusted ferritin) and anemia.
[9] Iron deficiency was defined as unadjusted sTfR > 8.3 mg/L.
[10] Iron deficiency was defined as inflammation-corrected ferritin < 15 µg/L.
[11] For 2001, vitamin A deficiency was defined as retinol < 0.7 µmol/L. For 2009, vitamin A deficiency defined as retinol binding protein (RBP) < 0.78 µmol/L calibrated to equal retinol < 0.7 µmol/L. For 2015-16, vitamin A deficiency defined as RBP < 0.46 µmol/L calibrated to equal retinol < 0.7 µmol/L.
[12] For 2001, vitamin A insufficiency was defined as retinol $\geq$ 0.7 to < 1.05 µmol/L. For 2009, vitamin A insufficiency defined as RBP $\geq$ 0.78 to < 1.14 µmol/L calibrated to equal retinol $\geq$ 0.7 to < 1.05 µmol/L. For 2015-16, vitamin A insufficiency defined as RBP $\geq$ 0.46 to < 0.86 µmol/L calibrated to equal retinol $\geq$ 0.7 to < 1.05 µmol/L.

Supplemental Table 5.1: Weighted prevalence of conditions of under- and overnutrition among non-pregnant women aged 15-45 in Malawi based on an analytic sample of women with no missing data

	MNS 2001	MNS 2009	MNS 2015-16
Weight status			
n	335	533	703
Underweight[1]	8.0 (4.5, 11.4)	4.8 (2.5, 7.2)	9.6 (7.1, 12.0)
Overweight[2]	8.2 (5.2, 11.2)	13.2 (9.2, 17.1)	10.8 (7.4, 14.3)
Obese[3]	2.3 (0.4, 4.2)	1.5 (0.6, 2.4)	3.0 (1.2, 4.8)
Total overweight or obese	10.5 (7.2, 13.7)	14.7 (10.6, 18.7)	13.9 (10.0, 17.7)
Anemia			
n	335	438	703
Anemia[4]	23.2 (18.0, 28.4)	31.3 (25.7, 37.0)	19.3 (15.7, 23.0)
Iron deficiency anemia (sTfR)[5]	11.2 (7.2, 15.3)	9.6 (5.5, 13.6)	8.6 (6.1, 11.0)
Iron deficiency anemia (inflammation-corrected ferritin)[6]	-	6.9 (3.8, 9.9)	7.4 (5.1, 9.8)
Micronutrient deficiencies and insufficiencies			
n	335	438	703
Iron deficiency (sTfR)[7]	32.2 (26.4, 38.1)	26.6 (20.7, 32.6)	24.3 (20.2, 28.5)
Iron deficiency (inflammation-adjusted ferritin)[8]	-	15.8 (11.2, 20.4)	15.4 (12.0, 18.9)
Vitamin A deficiency[9]	58.8 (50.8, 66.7)	1.4 (0.2, 2.7)	0.3 (0.0, 0.8)
Vitamin A insufficiency[10]	32.0 (25.8, 38.1)	9.1 (5.8, 12.5)	5.7 (3.3, 8.2)

Data are percent and 95% CIs.

[1] Underweight defined as BMI < 18.5 kg/m^2.

[2] Overweight defined as BMI 25.0-29.9 kg/m^2.

[3] Obese defined as $\geq$ 30.0 kg/m^2.

[4] Anemia defined as hemoglobin adjusted for altitude < 12.0 g/dL in non-pregnant women.

[5] Iron deficiency anemia was defined as iron deficiency (using sTfR) and anemia.

[6] Iron deficiency anemia was defined as iron deficiency (using inflammation-adjusted ferritin) and anemia.

[7] Iron deficiency was defined as unadjusted sTfR > 8.3 mg/L.

[8] Iron deficiency was defined as inflammation-adjusted ferritin < 15 µg/L.

[9] For 2001, vitamin A deficiency was defined as retinol < 0.7 µmol/L. For 2009, vitamin A deficiency defined as retinol binding protein (RBP) < 0.78 µmol/L calibrated to equal retinol < 0.7 µmol/L. For 2015-16, vitamin A deficiency defined as RBP < 0.46 µmol/L calibrated to equal retinol < 0.7 µmol/L.

[10] For 2001, vitamin A insufficiency was defined as retinol $\geq$ 0.7 to < 1.05 µmol/L. For 2009, vitamin A insufficiency defined as RBP $\geq$ 0.78 to < 1.14 µmol/L calibrated to equal retinol $\geq$ 0.7 to < 1.05 µmol/L. For 2015-16, vitamin A insufficiency defined as RBP $\geq$ 0.46 to < 0.86 µmol/L calibrated to equal retinol $\geq$ 0.7 to < 1.05 µmol/L.

Supplemental Table 5.2: Age-standardized weighted prevalence of conditions of under- and overnutrition among non-pregnant women aged 15-45 in Malawi based on imputed data

	MNS 2001	MNS 2009	MNS 2015-16
Weight status			
n	450	623	737
Underweight[1]	7.5 (4.6, 10.4)	5.2 (2.9, 7.6)	9.8 (7.5, 12.2)
Overweight[2]	7.8 (5.3, 10.4)	12.7 (8.9, 16.4)	10.4 (7.2, 13.7)
Obese[3]	1.6 (0.2, 2.9)	1.7 (0.6, 2.7)	2.9 (1.2, 4.6)
Total overweight or obese	9.4 (6.8, 12.1)	14.3 (10.5, 18.2)	13.1 (9.5, 16.7)
Anemia			
n	450	492	737
Anemia[4]	27.8 (22.4, 33.2)	37.0 (31.0, 43.0)	22.5 (18.3, 26.7)
Iron deficiency anemia (sTfR)[5]	11.8 (7.8, 15.8)	10.9 (6.8, 15.0)	9.9 (7.2, 12.5)
Iron deficiency anemia (inflammation-corrected ferritin)[6]	-	6.9 (4.1, 9.8)	8.0 (5.4, 10.6)
Micronutrient deficiencies and insufficiencies			
n	450	492	737
Iron deficiency (sTfR)[7]	31.7 (25.9, 37.6)	26.7 (21.1, 32.3)	25.0 (20.7, 29.3)
Iron deficiency (inflammation-corrected ferritin)[8]	-	15.5 (11.5, 19.5)	15.6 (12.1, 19.0)
Vitamin A deficiency[9]	59.1 (52.5, 65.7)	1.3 (0.3, 2.3)	0.3 (-0.1, 0.7)
Vitamin A insufficiency[10]	31.9 (26.2, 37.5)	9.3 (6.2, 12.4)	5.2 (3.0, 7.5)

Data are percent and 95% CIs.

[1] Underweight defined as BMI < 18.5 kg/m^2.

[2] Overweight defined as BMI 25.0-29.9 kg/m^2.

[3] Obese defined as $\geq$ 30.0 kg/m^2.

[4] Anemia defined as hemoglobin adjusted for altitude < 12.0 g/dL in non-pregnant women.

[5] Iron deficiency anemia was defined as iron deficiency (using sTfR) and anemia.

[6] Iron deficiency anemia was defined as iron deficiency (using inflammation-adjusted ferritin) and anemia.

[7] Iron deficiency was defined as unadjusted sTfR > 8.3 mg/L.

[8] Iron deficiency was defined as inflammation-corrected ferritin < 15 µg/L.

[9] For 2001, vitamin A deficiency was defined as retinol < 0.7 µmol/L. For 2009, vitamin A deficiency defined as retinol binding protein (RBP) < 0.78 µmol/L calibrated to equal retinol < 0.7 µmol/L. For 2015-16, vitamin A deficiency defined as RBP < 0.46 µmol/L calibrated to equal retinol < 0.7 µmol/L.

[10] For 2001, vitamin A insufficiency was defined as retinol $\geq$ 0.7 to < 1.05 µmol/L. For 2009, vitamin A insufficiency defined as RBP $\geq$ 0.78 to < 1.14 µmol/L calibrated to equal retinol $\geq$ 0.7 to < 1.05 µmol/L. For 2015-16, vitamin A insufficiency defined as RBP $\geq$ 0.46 to < 0.86 µmol/L calibrated to equal retinol $\geq$ 0.7 to < 1.05 µmol/L.

Chapter 6: Urban Residence is Associated with Higher Prevalence of Individual-Level Double Burden of Malnutrition in Malawian Women

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Abstract

Background: Urbanization in sub-Saharan Africa may contribute to a double burden of malnutrition (DBM) whereby both overweight and undernutrition coexist. However, little is known about the magnitude and distribution of the individual-level DBM in sub-Saharan countries.

Objective: To assess the prevalence of the individual-level DBM in Malawian women. To model the associations between overweight, anemia, micronutrient deficiencies, and DBM and urban or rural residence. To test whether the prevalence of the DBM would differ from that expected by chance, assuming the conditions were independent.

Methods: We analyzed nationally representative data based on a sample of 723 non-pregnant women of reproductive age (15-49 years) from the 2015-16 Malawi Micronutrient Survey. DBM was defined two ways: 1- co-occurring overweight (body mass index $\geq$25 kg/m^2) and anemia (hemoglobin adjusted for altitude and smoking <12.0 g/dL) and 2- co-occurring overweight and any micronutrient deficiency (zinc deficiency [<70 μg/dL morning fasted samples, <66 μg/dL morning non-fasting samples, and <59 μg/dL afternoon non-fasting samples], iron deficiency [inflammation-adjusted ferritin <15 μg/L], vitamin A deficiency [retinol binding protein <0.46

μmol/L calibrated to equal retinol <0.7 μmol/L], vitamin B12 deficiency [<150 pmol/L], or folate deficiency [<6.8 nmol/L]). We modeled five associations: between 1- overweight, 2- anemia, 3- micronutrient deficiencies, 4 and 5-DBM with each definition and residence using unadjusted and adjusted (for wealth, education, age) logistic regression models. The Rao-Scott modified Chi Square test was used to compare the observed and expected prevalence (product of the prevalence estimates of overweight and anemia or micronutrient deficiencies) of DBM.

Results: The national prevalence (95% CI) of overweight, anemia, and any micronutrient deficiency was 14.5% (10.6, 18.4), 19.9% (16.5, 23.4), and 72.8% (67.7, 77.8), respectively. The DBM prevalence (95% CI) was 3.4% (1.3, 5.5) and 10.8% (7.0, 14.5) for co-occurring overweight and anemia and co-occurring overweight and any micronutrient deficiency, respectively. Overweight prevalence in women differed by residence [urban 34.4 (25.8, 43.0), rural 12.5 (8.8, 16.2), adjusted OR [aOR]: 2.3 (1.4, 3.7)]. Prevalence of either anemia or any micronutrient deficiency did not differ by residence. Co-occurring overweight and anemia prevalence in women did not differ by residence [urban 6.9 (0.6, 13.2) vs. rural 3.0 (0.8, 5.3), p=0.36], however, urban women were 3-times more likely to have co-occurring overweight and any micronutrient deficiency than rural women [urban 32.6 (24.1, 41.2) vs. rural 8.6 (5.2, 11.9), aOR: 3.2 (1.8, 5.6)]. There were no statistically significant differences in observed and expected prevalence estimates of the DBM, by either definition.

Conclusions: Given that the national co-occurrence of overweight and anemia or micronutrient deficiencies was independent, public health programs may need to address these issues separately. However, the higher prevalence of overweight and the co-occurrence of overweight and micronutrient deficiencies in women in urban areas suggests that urban programs need to address both over- and undernutrition to improve women's health.

Introduction

Low- and middle-income countries (LMICs) are experiencing a rapid increase in overweight, obesity, and diet-related chronic diseases (NCDs) in the face of persisting undernutrition (3, 4, 96, 98). The coexistence of under- and overnutrition, termed the 'double burden of malnutrition' (DBM), can occur at the population level (both undernutrition and overweight, obesity, or NCDs in the same community, region, or country), household level (for example, an overweight adult with a child who is underweight or stunted), and individual level (for example, simultaneous development of overweight and micronutrient deficiencies within the same individual, or overweight in an adult who was stunted in childhood) (1). Addressing this DBM is high on the United Nations global health agenda given the adverse health consequences of malnutrition and negative impact on developing economies due to lost economic productivity (3, 99). Sustainable Development Goal 2 calls for ending all forms of malnutrition, and the United Nations Decade of Action on Nutrition from 2016 to 2025 aims to strengthen action to contribute to achieving this goal (1). Moving this agenda forward requires knowledge of the magnitude and distribution of the DBM at every level. Although many studies have examined the DBM at the population (4, 97, 100) or household levels (28, 43, 47, 101), comparatively little research has focused on the individual-level DBM, especially in sub-Saharan Africa (50).

Urbanization may be a key underlying driver of the DBM in LMICs (14). Urbanization and attendant economic growth are thought to expand access to processed foods, increase exposure to food marketing, and reduce physical activity through more motorized transportation and sedentary occupations (14, 17, 19, 34). These macrolevel changes in environment and lifestyle are believed to decrease energy expenditure and create shifts away from diets composed of legumes, coarse grains, and vegetables and toward energy-dense diets composed of foods high in refined carbohydrates and added sugars, thereby contributing to the rise in overweight prevalence (14, 19). At the same time, it is hypothesized that diets associated with this nutrition

transition play a role in the continued problem of micronutrient deficiencies in LMICs, since processed and packaged foods are often low in micronutrients (17, 51). Given the potential role of urbanization in the DBM, many empirical studies have investigated the prevalence of overweight and anemia or micronutrient deficiencies in people who reside in urban and rural areas (4, 34). However, since these are ecological studies, their findings cannot be used to make inferences about the co-occurrence of overweight and anemia or micronutrient deficiencies within the same individual.

Due to scarcity of micronutrient status data (36-38), previous studies of the DBM at the individual-level have examined co-occurring overweight and anemia (24, 27, 50-52, 102), with anemia used to reflect micronutrient deficiencies. However, solely assessing co-occurring overweight and anemia may not provide a clear understanding of the individual-level DBM, because anemia is not only associated with micronutrient deficiencies but also non-nutritional factors such as malaria and other infections, inflammation, and hemoglobinopathies (11, 103). As such, analyses of co-occurring overweight and micronutrient deficiencies are needed to better elucidate the issue of the individual-level DBM, particularly in LMICs with a high infection burden (11).

We used nationally representative data based on a sample of women of reproductive age to investigate the individual-level DBM in Malawi, an urbanizing sub-Saharan African country with unresolved undernutrition and problems of overweight and obesity (4, 104). Most studies of the individual-level DBM have been conducted in middle-income countries, where the nutrition transition is in advanced stages (50). Malawi is a low-income country in the early stages of the nutrition transition (21, 22), and thus offers a different context in which to investigate the DBM in individual women. Our objectives were threefold. First, we estimated the prevalence of two characterizations of the DBM at the individual level in Malawian women (1- co-occurring overweight and anemia, 2- co-occurring overweight and micronutrient deficiencies). Second, we

examined associations between overweight, anemia, micronutrient deficiencies, and the individual-level DBM and residence in urban or rural areas. Finally, we tested whether the prevalence of DBM would differ from that expected by chance, assuming the conditions were independent.

Methods

Data source and study population

We analyzed nationally representative data based on a sample of non-pregnant women of reproductive age (15-49 years) in the 2015-16 Malawi Micronutrient Survey (MNS), which was conducted in coordination with the 2015-16 Malawi Demographic and Health Survey (MDHS) (58, 59). The MDHS used the 2008 Malawi Population and Housing Census and employed a two-stage cluster sampling design. In the first stage of sampling, clusters were selected using a probability proportional to population size approach. The second stage involved selecting 30 households per urban cluster and 33 households per rural cluster by applying an equal probability systematic selection method. Additional details of the MDHS sampling methodology are presented elsewhere (59). For the MNS, a subsample of MDHS clusters were randomly selected, and a total of 20 households per urban cluster and 22 per rural cluster were included (58). In each household, eligible participants (defined as usual members of the household who spent the night in that household before the survey) were invited to participate. We restricted all analyses to non-pregnant women since weight status among pregnant women and non-pregnant women are not comparable. Of 830 eligible women, we excluded women who were pregnant (n=34), women for whom pregnancy status was not available (n=18), and women who had missing (n=10) or biologically implausible BMI values (beyond 5 SD from reference means; n=3) (34), missing values on anemia or micronutrient status (n=41), or missing values on demographic variables used in our analysis (n=1). Our final analytic sample consisted of 723 non-pregnant women. The

proportion of missing or implausible BMI data was 1.8%, indicating good anthropometric data quality (105).

Characterizations of the double burden of malnutrition at the individual level

We examined two characterizations of the DBM at the individual level in Malawian women: 1) co-occurring overweight and anemia and 2) co-occurring overweight and micronutrient deficiencies (one or more deficiencies in the following micronutrients: zinc, iron, folate, vitamin B12, and vitamin A). In sub-analyses, we examined co-occurring overweight and single micronutrient deficiencies and insufficiencies (folate insufficiency, vitamin B12 depletion, and vitamin A insufficiency).

Measurement of overweight and conditions of undernutrition

Weight was measured with a digital floor scale (SECA brand) to the nearest 0.1 kilogram (kg), and a wooden stadiometer (ShorrBoard ®) was used to measure height to the nearest 0.1 centimeter. We used weight and height measurements to calculate body mass index (BMI) and classify women into three weight categories, using the WHO recommended cut-off points: underweight (BMI < 18.5 kg/m^2), normal weight (BMI 18.5 – 24.9 kg/m^2), and overweight (including obesity) (BMI 25 – 29.9 kg/m2 [overweight], ≥ 30 kg/m2 [obese]) (79). A BMI ≥ 25 indicates excess weight and has been shown to be associated with increased risk of adverse health outcomes, making it appropriate to collapse BMI categories of overweight and obese (51).

We measured deficiencies in zinc, iron, folate, vitamin B12, and vitamin A using venous blood samples. Blood samples were collected from participants who consented, using venipuncture into one trace element free and a second EDTA-containing Vacutainer. Anemia was tested in the field using the HemoCue 301 and defined as hemoglobin (adjusted for altitude and smoking) < 12.0 g/dL in non-pregnant women (106). Zinc deficiency was defined as serum zinc concentration < 70 μg/dL for morning fasted samples, < 66 μg/dL for morning non-fasting samples, and < 59 μg/dL for afternoon non-fasting samples (107). Iron deficiency was defined as

inflammation-adjusted ferritin < 15 μg/L (81). We adjusted ferritin concentrations for CRP and AGP concentrations using the Biomarkers Reflecting Inflammation and Nutritional Determinants of Anemia internal (country-specific) regression-corrected approach (81, 108). Folate deficiency was based on risk of megaloblastic anemia defined as serum folate concentration < 6.8 nmol/L (109). Vitamin B12 deficiency was defined as serum vitamin B12 concentration < 150 pmol/L (110). Vitamin A deficiency was defined as retinol binding protein (RBP) < 0.46 μmol/L calibrated to equal retinol < 0.7 μmol/L using regression analysis (82).

We used blood samples to measure folate insufficiency, vitamin B12 depletion, and vitamin A insufficiency. Folate insufficiency was defined as red blood cell folate < 748 nmol/L (111). Vitamin B12 depletion was defined as serum vitamin B12 concentration < 220 pmol/L (111). Vitamin A insufficiency was defined as RBP $\geq$ 0.46 to < 0.86 μmol/L calibrated to equal retinol $\geq$ 0.7 to < 1.05 μmol/L using regression analysis (82).

Statistical analysis

All analyses were conducted in SAS 9.4 (SAS Institute, Inc, Cary, North Carolina) and used survey weights to generate results representative of women in Malawi. Survey procedures in SAS were used to account for the complex sampling design. We generated descriptive statistics for socio-demographic characteristics of women (residence, education level, the household wealth index, and age).

We calculated the prevalence of overweight, anemia, any micronutrient deficiency, co-occurring overweight and anemia, and co-occurring overweight and any micronutrient deficiencies. In a bivariate analysis, we examined the association between residence and overweight, using the Rao Scott modified Chi Square test, which accounted for the complex survey design. To calculate the odds of overweight in women residing in urban areas compared to women in rural areas, we modeled the association between overweight as the dependent variable and residence as the independent variable, using unadjusted and adjusted (for wealth, education,

age) logistic regression models. We evaluated multicollinearity among our independent variables by assessing variance inflation factors. We conducted similar analyses to assess the association between residence and each of the following outcomes: anemia, any micronutrient deficiency, co-occurring overweight and anemia, and co-occurring overweight and any micronutrient deficiency.

The Rao-Scott modified Chi Square test was used to compare the observed and expected prevalence of co-occurring overweight and anemia. The expected prevalence of co-occurring overweight and anemia was estimated as the product of overweight prevalence and anemia prevalence, accounting for complex survey variables (weight, strata, and cluster). We also compared the observed and expected prevalence of co-occurring overweight and anemia stratified by residence. We carried out a similar analysis to compare the observed and expected prevalence of co-occurring overweight and micronutrient deficiencies.

In sub-analyses, we repeated the analyses described above to examine the co-occurrence of overweight and deficiencies in single micronutrients including: zinc, iron, folate, vitamin B12, and vitamin A. We also examined the co-occurrence of overweight and single micronutrient insufficiencies including: folate insufficiency, vitamin B12 depletion, and vitamin A insufficiency. In addition, we estimated the prevalence of micronutrient deficiencies and insufficiencies in women who were underweight, normal weight, and overweight. In bivariate analyses, we assessed whether the prevalence of these conditions differed according to weight status. For all analyses and sub-analyses, associations were considered statistically significant at an alpha level of 0.05 set a priori.

Results

Socio-demographic characteristics of non-pregnant women of reproductive age in Malawi are provided in Table 6.1. Among women in our sample, 79.0% had less than a secondary education and 21.0% had a secondary education or higher. Approximately equal proportions of women were in each wealth category since the household wealth index was divided into quintiles

(poorest: 22.7%; poorer: 19.5%; middle: 19.6%; richer: 25.1%; richest: 13.2%). Women aged 15-19, 20-29, 30-29, and 40-49 comprised 20.2%, 38.6%, 24.7%, and 16.5% of the sample, respectively. The proportion of women residing in urban areas and rural areas was 9.1% and 90.9%, respectively. We found no statistically significant differences in socio-demographic characteristics between women in our analytic sample and those who were excluded for this analysis.

Prevalence of single conditions of malnutrition

Among non-pregnant women of reproductive age in Malawi, prevalence estimates of overweight, anemia, and any micronutrient deficiency were 14.5%, 19.9%, and 72.8%, respectively (Table 6.2). The prevalence of overweight in women was higher in urban areas than in rural areas (34.4% vs. 12.5%, p=0.02) (Table 6.2). The prevalence of anemia did not differ in urban and rural women (17.8% vs. 20.2%, p=0.69), nor did the prevalence of any micronutrient deficiency (87.8% vs. 71.3%, p=0.15). In unadjusted multiple logistic regression models, women in urban areas had higher odds of being overweight (OR: 3.7 [95% CI: 2.2, 6.1]) than women in rural areas (Table 6.3). The odds of having anemia (OR: 0.9 [95% CI: 0.4, 2.0]) and any micronutrient deficiency (OR: 2.9 [95% CI: 0.8, 10.6]) did not differ among women in urban areas and those in rural areas. In adjusted multiple logistic regression models, urban women were 2-times more likely to be overweight than rural women (adjusted OR [aOR]: 2.3 [95% CI: 1.4, 3.7]). There was no significant difference in the odds of anemia in urban vs. rural women (aOR 1.0 [95% CI: 0.4, 2.8]). Similarly, the association between urban residence and any micronutrient deficiencies remained non-significant (aOR: 3.7 [95% CI: 1.0, 13.8]).

The prevalence of single micronutrient deficiencies varied in this population. The prevalence of zinc deficiency was highest (61.8%), followed by iron deficiency (16.0%), vitamin B12 deficiency (12.4%), folate deficiency (7.6%), and vitamin A deficiency (0.3%). The prevalence of vitamin B12 deficiency in women was lower in urban areas than in rural areas

(0.4% vs. 13.6%, p=0.02). Zinc deficiency, iron deficiency, and folate deficiency did not differ according to residence. Because the prevalence of vitamin A deficiency was very low, vitamin A deficiency prevalence in urban vs. rural areas could not be evaluated.

In unadjusted logistic regression models, the odds of being zinc deficient (OR: 3.3 [95% CI: 1.0, 10.9]) did not differ among women in urban areas and those in rural areas. However, in adjusted multiple logistic regression models, urban residence became significantly associated with zinc deficiency after adjustment for education, age, and household wealth, with women in urban areas having higher odds of being zinc deficient (aOR: 4.5 [95% CI: 1.2, 16.4]) than women in rural areas.

Prevalence estimates of folate insufficiency, vitamin B12 depletion, and vitamin A insufficiency were 80.9%, 39.6%, and 5.0%, respectively. Folate insufficiency in women was higher in urban areas than in rural areas (98.3% vs. 79.2%, p=0.02). There were no differences in prevalence estimates of vitamin B12 depletion and vitamin A insufficiency by residence. In unadjusted multiple logistic regression models, women in urban areas had higher odds of being folate insufficient (OR: 15.2 [95% CI: 3.6, 63.8]) than women in rural areas (Table 6.3). In adjusted multiple logistic regression models, women in urban areas had higher odds of being folate insufficient (aOR: 12.0 [95% CI: 2.8, 51.9]) as compared to women in rural areas.

Prevalence of co-occurring overweight and anemia or micronutrient deficiencies

The prevalence of DBM among Malawian women, defined as co-occurring overweight and anemia was 3.4% (95% CI: 1.3, 5.5), and defined as co-occurring overweight and micronutrient deficiencies was 10.8% (95% CI: 7.0, 14.5) (Table 6.2). The prevalence of co-occurring overweight and anemia in women did not differ in urban and rural areas (6.9% vs. 3.0%, p=0.36). The prevalence of co-occurring overweight and micronutrient deficiencies was higher among women in urban areas than in rural areas (32.6% vs. 8.6%, p=0.02) (Figure 6.1).

In an unadjusted multiple logistic regression model, women in urban areas had higher odds of co-occurring overweight and micronutrient deficiencies compared to rural areas (OR: 5.2 [95% CI: 2.9, 9.1]) (Table 6.3). The strength of this association was attenuated in adjusted models, controlling for education, household wealth, and age, but remained statistically significant. The adjusted odds of co-occurring overweight and micronutrient deficiencies were more than three times higher for women in urban areas compared to rural areas (aOR: 3.2 [95% CI: 1.8, 5.6]). Due to the low prevalence of co-occurring overweight and anemia, we did not use unadjusted and adjusted multiple logistic regression models to examine characteristics associated with co-occurring overweight and anemia.

In sub-analyses, the prevalence of co-occurring overweight and single micronutrient deficiencies were as follows: 9.8% for co-occurring overweight and zinc deficiency; 2.6% for co-occurring overweight and iron deficiency; 1.8% for co-occurring overweight and folate deficiency; 0.8% for co-occurring overweight and vitamin B12 deficiency; and 0.1% for co-occurring overweight and vitamin A deficiency (Table 6.2). The prevalence estimates of co-occurring overweight and folate insufficiency, co-occurring overweight and vitamin B12 depletion, and co-occurring overweight and vitamin A insufficiency in women were 12.5%, 4.4%, and 0.0%, respectively. In bivariate analyses, the prevalence of co-occurring overweight and zinc deficiency was higher among women in urban areas than rural areas (31.3% vs. 7.7%, p=0.03). Similarly, the prevalence of co-occurring overweight and folate insufficiency was higher among women in urban areas than rural areas (34.2% vs. 10.3%, p=0.02). The prevalence estimates of co-occurring overweight with other single micronutrient deficiencies (iron deficiency, folate deficiency) and insufficiencies (vitamin B12 depletion) did not vary among women according to residence. Differences in the prevalence estimates of co-occurring overweight and vitamin B12 deficiency, co-occurring overweight and vitamin A deficiency, and co-occurring overweight and vitamin A insufficiency could not be assessed due to no unweighted

cases with these co-occurring forms of malnutrition in urban areas. Women in urban areas had higher odds of co-occurring overweight and zinc deficiency (OR: 5.5 [95% CI: 2.9, 10.2]) and co-occurring overweight and folate insufficiency (OR: 4.5 [95% CI: 2.7, 7.5]) than women in rural areas. The same relationships remained in adjusted analyses. Women in urban areas had higher odds of co-occurring overweight and zinc deficiency (aOR: 3.4 [95% CI: 1.8, 6.5]) and co-occurring overweight and folate insufficiency (aOR: 2.6 [95% CI: 1.6, 4.2]) compared to women in rural areas.

In sub-analyses, we also found that the prevalence of anemia and micronutrient deficiencies and insufficiencies did not significantly differ according to weight status categorized as underweight, normal weight, and overweight (Supplemental Table 6.1). The exception was vitamin A insufficiency, which was highest in underweight women (underweight: 11.5%, normal weight: 5.2%, overweight: 0.2%, p=0.04). Furthermore, we found that the prevalence of anemia and micronutrient deficiencies and insufficiencies did not significantly differ between normal weight and overweight weight women, apart from vitamin B12 deficiency (normal weight: 14.0%, overweight: 5.8%, p=0.01) and vitamin A insufficiency (normal weight: 5.2%, overweight: 0.2%, p=0.0005) (Supplemental Table 6.2).

Observed versus expected prevalence of co-occurring overweight and anemia or micronutrient deficiencies

We investigated whether the prevalence of DBM would differ from that expected by chance, assuming the conditions were independent. There were no statistically significant differences in observed and expected prevalence estimates of the DBM, by either definition (co-occurring overweight and anemia or co-occurring overweight and micronutrient deficiencies) or in analyses stratified by residence (Table 6.4).

In sub-analyses, we found statistically significant differences in observed and expected prevalence estimates of co-occurring overweight and vitamin B12 deficiency and co-occurring

overweight and vitamin A insufficiency in women, with the observed prevalence estimates being lower than the expected estimates. In stratified analyses by residence, these same findings held among women in rural areas. Among women in urban areas, we found that the observed prevalence of co-occurring overweight and iron deficiency was significantly lower than the expected prevalence. We did not find statistically significant differences in observed and expected prevalence estimates of other co-occurring overweight and single micronutrient deficiencies and insufficiencies.

Discussion

The prevalence of co-occurring overweight and anemia was very low nationally and did not differ in urban and rural areas. In contrast, we found that more than one in ten women had co-occurring overweight and micronutrient deficiencies. Additionally, women in urban areas were 3-times more likely to have co-occurring overweight and micronutrients deficiencies than women in rural areas.

Nationally, the prevalence of the individual-level DBM observed in Malawi was not statistically independent from its components of overweight and anemia or micronutrient deficiencies. In addition, results from stratified analyses showed that the prevalence of DBM in women residing in urban areas was not independent. In sub-analyses, we found that co-occurring overweight and vitamin B12 deficiency and co-occurring overweight and vitamin A insufficiency in women were statistically independent nationally and in rural areas, while co-occurring overweight and iron deficiency was statistically independent in urban areas. However, the differences in the observed and expected prevalence estimates were minimal. These findings suggest that the DBM we observe in Malawi is by chance and not due to specific exposures that put women at risk of developing overweight together with nutritional deficiencies indicative of undernutrition. Studies conducted in India, Brazil, and Ecuador to examine co-occurring overweight and anemia in women reported similar results (24, 27, 112). Previous studies, to the

best of our knowledge, have not evaluated whether co-occurring overweight and micronutrient deficiencies in women is statistically independent from its components of overweight and micronutrient deficiencies. Our findings are aligned with the results of studies that focused on the DMB at the household-level. Using 121 datasets from 54 countries, Dieffenbach and Stein found that stunted children aged 2 to 5 years and overweight or obese mother pairs were not statistically independent, leading them to conclude that this characterization of the household-level DBM was a "statistical artifact," rather than a distinct entity (113). Subsequent research in Latin America found that in 5 of 6 countries (Brazil, Colombia, Ecuador, Guatemala, and Mexico) the observed prevalence of a stunted child under five and a overweight or obese woman within the same household was significantly lower than the prevalence expected by chance, but all absolute differences were small and not considered to be practically meaningful (27).

Currently, there is no international cut-off for establishing whether the DBM is present at the population, household, or individual level (29). Moreover, no criteria exist for assessing whether the DBM is a mild, moderate, or severe public health problem like that developed for forms of malnutrition such as anemia. However, the prevalence of co-occurring overweight and anemia in Malawian women was lower than the prevalence observed in other LMICs. For example, a recent study in India found that 9% of women had co-occurring overweight and anemia, though the results are not directly comparable since BMI cut-offs for Asian populations were used (24). Studies from Latin American countries have found even higher proportions of co-occurring overweight and anemia in women, including approximately 12% in Guatemala and 14% in Brazil (27). It is not surprising that co-occurring overweight and anemia is higher in Guatemala and Brazil than that observed in Malawi, given the very high prevalence of both overweight and anemia in these Latin American countries. In Guatemala, 40.6% of women are overweight, while 24.5% of women have anemia. The prevalence of these forms of malnutrition is even higher in Brazil, where 64.9% are overweight and 30.6% have anemia. The differences in

the prevalence of overweight, as well as co-occurring overweight and anemia, between women in other LMICs and Malawian women may reflect differences in the stages of the nutrition transition in these settings. While the nutrition transition is advanced in some countries in Latin America (52, 114), for example, sub-Saharan African countries such as Malawi are still in the early stages of this transition (21, 22).

It is not possible to assess how the prevalence of co-occurring overweight and micronutrient deficiencies in Malawian women compares to the prevalence observed in other LMICs since no other studies, to the best of our knowledge, have used the same definition to characterize the individual-level DBM. Nonetheless, given that the nutrition transition is in an early stage in Malawi (21), the already considerable proportion of women with co-occurring overweight and micronutrient deficiencies is noteworthy. Research investigating co-occurring overweight and micronutrient deficiencies in other LMICs is warranted. In LMICs such as Mexico and Cameroon, for example, there may be even higher levels of co-occurring overweight and micronutrient deficiencies in women than that found in Malawian women, as both Mexico and Cameroon have larger burdens of overweight (43, 104) than Malawi and high levels of micronutrient deficiencies (11).

In sub-analyses, we found that the prevalence of co-occurring overweight and micronutrient deficiencies in women appeared to be influenced largely by the prevalence of co-occurring overweight and zinc deficiency, given that the prevalence estimates of co-occurring overweight and other single micronutrient deficiencies (iron, folate, vitamin B12, vitamin A) were relatively low. Our results are consistent with a large, cross-sectional analysis from Vietnam, where the prevalence estimates of co-occurring overweight and zinc deficiency (12.2%) was highest and co-occurring overweight and iron deficiency and co-occurring overweight and vitamin B12 deficiency were low in comparison (2.3% and 3.0%, respectively) (115). Similar to the high levels of zinc deficiency in women found in Vietnam (67%), Malawian women bear a

high burden of zinc deficiency (62%) (116). Evidence from Malawi corroborates the high levels of zinc deficiency observed in our study. Risk factors for zinc deficiency include consumption of crops grown on frequently occurring low-pH soils (117) and reductions in zinc concentrations of commonly consumed maize flour due to processing (117). A study using nationally-representative data from the Third Integrated Household Survey of Malawi found that more than half of households in Malawi were at risk of zinc deficiencies due to inadequate dietary supplies (118). That same study estimated that nearly one-third of households with adequate energy supply had inadequate supplies of zinc (118). Thus, it is reasonable that overweight and zinc deficiency co-occurs in Malawian women.

Perhaps one of the most salient findings of our analysis is that the prevalence of co-occurring overweight and micronutrient deficiencies was nearly three times that of co-occurring overweight and anemia. In previous studies that have examined co-occurring overweight and anemia in women, anemia has been used to reflect micronutrient deficiencies, such as deficiencies of iron, folate, vitamin B12, and vitamin A (24, 51). Although research supports the role of micronutrient deficiencies in the etiology of anemia, there is now strong evidence that the contribution of micronutrient deficiencies to anemia varies by setting (11, 41, 119). A recent study using nationally-representative data from 10 countries found that the proportion of anemia that was attributable to iron deficiency differed according to a country's burden of infectious disease and inflammation (11). The proportion of anemic women who were iron deficient was markedly lower in countries with a high-infection burden (35%) relative to moderate- and low-infection countries (65% and 71%, respectively) (11). In the same study, vitamin A insufficiency was significantly associated with anemia, whereas vitamin B12 and folate deficiencies were not (11). Moreover, non-nutritional factors, such as chronic disease, genetic blood diseases, malaria, and inflammation, are not only known to be associated with anemia, but may contribute even more to the development of anemia than nutritional causes in some settings (11, 41, 103, 119). In

the context of Malawi, using anemia as a proxy for micronutrient deficiencies would have substantially underestimated the prevalence of co-occurring overweight and micronutrient deficiencies. In other contexts, such as countries with a high infection burden, relying on anemia only may lead to an overestimation of the prevalence of co-occurring overweight and micronutrient deficiencies. Still, in other settings anemia may closely reflect micronutrient deficiencies. An understanding of the context-specific determinants of anemia is therefore needed to assess whether anemia serves as an appropriate proxy for micronutrient deficiencies, as well as to interpret prevalence estimates of co-occurring overweight and anemia. Moreover, given that anemia does not reflect micronutrient deficiencies uniformly across contexts, making direct comparisons of prevalence estimates of co-occurring overweight and anemia across LMICs is problematic. Additional studies that examine co-occurring overweight and anemia and co-occurring overweight and micronutrient deficiencies in other LMICs are needed to explore the extent to which the prevalence estimates of these two characterizations of the individual-level DBM differ in other settings.

We have shown that women in urban areas bear a larger burden of co-occurring overweight and micronutrient deficiencies than women in rural areas. The patterning by residence observed in our study is consistent with studies that have assessed the prevalence of these conditions at the population level. Sub-Saharan Africa, along with South Asia, are the only regions in the world where overweight remains concentrated in urban areas (17, 32). Simultaneously, cross-sectional studies have shown that intakes of micronutrients, such as vitamin B12 and folate, are low among urban women in sub-Saharan Africa (120). Notably, we did not find a significant association between urban residence and co-occurring overweight and anemia in Malawian women. By contrast, a pooled analysis of nationally representative data for 30 sub-Saharan African countries found that women in periurban and urban areas had

significantly higher odds of concurrent overweight and anemia than women in rural areas (periurban, OR: 1.18; urban, OR: 1.43) (50).

While the focus of our study was to examine the individual-level DBM, a notable finding was that there was variation in the distribution of some single micronutrient deficiencies in women across urban and rural areas, but no variation of other single micronutrient deficiencies by residence. For example, vitamin B12 deficiency prevalence was higher in rural areas than in urban areas. On the other hand, zinc deficiency prevalence and folate insufficiency prevalence were higher in urban areas, as was the prevalence of any micronutrient deficiency. Meanwhile, iron deficiency prevalence and folate deficiency prevalence did not vary by residence in urban or rural areas. In addition, Malawian women in urban areas were two times more likely to be overweight than women in rural areas. These findings, along with our findings of the distribution of the DBM, suggest that in urban areas there is an opportunity to deliver programs that address over- and undernutition among women in a coordinated manner (27). In rural areas, food security interventions such as the Government of Malawi's Social Cash Transfer Program, which has been shown to achieve increased diet quantity in beneficiary households (84), can be leveraged to also improve diet quality and contribute to the alleviation of micronutrient deficiencies. Furthermore, our finding that anemia and micronutrient deficiencies and insufficiencies largely affected women across the weight spectrum suggests that programming to address these forms of undernutrition needs to target all women, regardless of weight status.

There were several limitations of our analysis. First, prevalence estimates for co-occurring overweight and vitamin A deficiency and co-occurring overweight and vitamin A insufficiency were based on a small number of unweighted cases, and thus, must be interpreted with caution. Second, although there are gradations of urbanicity (121), our analysis used a dichotomous urban-rural measure for residence (4, 59). Research using measures with improved ability to capture degrees of urbanization is warranted, particularly given the growth of periurban

areas in LMICs (50, 122). Third, there is variation in the socio-economic status levels of women residing in urban areas, and studies have shown that overweight shifts from individuals with high socio-economic status to those in lower socio-economic status groups as countries develop economically (17). Future research to investigate how the prevalence of the individual-level DBM varies by socio-economic status in countries at various stages of economic development may provide further insight into the subpopulations most affected by co-occurring overweight and micronutrient deficiencies. Fourth, we used RBP rather than retinol as an indicator of vitamin A status. However, RBP concentration has been shown to be a good predictor of plasma retinol concentration (82), and we used population-specific cut-offs calibrated to equal retinol cut-offs for vitamin A deficiency and insufficiency (82). Finally, dietary data for women were not available to explore the relationship between dietary patterns and women's nutritional status. Analyses of food consumption data may help explain differences in women's nutritional status according to residence. For example, such analyses could uncover reasons that zinc deficiency was higher in women in urban areas compared to their rural counterparts, such as differential intakes of total zinc, lower consumption of higher bioavailable animal-source zinc, or higher intake of phytate, which inhibits zinc absorption (123-125).

A major strength of this study was its examination of co-occurring overweight and micronutrient deficiencies, in addition to co-occurring overweight and anemia. Micronutrient status data are not routinely collected (11, 36, 37), due to complexity and expense of collecting and analyzing specimens for micronutrient biomarkers (36). Consequently, evaluations of co-occurring overweight and micronutrient deficiencies, are rare. An additional strength was that we use a comprehensive definition of co-occurring overweight and micronutrient deficiencies by using a 'micronutrient index' that captures the presence of one or more micronutrient deficiencies. This is an improvement upon previous studies which only provided estimates of co-occurring overweight with single micronutrient deficiencies. Lastly, we examined the prevalence

of the individual-level DBM in women by residence in urban or rural areas, which is useful given that national estimates can mask variations in the prevalence within countries.

In conclusion, this study is one of the few to investigate the DBM at the individual level in women in sub-Saharan Africa (50, 126). As urbanization and economic development continues and the nutrition transition advances in Malawi, it will be important to monitor the individual-level DBM on national and subnational levels. Evidence from other LMICs consistently shows that overweight rises and urban-rural differences in overweight diminish with increasing economic development and further urbanization (17). This pattern portends a growing proportion of women with co-occurring overweight and anemia or micronutrient deficiencies in Malawi, particularly if anemia and micronutrient deficiencies remain at current levels.

Chapter 6 Tables and Figures

Table 6.1: Socio-demographic characteristics of non-pregnant women of reproductive age in Malawi

	All (n = 723)
Residence	
Urban	9.1 (1.5, 16.8)
Rural	90.9 (83.2, 98.5)
Education	
< Secondary	79.0 (73.2, 84.8)
≥ Secondary	21.0 (15.2, 26.8)
Wealth	
Poorest	22.7 (16.8, 28.6)
Poorer	19.5 (14.6, 24.4)
Middle	19.6 (15.9, 23.3)
Richer	25.1 (19.8, 30.3)
Richest	13.2 (7.5, 18.9)
Age, years	
15-19	20.2 (16.3, 24.0)
20-29	38.6 (32.7, 44.5)
30-39	24.7 (20.4, 29.0)
40-49	16.5 (13.5, 19.6)

Data are weighted percent and 95% CIs.

Table 6.2: Weighted prevalence estimates of single conditions of malnutrition and co-occurring overweight and undernutrition among non-pregnant women of reproductive age in Malawi, according to residence (n=723)

	Total	Urban	Rural	p value[1]
Single malnutrition conditions				
Overweight[2]	14.5 (10.6, 18.4)	34.4 (25.8, 43.0)	12.5 (8.8, 16.2)	0.02
Anemia[3]	19.9 (16.5, 23.4)	17.8 (6.4, 29.2)	20.2 (16.5, 23.8)	0.69
Micronutrient deficiencies				
≥ 1 micronutrient deficiencies[4]	72.8 (67.7, 77.8)	87.8 (74.3, 100.0)	71.3 (66.3, 76.3)	0.15
Zinc deficiency[5]	61.8 (54.8, 68.9)	82.8 (66.2, 99.5)	59.7 (52.7, 66.8)	0.15
Iron deficiency[6]	16.0 (12.6, 19.4)	16.2 (7.5, 24.9)	16.0 (12.3, 19.7)	0.96
Folate deficiency[7]	7.6 (4.7, 10.5)	4.5 (0.0, 9.3)	7.9 (4.8, 11.1)	0.36
Vitamin B12 deficiency[8]	12.4 (8.7, 16.2)	0.4 (0.0, 1.0)	13.6 (9.6, 17.6)	0.02
Vitamin A deficiency[9]	0.3 (0.0, 0.8)	-	0.4 (0.0, 0.9)	-
Micronutrient insufficiencies				
Folate insufficiency[10]	80.9 (75.3, 86.6)	98.3 (96.0, 100.0)	79.2 (73.3, 85.1)	0.02
Vitamin B12 depletion[11]	39.6 (33.2, 46.0)	19.6 (6.7, 32.4)	41.6 (34.8, 48.5)	0.05
Vitamin A insufficiency[12]	5.0 (2.8, 7.2)	1.0 (0.0, 2.4)	5.4 (3.1, 7.8)	0.07
Co-occurring overweight and anemia				
Overweight + anemia	3.4 (1.3, 5.5)	6.9 (0.6, 13.2)	3.0 (0.8, 5.3)	0.36
Co-occurring overweight and micronutrient deficiencies				
Overweight + ≥ 1 micronutrient deficiencies	10.8 (7.0, 14.5)	32.6 (24.1, 41.2)	8.6 (5.2, 11.9)	0.02
Overweight + zinc deficiency	9.8 (6.1, 13.6)	31.3 (22.1, 40.4)	7.7 (4.4, 11.0)	0.03
Overweight + iron deficiency	2.6 (1.0, 4.1)	2.5 (0.0, 5.3)	2.6 (0.9, 4.3)	0.97
Overweight + folate deficiency	1.8 (0.8, 2.9)	1.5 (0.0, 3.2)	1.8 (0.7, 3.0)	0.73
Overweight + vitamin B12 deficiency	0.8 (0.2, 1.5)	-	0.9 (0.2, 1.7)	-
Overweight + vitamin A deficiency	0.1 (0.0, 0.3)	-	0.1 (0.0, 0.3)	-
Co-occurring overweight and micronutrient insufficiencies				
Overweight + folate insufficiency	12.5 (8.9, 16.0)	34.2 (25.7, 42.8)	10.3 (7.1, 13.5)	0.02
Overweight + vitamin B12 depletion	4.4 (2.0, 6.7)	1.6 (0.0, 3.8)	4.6 (2.0, 7.2)	0.21
Overweight + vitamin A insufficiency	0.0 (0.0, 0.1)	-	0.0 (0.0, 0.1)	-

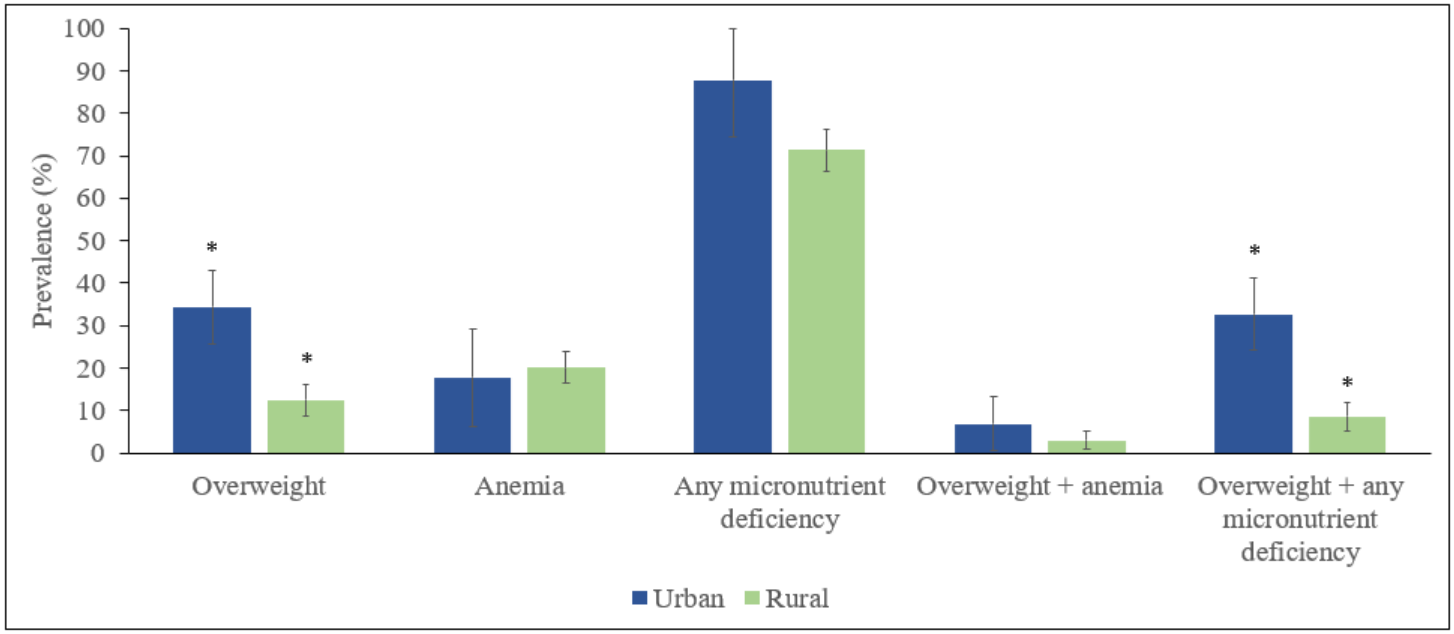
Data are weighted proportions and 95% CIs.

-, for prevalence estimates, 0 unweighted cases. For p-value, cannot be calculated.

[1] Based on Rao-Scott modified Chi-Square test.

[2] Overweight defined as BMI $\geq$ 25.0 kg/m^2.
[3] Anemia defined as hemoglobin (adjusted for altitude and smoking) < 12.0 g/dL for non-pregnant women.
[4] $\geq$ 1 micronutrient deficiencies defined as a deficiency in one or more of the following micronutrients: zinc, iron, folate, vitamin B12, vitamin A.
[5] Zinc deficiency defined as serum zinc concentration < 70 µg/dL for morning fasted samples, < 66 µg/dL for morning non-fasting samples, and < 59 µg/dL for afternoon non-fasting samples.
[6] Iron deficiency defined as inflammation-corrected ferritin < 15 µg/L.
[7] Folate deficiency was based on risk of megaloblastic anemia defined as serum folate concentration < 6.8 nmol/L.
[8] Vitamin B12 deficiency defined as serum vitamin B12 concentration < 150 pmol/L.
[9] Vitamin A deficiency defined as retinol binding protein (RBP) < 0.46 µmol/L calibrated to equal retinol < 0.7 µmol/L using regression analysis.
[10] Folate insufficiency defined as red blood cell folate concentration < 748 nmol/L.
[11] Vitamin B12 depletion defined as serum vitamin B12 concentration < 220 pmol/L.
[12] Vitamin A insufficiency defined as RBP $\geq$ 0.46 to < 0.86 µmol/L calibrated to equal retinol $\geq$ 0.7 to < 1.05 µmol/L using regression analysis.

Figure 6.1: Weighted prevalence estimates of overweight, anemia, and any micronutrient deficiencies and two characterizations of the individual-level double burden[1] (n=723)



[1] Individual level-double burden defined two ways: co-occurring overweight and anemia, and co-occurring overweight and any micronutrient deficiency.
*p<.05

Table 6.3: Associations between urban residence and single conditions of malnutrition and co-occurring overweight and undernutrition among non-pregnant women of reproductive age in Malawi (n=723)

	Unadjusted OR (95% CI)	**Adjusted OR (95% CI)**[1]
Single malnutrition conditions		
Overweight[2]	3.7 (2.2, 6.1) ***	2.3 (1.4, 3.7) ***
Anemia[3]	0.9 (0.4, 2.0)	1.0 (0.4, 2.8)
≥ 1 micronutrient deficiencies[4]	2.9 (0.8, 10.6)	3.7 (0.99, 13.8)
Zinc deficiency[5]	3.3 (1.0, 10.9)	4.5 (1.2, 16.4) *
Folate insufficiency[6]	15.2 (3.6, 63.8) ***	12.0 (2.8, 51.9) ***
Co-occurring overweight and micronutrient deficiencies		
Overweight + ≥ 1 micronutrient deficiencies	5.2 (2.9, 9.1) ***	3.2 (1.8, 5.6) ***
Overweight + zinc deficiency	5.5 (2.9, 10.2) ***	3.4 (1.8, 6.5) ***
Co-occurring overweight and micronutrient insufficiency		
Overweight + folate insufficiency	4.5 (2.7, 7.5) ***	2.6 (1.6, 4.2) ***

Data are ORs (95% CI). Reference for ORs is rural residence.

[1] Adjusted for education (< secondary, ≥ secondary), household wealth index (poorest, poorer, middle, richer, richest), and age in years (continuous).

**P < 0.05; **P < 0.01; ***P < 0.001*

[2] Overweight defined as BMI ≥ 25.0 kg/m^2.

[3] Anemia defined as hemoglobin (adjusted for altitude and smoking) < 12.0 g/dL for non-pregnant women.

[4] ≥ 1 micronutrient deficiencies defined as a deficiency in one or more of the following micronutrients: zinc, iron, folate, vitamin B12, vitamin A.

[5] Zinc deficiency defined as serum zinc concentration < 70 µg/dL for morning fasted samples, < 66 µg/dL for morning non-fasting samples, and < 59 µg/dL for afternoon non-fasting samples.

[6] Folate insufficiency defined as red blood cell folate concentration < 748 nmol/L.

Table 6.4: Comparison of the observed prevalence of co-occurring overweight and undernutrition with the prevalence expected by chance among non-pregnant women of reproductive age in Malawi (n=723)

	Observed co-occurrence (%)	**Expected co-occurrence (%)**	***P value***[1]
Co-occurring overweight and anemia			
OW + anemia[2,3]	3.4	2.9	0.53
Urban	6.9	6.1	0.69
Rural	3.0	2.5	0.53
Co-occurring overweight and micronutrient deficiencies			
OW + ≥ 1 micronutrient deficiencies[4]	10.8	10.5	0.73
Urban	32.6	30.2	0.30
Rural	8.6	8.9	0.67
OW + zinc deficiency[5]	9.8	9.0	0.27
Urban	31.3	28.5	0.27
Rural	7.7	7.5	0.77
OW + iron deficiency[6]	2.6	2.3	0.65
Urban	2.5	5.6	0.0097**
Rural	2.6	2.0	0.32
OW + folate deficiency[7]	1.8	1.1	0.09
Urban	1.5	1.5	0.89
Rural	1.8	1.0	0.06
OW + vitamin B12 deficiency[8]	0.8	1.8	0.0091**
Urban	-	0.1	-
Rural	0.9	1.7	0.04*
OW + vitamin A deficiency[9]	0.1	0.0	0.55
Urban	-	-	-
Rural	0.1	0.0	0.51
Co-occurring overweight and micronutrient insufficiencies			
OW + folate insufficiency[10]	12.5	11.7	0.18
Urban	34.2	33.8	0.24
Rural	10.3	9.9	0.47
OW + vitamin B12 depletion[11]	4.4	5.7	0.12
Urban	1.6	6.7	0.10
Rural	4.6	5.2	0.50
OW + vitamin A insufficiency[12]	0.0	0.7	0.0001***
Urban	-	0.3	-
Rural	0.0	0.7	0.0004***

OW, overweight.
Data are weighted proportions.
**P < 0.05; **P < 0.01; ***P < 0.001*
-, for prevalence estimates, 0 unweighted cases. For chi-square test statistic and p-value, cannot be calculated.
[1] Based on Rao-Scott modified Chi-Square test.
[2] Overweight defined as BMI ≥ 25.0 kg/m^2.
[3]Anemia defined as hemoglobin (adjusted for altitude and smoking) < 12.0 g/dL in pregnant women.
[4] ≥ 1 micronutrient deficiencies defined as a deficiency in one or more of the following micronutrients: zinc, iron, folate, vitamin B12, vitamin A.

[5] Zinc deficiency defined as serum zinc concentration < 70 µg/dL for morning fasted samples, < 66 µg/dL for morning non-fasting samples, and < 59 µg/dL for afternoon non-fasting samples.
[6] Iron deficiency defined as inflammation-corrected ferritin < 15 µg/L.
[7] Folate deficiency was based on risk of megaloblastic anemia defined as serum folate concentration < 6.8 nmol/L.
[8] Vitamin B12 deficiency defined as serum vitamin B12 concentration < 150 pmol/L.
[9] Vitamin A deficiency defined as retinol binding protein < 0.46 µmol/L calibrated to equal retinol < 0.7 µmol/L.
[10] Folate insufficiency defined as red blood cell folate concentration < 748 nmol/L.
[11] Vitamin B12 depletion defined as serum vitamin B12 concentration < 220 pmol/L.
[12] Vitamin A insufficiency defined as retinol binding protein $\geq$ 0.46 to < 0.86 µmol/L calibrated to equal retinol $\geq$ 0.7 to < 1.05 µmol/L.

Supplemental Table 6.1: Anemia and micronutrient deficiencies and insufficiencies according to weight status (underweight, normal weight, overweight) in Malawian women of reproductive age (n=723)

Category	Underweight	Normal Weight	Overweight	p value[1]
Anemia[2]				0.67
No	76.2 (61.8, 90.6)	81.2 (77.0, 85.3)	76.5 (64.8, 88.3)	
Yes	23.8 (9.4, 38.2)	18.8 (14.7, 23.0)	23.5 (11.7, 35.2)	
Micronutrient deficiencies				
≥ 1 micronutrient deficiencies[3]				0.68
No	32.9 (17.4, 48.3)	26.9 (22.1, 31.6)	25.6 (13.7, 37.5)	
Yes	67.1 (51.7, 82.6)	73.1 (68.4, 77.9)	74.4 (62.5, 86.3)	
Zinc deficiency[4]				0.50
No	41.7 (25.7, 57.6)	38.9 (31.7, 46.1)	32.0 (19.1, 44.9)	
Yes	58.3 (42.4, 74.3)	61.1 (53.9, 68.3)	68.0 (55.1, 80.9)	
Iron deficiency[5]				0.27
No	75.2 (61.5, 88.9)	85.4 (81.8, 89.1)	82.2 (73.4, 91.1)	
Yes	24.8 (11.1, 38.5)	14.6 (10.9, 18.2)	17.8 (8.9, 26.6)	
Folate deficiency[6]				0.21
No	91.8 (84.4, 99.3)	93.4 (90.5, 96.3)	87.5 (79.9, 95.0)	
Yes	8.2 (0.7, 15.6)	6.6 (3.7, 9.5)	12.5 (5.0, 20.1)	
Vitamin B12 deficiency[7]				0.23
No	90.0 (76.2, 100.0)	86.0 (81.4, 90.7)	94.2 (89.8, 98.5)	
Yes	10.0 (0.0, 23.8)	14.0 (9.3, 18.6)	5.8 (1.5, 10.2)	
Vitamin A deficiency[8]				
No	100 (100.0, 100.0)	99.7 (99.1, 100)	99.3 (97.9, 100.0)	-
Yes	-	0.3 (0.0, 0.9)	0.7 (0.0, 2.1)	
Micronutrient insufficiencies				
Folate insufficiency[9]				0.36
No	19.3 (8.0, 30.5)	20.1 (14.0, 26.2)	13.7 (5.2, 22.2)	
Yes	80.7 (69.5, 92.0)	79.9 (73.8, 86.0)	86.3 (77.8, 94.8)	
Vitamin B12 depletion[10]				0.07
No	70.6 (55.7, 85.5)	57.3 (50.2, 64.5)	69.9 (56.6, 83.3)	
Yes	29.4 (14.5, 44.3)	42.7 (35.5, 49.8)	30.1 (16.7, 43.4)	
Vitamin A insufficiency[11]				0.04*
No	88.5 (78.7, 98.2)	94.8 (92.4, 97.3)	99.8 (99.3, 100.0)	
Yes	11.5 (1.8, 21.3)	5.2 (2.7, 7.6)	0.2 (0.0, 0.7)	

Data are percent and 95% CI

-, for prevalence estimates, 0 unweighted cases. For p-value, cannot be calculated.

[1] Based on Rao-Scott Chi-Square Test. **P < 0.05; **P < 0.01; ***P < 0.001*

[2] Anemia defined as hemoglobin (adjusted for altitude and smoking) < 12.0 g/dL for non-pregnant women.

[3] ≥ 1 micronutrient deficiencies defined as a deficiency in one or more of the following micronutrients: zinc, iron, folate, vitamin B12, vitamin A.

[4] Zinc deficiency defined as serum zinc concentration < 70 μg/dL for morning fasted samples, < 66 μg/dL for morning non-fasting samples, and < 59 μg/dL for afternoon non-fasting samples.

[5] Iron deficiency defined as inflammation-corrected ferritin < 15 μg/L.

[6] Folate deficiency was based on risk of megaloblastic anemia defined as serum folate concentration < 6.8 nmol/L.

[7] Vitamin B12 deficiency defined as serum vitamin B12 concentration < 150 pmol/L.

[8] Vitamin A deficiency defined as retinol binding protein (RBP) < 0.46 µmol/L calibrated to equal retinol < 0.7 µmol/L using regression analysis.
[9] Folate insufficiency defined as red blood cell folate concentration < 748 nmol/L.
[10] Vitamin B12 depletion defined as serum vitamin B12 concentration < 220 pmol/L.
[11] Vitamin A insufficiency defined as RBP ≥ 0.46 to < 0.86 µmol/L calibrated to equal retinol ≥ 0.7 to < 1.05 µmol/L using regression analysis.

Supplemental Table 6.2: Anemia and micronutrient deficiencies and insufficiencies according to weight status (normal weight, overweight) in Malawian women of reproductive age (n=660)

Category	Normal Weight	Overweight	p value[1]
Anemia[2]			0.49
No	81.2 (77.0, 85.3)	76.5 (64.8, 88.3)	
Yes	18.8 (14.7, 23.0)	23.5 (11.7, 35.2)	
Micronutrient deficiencies			
≥ 1 micronutrient deficiencies[3]			0.82
No	26.9 (22.1, 31.6)	25.6 (13.7, 37.5)	
Yes	73.1 (68.4, 77.9)	74.4 (62.5, 86.3)	
Zinc deficiency[4]			0.30
No	38.9 (31.7, 46.1)	32.0 (19.1, 44.9)	
Yes	61.1 (53.9, 68.3)	68.0 (55.1, 80.9)	
Iron deficiency[5]			0.48
No	85.4 (81.8, 89.1)	82.2 (73.4, 91.1)	
Yes	14.6 (10.9, 18.2)	17.8 (8.9, 26.6)	
Folate deficiency[6]			0.07
No	93.4 (90.5, 96.3)	87.5 (79.9, 95.0)	
Yes	6.6 (3.7, 9.5)	12.5 (5.0, 20.1)	
Vitamin B12 deficiency[7]			0.01*
No	86.0 (81.4, 90.7)	94.2 (89.8, 98.5)	
Yes	14.0 (9.3, 18.6)	5.8 (1.5, 10.2)	
Vitamin A deficiency[8]			0.58
No	99.7 (99.1, 100.0)	99.3 (97.9, 100.0)	
Yes	0.3 (0.0, 0.9)	0.7 (0.0, 2.1)	
Micronutrient insufficiencies			
Folate insufficiency[9]			0.18
No	20.1 (14.0, 26.2)	13.7 (5.2, 22.2)	
Yes	79.9 (73.8, 86.0)	86.3 (77.8, 94.8)	
Vitamin B12 depletion[10]			0.09
No	57.3 (50.2, 64.5)	69.9 (56.6, 83.3)	
Yes	42.7 (35.5, 49.8)	30.1 (16.7, 43.4)	
Vitamin A insufficiency[11]			0.0005***
No	94.8 (92.4, 97.3)	99.8 (99.3, 100.0)	
Yes	5.2 (2.7, 7.6)	0.2 (0.0, 0.7)	

Data are percent and 95% CI
[1] Based on Rao-Scott Chi-Square Test. **P < 0.05; **P < 0.01; ***P < 0.001*
[2] Anemia defined as hemoglobin (adjusted for altitude and smoking) < 12.0 g/dL for non-pregnant women.

[3] ≥ 1 micronutrient deficiencies defined as a deficiency in one or more of the following micronutrients: zinc, iron, folate, vitamin B12, vitamin A.
[4] Zinc deficiency defined as serum zinc concentration < 70 µg/dL for morning fasted samples, < 66 µg/dL for morning non-fasting samples, and < 59 µg/dL for afternoon non-fasting samples.
[5] Iron deficiency defined as inflammation-corrected ferritin < 15 µg/L.
[6] Folate deficiency was based on risk of megaloblastic anemia defined as serum folate concentration < 6.8 nmol/L.
[7] Vitamin B12 deficiency defined as serum vitamin B12 concentration < 150 pmol/L.
[8] Vitamin A deficiency defined as retinol binding protein (RBP) < 0.46 µmol/L calibrated to equal retinol < 0.7 µmol/L using regression analysis.
[9] Folate insufficiency defined as red blood cell folate concentration < 748 nmol/L.
[10] Vitamin B12 depletion defined as serum vitamin B12 concentration < 220 pmol/L.
[11] Vitamin A insufficiency defined as RBP ≥ 0.46 to < 0.86 µmol/L calibrated to equal retinol ≥ 0.7 to < 1.05 µmol/L using regression analysis.

Chapter 7: Summary and Conclusions

Summary of main findings

This dissertation used qualitative and quantitative methods to understand the process of collecting national nutrition data to monitor under- and overnutrition and investigate the DBM in Malawi. We found that the survey model for collecting nutrition data in Malawi needs improvement. There was strong interest amongst stakeholders from the Government of Malawi to integrate the 2015-16 MNS into the 2015-16 MDHS. Perceived benefits of integrating the surveys included potential cost-savings for the Malawi Government and lower respondent burden. However, stakeholders from the Malawi Government, international agencies, and data collection teams did not view the MNS and MDHS to be fully integrated during implementation of the surveys. The lack of full integration of the surveys created serious challenges, such as complex field logistics, high time investment, duplication in the nutrition data collected, and difficulties in gaining buy-in among all stakeholders. Given these challenges, stakeholders voiced concern about the model of implementation of the MDHS and MNS and described a need for improved survey models to obtain national nutrition data. Of note, however, Malawi Government stakeholders ultimately were pleased that the country completed the surveys despite the challenges and the data would be available to inform policy making. Their views underscored the demand for national nutrition data in Malawi.

With the use of data from nationally representative nutrition surveys, we showed that overweight and obesity co-exist with issues of undernutrition at the population and individual levels in Malawian women. Unlike most other LMICs that are experiencing a growing problem of overweight and obesity (30, 97), the prevalence of overweight and obesity in women has not changed from 2001 through 2015-16. Still, in 2015-16, the prevalence of obesity was approximately 3%, and the prevalence of overweight was about 10%. While the prevalence of obesity was low, the fact that approximately one in ten women were overweight is concerning

given existing evidence on the health effects of overweight. The lowest overall risk of death has been observed to be for a BMI of 20 to 25 (127). Evidence from a recent meta-analysis of 239 prospective studies showed that overweight was associated with higher all-cause mortality (128). At the same time, Malawi has experienced increases in underweight prevalence, in contrast to the majority of LMICs which have seen declining levels of underweight (96). Iron deficiency anemia and iron deficiency prevalence has not changed in recent years, as shown using two indicators of iron status. Notably, the prevalence of iron deficiency in Malawian women is lower than the prevalence in other sub-Saharan African countries with data on women's iron status, such as Cameroon, Cote d'Ivoire, and Liberia (81).

Our results illustrate that Malawi is making progress on some fronts. We found marked declines in the prevalence of both vitamin A deficiency and vitamin A insufficiency between 2001 and 2015-16. In 2015-16, the prevalence of vitamin A deficiency in women was less than 1%. A very low prevalence of vitamin A deficiency among preschool children, school-aged children, and men in 2015-16 has been reported elsewhere (4%, 1%, and <1%, respectively) (58). Thus, vitamin A deficiency is no longer a public health problem in Malawi (i.e., < 5% prevalence of vitamin A deficiency) (37). This is a major achievement for the country, which has shown strong political will and made significant investments in vitamin A interventions to improve the vitamin A status of its population. We also found reductions in anemia prevalence from 2001 through 2015-16, with a prevalence of less than 20% in 2015-16. Thus, according to the World Health Organization's classification of the public health significance of anemia, anemia in women is now a mild public health problem in the country (106).

Examining the DBM at the individual level, we found that the prevalence of co-occurring overweight and anemia was low. However, more than one in ten women had co-occurring overweight and micronutrient deficiencies. Furthermore, we found the individual-level DBM to

be a larger problem in women in urban areas; women in urban areas were 3-times more likely to have co-occurring overweight and micronutrient deficiencies than women in rural areas.

Strengths and limitations

A key strength of this dissertation was the examination of the DBM in women at both the population and individual levels. In addition to evaluating trends in women's nutritional status, we documented the existence of co-occurring overweight and anemia or micronutrient deficiencies in individual women. Together, this work provides a more complete understanding of the DBM among women than research focused only on the population level DBM or individual-level DBM. Another major strength of this dissertation was that it used micronutrient status data from nationally representative nutrition surveys in quantitative analyses. Such data are relatively rare, given that health and nutrition surveys do not routinely collect biomarkers to assess micronutrient status (11, 36-38). Thus, this dissertation was able to improve upon existing approaches to measure the DBM. For example, to investigate the individual-level DBM, we measured co-occurring overweight and micronutrient deficiencies, rather than only co-occurring overweight and anemia, which is critical because anemia may result from non-nutritional factors as well as micronutrient deficiencies (11).

Also, the use of a qualitative research approach to evaluate the implementation of the 2015-16 MDHS and MNS was a major strength of this dissertation. Qualitative research allowed us to gain a detailed, in-depth understanding of what worked and what was challenging during implementation of the MDHS and MNS from the perspective of stakeholders who implemented the surveys. Furthermore, there were several strengths in how we carried out the qualitative research. First, we achieved diversity in our sample by purposively sampling participants from multiple stakeholder groups, including the Malawi Government, international agencies, and MDHS and MNS data collection teams. Thus, we were able to capture the perspectives of a variety of stakeholders with experience in all three phases of the MDHS and MNS

implementation process, including: preparation; data collection; and data analysis, reporting, and dissemination. Second, interviewers were trained on best practices for qualitative interviewing (for example, asking open-ended and non-leading questions, remaining neutral, developing rapport, using active listening, and probing), and they were re-trained after conducting the first several interviews to help ensure the collection of high quality data. Third, we used an inductive process of data collection, whereby we identified issues emerging from initial interviews and refined questions and probes on the interview guide for subsequent interviews (54). This process enabled us to go deeper into each issue as the data collection continued. Fourth, we employed strategies to validate our analyses (54), such as using the concept-indicator model and checking that we had developed codes that collectively represented the themes we had identified (76).

The research presented in this dissertation has limitations. First, the 2001 MNS and 2009 MNS data sets used for our analysis of trends in women's nutritional status had substantial missing data, which had the potential to undermine the validity of our findings (62). We addressed the problem of missing data by using multiple imputation, a robust method that has advantages over other strategies such as complete case analysis (63). Second, serum ferritin was not collected to assess iron status in the 2001 MNS. Consequently, it was only possible to evaluate trends in iron deficiency anemia and iron deficiency defined using ferritin from 2009 to 2015-16. Still, we were able to evaluate trends in iron deficiency anemia and iron deficiency from 2001 through 2015-16 using the sTfR definition. Third, there were some differences in the methods for data collection, measurement, and laboratory analyses across the three surveys. In the 2001 and 2009 MNS's, the HemoCue 201 model was used to measure hemoglobin, and in the 2015-16 MNS, the HemoCue 301 model was used. Studies have shown that these models may not produce the same results, but the differences are minimal (89). It is also important to note that capillary blood samples were used to measure hemoglobin in 2001 and 2009, compared to venous blood samples in 2015-16. One large study found that hemoglobin results in capillary blood

samples were slightly higher than in venous blood samples, however, the difference was small and not of relevance from a clinical perspective (89). A separate study using the HemoCue 201 model found no significant difference in hemoglobin results between venous and capillary blood samples (89). Fourth, we used RBP rather than retinol as an indicator of vitamin A status. Using retinol values to produce prevalence estimates of vitamin A deficiency would have improved our ability to compare our results to other studies (82). However, RBP is more robust to heat and light exposure and costs less to measure than retinol (80, 82). Also, at the population level, plasma RBP concentration has been shown to be a good predictor of plasma retinol concentration (82). Retinol was measured in a subsample of women, which allowed for the use of population-specific cut-offs calibrated to equal retinol cut-offs for vitamin A deficiency and insufficiency (82).

Another limitation of this research worth noting was that we did not include MDHS and MNS survey respondents as part of our sample in our qualitative evaluation of the MDHS and MNS. While the purpose of the research was to understand perspectives of stakeholders implementing the surveys, through in-depth interviews with these stakeholders we learned that a perceived benefit of integrating the MDHS and MNS was lower respondent burden. If more resources were available, we could have applied an iterative process of sampling and recruited survey respondents. Including survey respondents in our sample would have allowed for an understanding of the issue of respondent burden from their perspective. However, during interviews with stakeholders, we probed on the issue of respondent burden, and thus, were able to gain a detailed understanding of the issue from the perspectives of a variety of stakeholders. Additionally, it was not feasible to capture the full scope of the issue of dissemination of MDHS and MNS results, as dissemination is still ongoing in Malawi. However, we intentionally scheduled interviews with some stakeholders involved in dissemination activities to be conducted after the main dissemination event. This ensured we captured data on the dissemination phase of the implementation process.

Finally, in investigations of the DBM, it is also pertinent to examine NCDs. In this dissertation, however, it was not possible to investigate prevalence and trends in NCDs because indicators of diabetes and other NCDs were not collected as part of the Malawi Micronutrient Surveys. Additionally, potential implementation challenges related to the collection of data on NCDs remain unknown, which is a particularly notable limitation given increasing interest among stakeholders in the Malawi Government to collect data on NCDs in future national surveys.

Public health implications

Contribution to the public health literature

With the use of micronutrient status data, this dissertation was able to address gaps in the scientific literature on the DBM at the population and individual levels, especially in low-income countries in sub-Saharan Africa. For example, trends in underweight and overweight are often studied to explore shifts in the burden of under- and overnutrition in LMICs undergoing the nutrition transition. However, trends in underweight cannot be used to draw conclusions about other conditions of undernutrition, such as micronutrient deficiencies, as illustrated by our results that show overweight women can be deficient in micronutrients. As such, previous studies of trends in underweight and overweight are insufficient for understanding the full scope of the DBM and changes over time. In our analysis, we evaluated trends in iron deficiency and vitamin A deficiency, in addition to trends in underweight and overweight. Therefore, the results of our analysis provided a more comprehensive portrayal of under- and overnutrition in Malawian women over time. In addition, we assessed the individual-level DBM using a definition of co-occurring overweight and micronutrient deficiencies. The use of this definition represents an advancement in how the individual-level DBM is measured and can be used in future studies. This dissertation also contributed to the limited evidence base on implementation of large, population-based nutrition surveys. The case example of the 2015-16 MDHS and MNS provided empirical evidence that Government stakeholders are highly interested in integrated survey

models. Additionally, our results expand knowledge of the perceived benefits and disadvantages of integrated survey models, as well as the challenges associated with implementing integrated surveys.

Implications for nutrition surveillance and interventions

Several implications for nutrition surveillance and interventions in Malawi and other LMICs emerge from this dissertation work. The findings illustrate that monitoring the prevalence of micronutrient deficiencies in addition to anemia is critical for ensuring nutrition policies and programs are evidence-informed and appropriate. Perhaps the most striking example of the value of data on micronutrient status is that of vitamin A. We found that vitamin A deficiency among women decreased substantially from 2001 through 2015-16, with vitamin A deficiency nearly reaching 0% in 2015-16. Similarly, results of the 2015-16 MNS for preschool children, school-aged children, and men presented elsewhere showed that vitamin A deficiency was 4%, 1%, and <1%, respectively (58). This is crucial information since Malawi has several interventions in place to improve vitamin A status in the population (i.e., fortification of oil and sugar with vitamin A, high-dose vitamin A supplementation) and, most recently, began scaling up micronutrient powders, which contain vitamin A. The results of our trend analysis, along with the results of the 2015-16 MNS, indicate that Malawi does not need to invest in additional vitamin A interventions. Furthermore, the country is now taking steps to assess whether vitamin A excess is evident in the population. If there are signs of vitamin A excess, Malawi should consider whether it is appropriate and justifiable to scale back vitamin A interventions, such as vitamin A supplementation, or remove vitamin A from the formulation of micronutrient powders. In the absence of data on vitamin A status, Malawi may have continued to focus solely on funding and scaling up vitamin A interventions, wasting limited resources and potentially causing vitamin A excess.

It also was apparent that data on iron status provided valuable insight on the issue of anemia. Specifically, the finding that the prevalence of iron deficiency anemia and iron deficiency in women did not decrease between 2001 and 2015-16 while anemia prevalence declined indicates that there are other important determinants of anemia in Malawian women. Additionally, this finding demonstrates that if Malawi had only measured anemia and used anemia as a proxy for iron deficiency, as most LMICs currently do, the country may have presumed incorrectly that iron deficiency prevalence was declining. Based on evidence that the prevalence of iron deficiency has not changed, greater efforts are needed to address iron deficiency, such as improved coverage of iron supplementation and interventions to improve dietary intake of iron. In addition, the utility of measuring zinc status was clear. When zinc status was measured for the first time in Malawi as part of the 2015-16 MNS, we found that zinc deficiency among women was greater than 60% nationally. This finding has brought attention to the issue of zinc deficiency and motivated policy makers to call for a new focus on zinc deficiency. It also has prompted discussions among policy makers and researchers on how to gather additional data to better understand the problem and incorporate strategies for improving zinc status into national programs. Notably, a theme that ran throughout this dissertation was that Malawi is unique among LMICs in collecting data on micronutrient status routinely. The utility of micronutrient status data for policy making in Malawi provides a compelling case for why other LMICs should follow Malawi's lead and build micronutrient status data collection into their national surveys.

Additionally, the results of this dissertation highlight that incorporating micronutrient status assessment into national health surveys is feasible and desirable among Government stakeholders given the numerous perceived benefits. Moreover, our findings suggest that greater integration of micronutrient status assessment into DHS surveys is worth pursuing in Malawi as the Government and international stakeholders design the next MNS planned as part of the 2018-

2022 National Multi-Sector Nutrition Strategic Plan, as well as in other LMICs (12). One potential approach is to include nutrition as an optional module within the DHS survey that countries can request to include, much like the optional modules on domestic violence, newborn care, and a variety of other topics currently available for inclusion.

Finally, this dissertation work underscores the need to have surveillance systems in place to monitor both under- and overnutrition. Nutrition surveillance systems in LMICs historically have focused on undernutrition and monitoring of overweight and obesity and NCDs is lacking. Although overweight and obesity are commonly assessed as part of national nutrition and health surveys (4, 59, 129), few of these surveys collect data to monitor overweight and obesity in subpopulations, such as men, school-aged children, and older adults (17). Routine data collection of overweight and obesity in both males and females and all age groups must be prioritized equally with monitoring of stunting, underweight, and other conditions of undernutrition (17). Furthermore, few surveillance systems in LMICs monitor NCDs (17). Taking the example of diabetes, a 2016 study reported that nationally representative biomarker data to assess diabetes status were not collected in 21 sub-Saharan African countries (98). In countries where these data were collected, the data were often outdated and based on small samples (98). As LMICs face growing burdens of obesity and NCDs, population-based surveys need to include collection of data on diabetes, cardiovascular disease, and hypertension (17). Assessment of NCDs could be incorporated into a nutrition module to be included in DHS surveys along with micronutrient status assessment. Such a module would provide a more comprehensive understanding of malnutrition, as it would provide data on both under- and overnutrition. Furthermore, data on under- and overnutrition can be used to examine the DBM at the population, household, and individual levels.

Concept of the double burden of malnutrition

In a 2011 article entitled 'Global Burden of Double Malnutrition: Has Anyone Seen It?', Corsi et al. wrote that "the scientific and policy narratives related to the double burden of malnutrition in LMICs need to be evidence-based in order to be focused and fair" (130). Nearly a decade later, this perspective remains relevant, especially considering the growing attention and focus on the DBM among researchers and policy makers (1, 2). On the one hand, the increasing focus on the DBM is critical for accelerating progress towards addressing all forms of malnutrition (42). On the other hand, there is a potential danger if the scientific community and policy makers embrace the concept of the DBM and do not use data to support the increasingly common assertation that LMICs are facing a DBM at the population, household, and individual levels. Our findings from Malawi, for example, showed that the prevalence of the co-occurrence of overweight and anemia or micronutrient deficiencies was low, except for the co-occurrence of overweight and zinc deficiencies. This finding suggests that the individual-level double burden of malnutrition among women is not an extensive problem in Malawi at present. As such, programming may not need to be designed to address the individual-level double burden. Such information is critical, since health resources are limited in Malawi and investments in unnecessary programming should be avoided.

Additionally, we need to ensure we have the right data when determining the extent of the problem of the DBM. For example, we cannot rely on the prevalence of overweight and obesity as the only indicator of overnutrition. In Malawi, for instance, the national prevalence of obesity is low compared to many other LMICs (27). Thus, some may conclude that undernutrition remains the most pressing concern and the DBM is not yet a substantial issue. However, the prevalence of overweight and obesity may not be a good reflection of the scope of the problem of NCDs, especially in sub-Saharan African countries like Malawi where overweight and obesity likely do not play the same role in driving increases in NCDs compared with high-income

countries (131, 132). For example, risk factors for type 2 diabetes in countries in sub-Saharan Africa may include not only traditional risk factors like overweight and obesity but also issues of undernutrition, such as maternal undernutrition, placental insufficiency, and low birthweight (131, 132). As such, measurement of overweight and obesity only is particularly insufficient in sub-Saharan African countries and may lead to inaccurate conclusions about the DBM. Surveillance of NCDs is therefore needed to assess the extent of the co-existence of under- and overnutrition.

Future research directions

Single conditions of malnutrition

The findings of this dissertation raise several additional research questions that can be explored using MNS data. For example, using data on malaria, CRP, and AGP, the role of infection and inflammation in explaining the trends and prevalence of anemia and micronutrient deficiencies should be explored (58). The 2015-16 MNS data also provide an excellent opportunity to examine determinants of anemia since data on multiple possible determinants are available, including micronutrient deficiencies (i.e., deficiencies in iron, folate, vitamin B12, and vitamin A), blood disorders, and infection and inflammation. Identifying the determinants of anemia would be very useful for informing the design of interventions to address anemia in Malawi. Additionally, given Malawi's success in reducing vitamin A deficiency, a study examining the impact of vitamin A interventions on vitamin A status would be worthwhile and could generate evidence readily usable by policy makers in Malawi and other LMICs interested in addressing vitamin A deficiency. Finally, our finding that the prevalence of zinc deficiency among women is very high should be followed up by a study to explore risk factors for zinc deficiency, as well as intra-household patterns of zinc deficiency.

There also are several research questions that would be useful to explore as a follow-up to this dissertation work, but which will require additional data to be collected. For instance,

given the high prevalence of HIV in Malawi (59), studies should explore the link between HIV and anemia and micronutrient deficiencies. Further research on trends in the prevalence of overweight and obesity also would be worthwhile. For example, DHS data on overweight and obesity are available as early as 1992, which would allow for an analysis of trends over a longer time span. DHS data also are representative by urban-rural residence, enabling an investigation of trends according to residence. Additionally, investigations are needed to understand risk factors for overweight and obesity, drivers of food choice, and barriers and facilitators to healthy lifestyle behaviors.

Double burden of malnutrition

There are many opportunities for research to extend understanding of the double burden of malnutrition in Malawi and other LMICs. First, studies in countries beyond Malawi should be conducted to test the independence of overweight and micronutrient deficiencies by comparing the observed and expected prevalence of the individual-level double burden of malnutrition. Countries such as Mexico, Ecuador, Cambodia, Cameroon, and Vietnam have national data on multiple micronutrient deficiencies and overweight that could be used to carry out this research. Second, building on the work presented here, future studies could evaluate trends in co-occurring overweight and anemia or micronutrient deficiencies in women. Given that overweight and micronutrient status data from the 2009 MNS were in separate data sets that could not be merged, this topic was not explored here, but would be a worthwhile investigation to shed light on the DBM at the individual level in women in other LMICs.

Third, it is worth investigating the possible health consequences of the co-occurrence of under- and overnutrition. While the adverse health outcomes associated with obesity and micronutrient deficiencies separately are commonly studied, the potential effects of the co-occurrence of these conditions are less explored, particularly in LMICs such as Malawi. For example, more research is needed to understand the link between obesity and iron deficiency. A

growing number of studies indicate that obesity-related inflammation may increase levels of hepcidin, which in turn may contribute to lower absorption of iron and thereby increase iron deficiency risk (133-137). Furthermore, micronutrient deficiencies may contribute to the development of diet-related chronic diseases and vice versa. For instance, since zinc functions as an antioxidant, zinc deficiency may be linked to oxidative stress, which contributes to the development of cardiovascular disease, diabetes, and other chronic diseases (51). Also, folate deficiency is associated with increased homocysteine levels, a factor known to increase cardiovascular disease risk (51). Existing research indicates that diabetes can lead to poor metabolism of zinc, though the relationship between diabetes and zinc has not been well studied in LMICs like Malawi, where zinc deficiency is widespread and diabetes prevalence is increasing (51, 138). More research on the effect of undernutrition in utero and early childhood on long-term risk of obesity and NCDs also is needed, as much of what is known on this topic is based on animal models and observational studies (132). This area of research is especially relevant in Malawi and other LMICs in sub-Saharan Africa, where undernutrition remains highly prevalent (58, 132). Altogether, these areas of research would improve understanding of the complex links between under- and overnutrition in individuals and help guide decisions on whether special interventions should be developed to tackle the individual-level DBM.

Finally, future research should examine the prevalence and trends in conditions of under- and overnutrition among subpopulations beyond women, such as preschool-aged children, school-aged children, and men. Research to understand the nutritional status of school-aged children and men in LMICs is especially needed, given that the focus of much of the epidemiological research on nutrition in these settings to date has focused on maternal and early childhood nutrition (3).

Nutrition surveillance

Research is needed to strengthen nutrition surveillance systems in LMICs, particularly as data needs increase. One neglected, but critical, research area is the development and evaluation of population-based survey models. Currently, there is little evidence on how to effectively and efficiently implement population-based surveys to collect national nutrition data, particularly in LMICs where resources are scarce. Rigorous evaluations of different survey models are therefore needed to build an evidence base that can inform the design and implementation of surveys. Examples of survey models that are already being implemented in LMICs to collect nutrition data include: stand-alone nutrition surveys; 'subsample' models in which nutrition data is collected in a subsample of respondents participating in health surveys; and 'linkage' models such as the 2015-16 MDHS and MNS. Evaluations of these survey models can be included as part of the scope of work set out for these surveys and tailored to the needs and interests of countries. For example, some countries may be concerned about the cost and sustainability of routine collection of nutrition data. Cost evaluations and qualitative research can be conducted to provide insight on these issues. Cross-country comparative research also is needed to better understand the advantages and disadvantages of different survey models and barriers and facilitators to implementation in different contexts. This area of work is ripe for implementation scientists in the field of nutrition and has the potential to not only inform data collection for nutrition, but also other health issues in LMICs.

Research specifically focused on the inclusion of NCD assessment in population-based surveys also would be beneficial. For example, evaluations should be conducted to assess the effect of integrating NCD assessment into surveys on response rates and data quality. On the one hand, it is possible that expanding the number of indicators assessed will increase respondent burden and thereby reduce their willingness to participate in the survey, or it may reduce the quality of data collected by data collection teams due to increased complexity and workload. On

the other hand, the opportunity to be tested for NCDs may serve as an incentive for participation, increasing response rates. Additionally, data collection teams may be able to add assessment of NCDs to their responsibilities easily given the proper training. Furthermore, it will be useful to evaluate implementation challenges and outcomes, such as cost, feasibility, and acceptability of NCD data collection among respondents.

Research to enhance measurement of nutritional status in population-based surveys is necessary to enable LMICs to collect high quality, reliable data. For example, anthropometric data collected in population-based surveys are prone to measurement error (139-141). As a result, these data are often unreliable and inaccurate and can lead to overestimation of the prevalence of poor nutritional status in populations (139). The design and evaluation of technology to improve the quality of anthropometric data is an exciting area of research. The Body Imaging for Nutritional Assessment Study, for instance, evaluated the use of 3D imaging for child anthropometry and found the technology to show promise for improving the quality of anthropometric data (139). Field trials that integrate and evaluate new technologies such as 3D imaging into health and nutrition surveys are warranted to assess the accuracy and acceptability of these tools in population-based surveys. Opportunities for technological developments and research also exist for improving assessment of iron status in settings of inflammation (38). One important example is the need for development of inflammation biomarker tests that are accurate, reliable, affordable, and field-friendly and can be used in population-based surveys (38). In addition, research is needed to address the lack of validated cut-off points to classify overweight and obesity, particularly in subpopulations such as children, adolescents, and specific ethnic groups (17). To carry out this research, population-based data on BMI, waist circumference, and associated health outcomes are needed (17, 142, 143), providing further impetus for improving nutrition surveillance. There is also a pressing need for research that can inform decisions about which tests and cutoffs to use for assessing diabetes in sub-Saharan African populations (98).

While hemoglobin A1c (HbA1c) is often used in national surveys in high-income countries, such as the National Health and Nutrition Examination Survey in the United States, HbA1c may not be a reliable measure in populations in sub-Saharan Africa. For example, hemoglobinopathies and iron deficiency, both of which are highly prevalent in sub-Saharan African countries (58), may affect HbA1c test results (58, 144). Additionally, some researchers have proposed that the BMI cut-off value for obesity should be lowered for blacks, since black subjects have been found to develop diabetes at lower levels of BMI compared to whites (145). If BMI cutoffs for obesity were to be lowered, the prevalence of overweight and obesity in Malawian women for example would increase, which would make the problem of obesity an even greater public health problem. More research is needed to examine the relationship between BMI and risk of diabetes, hypertension, and cardiovascular disease in order to derive BMI cut-off points for obesity in sub-Saharan African populations and to validate these cut-off points.

Conclusion

Malawi offered a unique opportunity to investigate the DBM and explore what works well and what is challenging in implementing population-based surveys to collect the nutrition data needed to assess under- and overnutrition. As Malawi and other LMICs experience a shift from predominant issues of undernutrition to a double burden of under- and overnutrition, the objectives of surveillance systems also must shift. Evolution of nutrition surveillance systems in LMICs to meet the data needs of today would be a step toward addressing the DBM. With greater knowledge of the magnitude and distribution of the problems of under- and overnutrition, governments will be better positioned to make evidence-informed decisions when designing programs and targeting health resources (13). Furthermore, while efforts are directed towards improving surveillance, it is not too early to design and implement interventions that can address the dual problems of under- and overnutrition, given the urgency of these public health issues in LMICs.

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Appendix

Appendix A: Qualitative In-Depth Interview Guide

INTERVIEW GUIDE

Malawi DHS and Micronutrient Survey Integration

Thank you for agreeing to meet today. I would like to talk with you because we are writing a report on the integration of the micronutrient survey into the DHS. The purpose of the report is to share lessons learned and present recommendations for future integrated surveys. The report will be shared with stakeholders involved in the survey. Also, we plan to write a paper so that we can share the lessons learned with others too. In order to do this successfully, we feel that it is very important to understand the perspectives of people who were involved in the surveys. So, we are interviewing you, along with the regional coordinators and team leads, and project partners.

During our discussion today, we will be talking about the integration of the MNS into the DHS. In other words, we'll be talking about how the MNS was combined with the DHS. I am most interested to hear your personal experience, opinions, and views. So, please don't feel shy and feel free to share your honest opinions. Your views are very valuable, and we want to learn from you.

I have a list of questions I would like to ask you. My questions focus only on the integration of the MNS with the DHS, including what went well and what could be improved. Although there were challenges that are specific to the MNS, those will not be the focus of our discussion. Feel free to bring up any topics you feel are related to our discussion on the integration of the surveys.

Also, I want to let you know that your participation in this interview is completely voluntary. If you want to stop at any time or don't feel comfortable answering a question, please let me know.

I would like to record our discussion so that we don't miss anything you say. Our discussion will remain completely confidential. The information you give will only be used for writing the report, and you will not be identified in the report. Is it okay to record the discussion?

Our discussion will last about 45 minutes. Do you have any questions before we start?

[Answer any questions.]

Let's begin.

WARM-UP QUESTIONS

1. Can you describe your role in the survey?

2. From your perspective, what are the benefits of combining the DHS and MNS?

KEY QUESTIONS

I'd like to talk about the <u>planning process</u> and what it was like <u>getting ready for the integration</u> of the surveys. Please think back to the time before data collection started.

3. During this planning period, what worked well?
   [Probes – i.e., specific topics to ask about if the person doesn't bring them up on their own]
   a. Timeline
   b. Logistics
   c. Supplies
   d. Funds/Budget

4. During this planning period, what challenges did you experience with MNS being combined with the DHS?
   [Probes – i.e., specific topics to ask about if the person doesn't bring them up on their own]
   a. Timeline
   b. Logistics
   c. Supplies
   d. Funds/Budget

5. For each of the challenges you mentioned, what suggestions do you have for how we can lessen these challenges in future integrated surveys?
   [If needed, remind the person of the challenges s/he mentioned.]

Now, I'd like to talk about <u>implementation of the surveys</u> – the time when we were collecting data in the field.

6. [ASK ONLY IF PERSON ATTENDED THE TRAINING] Did the training adequately prepare you to work with the DHS?
   a. If yes, how?
   b. If no, why not?

7. [ASK ONLY IF PERSON ATTENDED THE TRAINING] If the DHS and MNS were to be integrated in the future, what suggestions would you have for the training?

8. During the implementation period, what positive experiences did you have with MNS being combined with the DHS? In other words, what worked well?

9. During the implementation period, what challenges did you experience with MNS being combined with the DHS?
   [Note: Not all probes will be relevant to everyone. For example, sample processing won't be relevant to people working on the data management. Please ask about the topics that are relevant to the person you're interviewing.]
   - Pilot
   - Handover
   - Logistics
   - Supplies
   - Informed consent and participation
   - Data collection
   - Data transfer (tracking of forms and questionnaires using transmittal sheets)
   - Sample processing
   - Working with local labs
   - Cold chain
   - Data management
   - Referrals
   - Staff
   - Funds/Budget
   - Ethical clearance
   - Overall coordination of partners
   - Governance of the survey/Roles/MNS Steering Committee

10. For each of the challenges you mentioned, what could we do differently to lessen these challenges in the future?
    [If needed, remind the person of the challenges s/he mentioned.]

Next, I'd like to talk about the <u>close-out of the surveys</u> – the time after data collection finished.

11. During the close-out of the survey, what went well?

12. During the close-out of the survey, what challenges did you experience with MNS being combined with the DHS?
    [Note: Not all probes will be relevant to everyone. Please ask about the topics that are relevant to the person you're interviewing.]
    - Shipping samples
    - Data management – data entry, data cleaning
    - Data analysis
    - Report writing
    - Budget/Funding

13. What would you change to lessen these challenges in the future?
    [If needed, remind the person of the challenges s/he mentioned.]

CLOSING QUESTIONS

14. Of all the challenges you talked about, which ones would concern you most for future integrated surveys?

15. If MNS were to be integrated into DHS or a similar type of survey, what would be your main recommendations for making the integration successful?

16. Is there anything else you would like to add that we haven't talked about yet?

Thank you for your time. I really appreciate you talking with me today.