Multisector intervention to accelerate reductions in child stunting: an observational study from 9 sub-Saharan African countries[1–4]

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ABSTRACT

Background: In sub-Saharan Africa, ~40% of children <5 y old are stunted, with levels that have remained largely unchanged over the past 2 decades. Although the complex determinants of undernutrition are well recognized, few studies have evaluated strategies that combine nutrition-specific, health-based approaches with food system– and livelihood-based interventions.

Objective: We examined changes in childhood stunting and its determinants after 3 y of exposure to an integrated, multisector intervention and compared these changes with national trends.

Design: A prospective observational trial was conducted across rural sites in 9 sub-Saharan African countries with baseline levels of childhood stunting >20%. A stratified random sample of households and resident children <2 y old from villages exposed to the program were enrolled in the study. Main outcome measures included principal determinants of undernutrition and childhood stunting, which was defined as a height-for-age *z* score less than −2. National trends in stunting were generated from demographic and health surveys.

Results: Three years after the start of the program in 2005–2006, consistent improvements were observed in household food security and diet diversity, whereas coverage with child care and disease-control interventions improved for most outcomes. The prevalence of stunting in children <2 y old at year 3 of the program (2008–2009) was 43% lower (adjusted OR: 0.57; 95% CI: 0.38, 0.83) than at baseline. The average national stunting prevalence for the countries included in the study had remained largely unchanged over the past 2 decades.

Conclusion: These findings provide encouraging evidence that a package of multisector interventions has the potential to produce reductions in childhood stunting. *Am J Clin Nutr* 2011;94:1632–42.

INTRODUCTION

The first MDG[5] is to reduce levels of extreme poverty and hunger by one-half by 2015. Progress on the hunger component of MDG 1 is critical for achieving other targets because undernutrition limits economic productivity (1, 2), increases vulnerability to infectious diseases (3), and contributes to over one-third of child deaths (3). Stunting is a slowing of linear growth that results from persistent deficits in nutritious food, inadequate child and maternal care, and/or frequent attacks of infectious disease (3, 4). This chronic manifestation of undernutrition affects 1 out of 3 children <5 y of age in the developing world (5). Although a number of countries have made substantial progress in reducing levels of stunting, declines in the African region have been marginal at best, from an estimated 38% in 1990 to 34% in 2008 (5). Moreover, because of population growth, the overall number of African children <5 y old who were stunted has increased from an estimated 43 million in 1990 to 52 million by 2008 (5).

The window of opportunity to influence child growth, nutritional status, and cognitive development are the first 1000 d of a child's life (from conception to 2 y of age) (6). Research on the impact of single interventions on early childhood stunting has shown small to moderate effects (7), which ranged from no effect (breastfeeding promotion and vitamin A supplementation) to a 15–17% decrease in stunting (zinc supplementation and safe complementary feeding) (7). Predictive models suggested that by combining food and micronutrient supplementation, fortification, and disease-control interventions, stunting prevalence could be

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[5] Abbreviations used: HAZ, height-for-age *z* score; MDG, Millennium Development Goal; MVP, Millennium Villages Project.

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reduced by one-third (7). Although a number of global health initiatives have attempted to deliver such multicomponent interventions in sub-Saharan Africa, large-scale evaluations have shown limited effects on stunting even with high levels of coverage (8–11).

We hypothesized that a reduction in chronic undernutrition is likely to require a more comprehensive approach that combines disease control and nutrition-specific interventions with wider multisector efforts to improve food and nutrition security (3–5, 12, 13). Although major global initiatives have recently been launched to support rapid, sustainable agricultural growth in smallholder farmers (14) and promote multisector approaches for addressing undernutrition (15), evaluations of such integrated models have been limited (7, 12).

The MVP is a multicountry, multisector rural-development initiative with the aim of demonstrating progress toward MDG targets (16). The project implements a concurrent package of evidence-based interventions in agriculture, health, education, and infrastructure sustained over a 10-y period. To examine potential early effects on undernutrition, we assessed the prevalence of childhood stunting and its proximate determinants across project sites in 9 sub-Saharan countries after the project's first 3 y. We hypothesized that the integrated model has the potential to generate powerful synergies in the acceleration of progress toward the MDGs, including halving hunger over the course of 5 y (16). For this study, the specific hypothesis is that by expanding coverage with proven nutrition-specific health interventions while simultaneously addressing the underlying causes of undernutrition (including agricultural productivity, food insecurity, and diet diversity), levels of child stunting across a diverse range of African agroecological systems can be reduced significantly. To contextualize intervention effects, we compared levels of stunting to national trends over the past 2 decades.

SUBJECTS AND METHODS

An observational trial was conducted across 9 MVP sites with a comparison of study outcomes at baseline and 3 y after the start of the intervention. Study-outcome indicators are described in **Table 1**. The intervention package and overall study approach are illustrated in **Figure 1**. The study and sampling designs are shown in **Figure 2**.

Setting

MVP sites were chosen to represent the major agroecological zones and farming systems in sub-Saharan Africa that present a range of challenges to income generation, food security, disease ecology, infrastructure, and health system development (16). Rural sites averaged ~40,000 people and were drawn from hunger hot spots with a baseline prevalence of child undernutrition of $\geq$20% (16). This study involved the following 9 project sites for which baseline and year-3 data were available: Koraro, Ethiopia; Bonsaaso, Ghana; Sauri, Kenya; Mwandama, Malawi; Tiby, Mali; Pampaida, Nigeria; Potou, Senegal; Mbola, Tanzania; and Ruhiira, Uganda.

Core interventions for addressing child undernutrition

A core set of investments and interventions for the achievement of MDGs has been identified by the United Nations Millennium Project (24). This set was adapted and flexibly implemented at project sites in response to local needs and conditions after extensive consultation with governments and local communities (25). Those investments and interventions that are critical for addressing child nutrition are summarized in Figure 1. Inputs are cost-limited, with an annual ceiling of $120 per person per capita across all sectors, including local management (25).

In agriculture, interventions to enhance food security and increase crop yields include the promotion of subsidized fertilizers and improved seeds for the major staple crops. Efforts to improve nutrition include support for nutritious crops alongside home gardens, fish farming, livestock, and small animal rearing. Agricultural interventions are combined with field training by extension staff on best agronomic practices. Income-generating activities include the introduction of high-value crops, agroprocessing initiatives, and microfinance programs to stimulate small-business development.

For health, at the start of the project, health services were either unavailable for large population groups or so inadequate that a basic health care infrastructure needed to be built or rebuilt (25). The project has been working closely with governments to improve coverage with essential maternal and child health interventions. Nutrition-specific health interventions included child-growth monitoring, vitamin A supplementation, and the treatment of acute malnutrition. In addition, basic maternal health interventions such as antenatal iron and folate supplementation and institutional delivery were supported by efforts to promote adequate weight gain during pregnancy and improve coverage with micronutrient supplementation. These interventions were complemented by a community health-worker program to promote exclusive breastfeeding for the first 6 mo of a child's life and locally appropriate improved complementary feeding.

Target population and sampling

Within each site, the delivery of the intervention package commenced with ~1000 households before subsequent expansion to a wider area. These households represented the target population for the study to be followed longitudinally (Figure 2). A population census was conducted at baseline to establish the sampling frame, and ~300 households were randomly sampled proportionally from strata defined by subvillage, wealth tertiles, and sex of household head. The sample size was determined on the basis of the ability to detect achievable site-specific and pooled changes on a range of MDG-related outcomes (16), including child stunting. In relation to stunting, with the use of sample sizes across 9 sites as reported in **Table 2**, the study could detect an OR reduction of 0.66. Assessments were conducted at baseline in sampled and consenting households (2005–2006); sampled households that were still resident in the sites 3 y later were surveyed again (year 3: 2008–2009). To maintain a sample size of 300 households, each household lost to attrition (ie, mobility or aging) in year 3 was replaced by sampling of another household from the same strata in the original demographic-sampling frame. At baseline, these replacement households were only enrolled in the demographic census and not in the other surveys or measurements. Only at year 3, replacement households were sampled for all study outcomes and, therefore, were part of the year-3 sample only. Both assessment rounds were conducted preharvest and at the same time period each year to maximize the recording of socioeconomic and nutritional vulnerabilities.

TABLE 1
Study indicators[1]

	Indicator	No. of items for composite indexes	Hypothesis direction of change	Source	Reference no. of tool
Proximate determinants					
Household food security					
Months of inadequate food supply	No. of months during the past 12 mo with inadequate food supply to meet household needs	12	−	Food-security questionnaire	17
Food-coping score	No. of questions on need for coping with food shortage during the past month answered with yes (range: 0–11)	11	−	Food-security questionnaire	18
No. of meals	No. of meals consumed by the household the day before the interview	NA	+	Food-security questionnaire	18
Diet diversity score	No. of food groups consumed on a weekly base (0–13)	12	+	Food-frequency questionnaire	19, 20
Adequate child care					
Breastfeeding for ≥6 mo	Proportion of children <5 y old who were breastfed for ≥6 mo	NA	+	Children's and women's health questionnaire	21
Breastfeeding initiation <6 h after birth	Proportion of children <5 y old who initiated breastfeeding during first 6 h after birth	NA	+	Children's and women's health questionnaire	21
Prelacteal feeding	Proportion of children <5 y old who received prelacteal feeding	NA	−	Children's and women's health questionnaire	21
Use of health service in case of fever or cough	Proportion of cases who used health service in case of fever or cough	NA	+	Children's and women's health questionnaire	21
Vitamin A supplementation	Proportion of children <5 y old who received adequate vitamin A supplementation	NA	+	Children's and women's health questionnaire	21
Infectious-disease control					
Use of long-lasting insecticide-treated bed net	Proportion of households that used long-lasting insecticide-treated bed net	NA	+	Children's and women's health questionnaire	21
Access to improved drinking water	Proportion of households with access to improved water sources. Improved water sources included household connections, public standpipes, boreholes, protected dug wells, protected springs, and rain-water collections.	NA	+	Socioeconomic questionnaire	21
Access to improved sanitation	Proportion of households with access to improved sanitation facilities. Improved sanitation included connection to a public sewers, connection to septic systems, pour-flush latrines, simple pit latrines, and ventilated improved pit latrines.	NA	+	Socioeconomic questionnaire	21
Diarrhea incidence	Proportion of children <5 y of age with diarrhea during the past 2 wk	NA	−	Children's and women's health questionnaire	21
Measles vaccination	Proportion of children 12–23 mo old who received adequate measles vaccination	NA	+	Children's and women's health questionnaire	21
Anthropometric outcomes					
Height-for-age z score	Height-for-age z score of children <2 y of age, with exclusion of outliers less than −6 and >6	NA	+	Anthropometric measurements	22, 23
Weight-for-age z score	Weight-for-age z score of children <2 y of age, with exclusion of outliers less than −6 and >5	NA	+	Anthropometric measurements	22, 23
Weight-for-height z score	Weight-for-height z score of children <2 y of age, with exclusion of outliers less than −5 and >5	NA	+	Anthropometric measurements	22, 23

(Continued)

TABLE 1 (*Continued*)

	Indicator	No. of items for composite indexes	Hypothesis direction of change	Source	Reference no. of tool
Stunting	Proportion of children <2 y of age with height-for-age z score less than −2	NA	−	Anthropometric measurements	22, 23
Underweight	Proportion of children <2 y in age with weight-for-age z score less than −2	NA	−	Anthropometric measurements	22, 23
Wasting	Proportion of children <2 y in age with weight-for-height z score less than −2	NA	−	Anthropometric measurements	22, 23

[1] −, the hypothesis is that this indicator decreases over the course of the program; +, the hypothesis is that this indicator increases over the course of the program; NA, not applicable.

Study-outcome indicators and impact pathways

The evaluation of potential pathway variables for child nutrition was guided by the UNICEF framework (4) for the assessment of food security (including diet diversity), child-care practices, and infectious-disease control (Figure 1). Study outcomes are described in Table 1. Data sources that were used to derive the study outcomes as well as sample sizes for each data source are shown in Figure 2. The sample size varied across indicators because of differences in the availability of data for that indicator and the unit of analysis (children <2 y of age, children <5 y of age, or households).

Household food security

A food-security questionnaire was administered to the household head and/or the person primarily responsible for food preparation. On the basis of tools of the Food and Nutrition Technical Assistance Project (17–19), a food-coping score was generated from equally weighted responses to 11 food-insecurity and -coping questions, where a positive response indicated food insecurity. The number of months of inadequate household food supply was calculated on the basis of a subjective assessment of the months for which the household did not have enough food to meet its needs (18). The number of meals was derived from the food-security questionnaire as the number of meals the respondent consumed in the 24 h before the interview.

A food-frequency questionnaire (20) was used to assess diet diversity on the basis of the reported frequency of consumption (times per day, week, month, or year) of 120 to 150 locally available food items. Household diet diversity scores were generated for weekly time periods for the following 12 food categories as recommended by the Food and Nutrition Technical Assistance Project/FAO (19): cereals; vitamin A–rich vegetables and tubers; white tubers and plantains; green leafy vegetables; other vegetables; legumes, seeds, and oily fruit; vitamin A–rich fruit; all other fruit; meat; eggs; milk; and fish.

Child-caring practices and disease control

A standard set of child-health indicators and disease-control indicators (Table 1) on the basis of Demographic and Health Survey tools (21) were generated from survey questions administered to 15–49-y-old women.

HAZ and stunting prevalence

HAZ and stunting prevalence were assessed in children in sampled households who were <2 y old, which is the critical window of opportunity for child growth. These children were born or conceived since the start of the intervention. The strategy for measurement of children between assessment rounds was modified to maximize the sample size; at baseline, the anthropometric measurement of children in sampled households was voluntary and generally took place at central locations, whereas in year 3, efforts were undertaken to actively track and measure all children in sampled households in an effort to increase the sample size. As a result of this modification, more children were assessed in year 3, and characteristics of measured children differed between survey rounds; relative to children whose measurements were taken at baseline, children measured in year 3 were younger (12 compared with16 mo) and came from larger households (9 compared with 7 members). The statistical analysis adjusted for these imbalances.

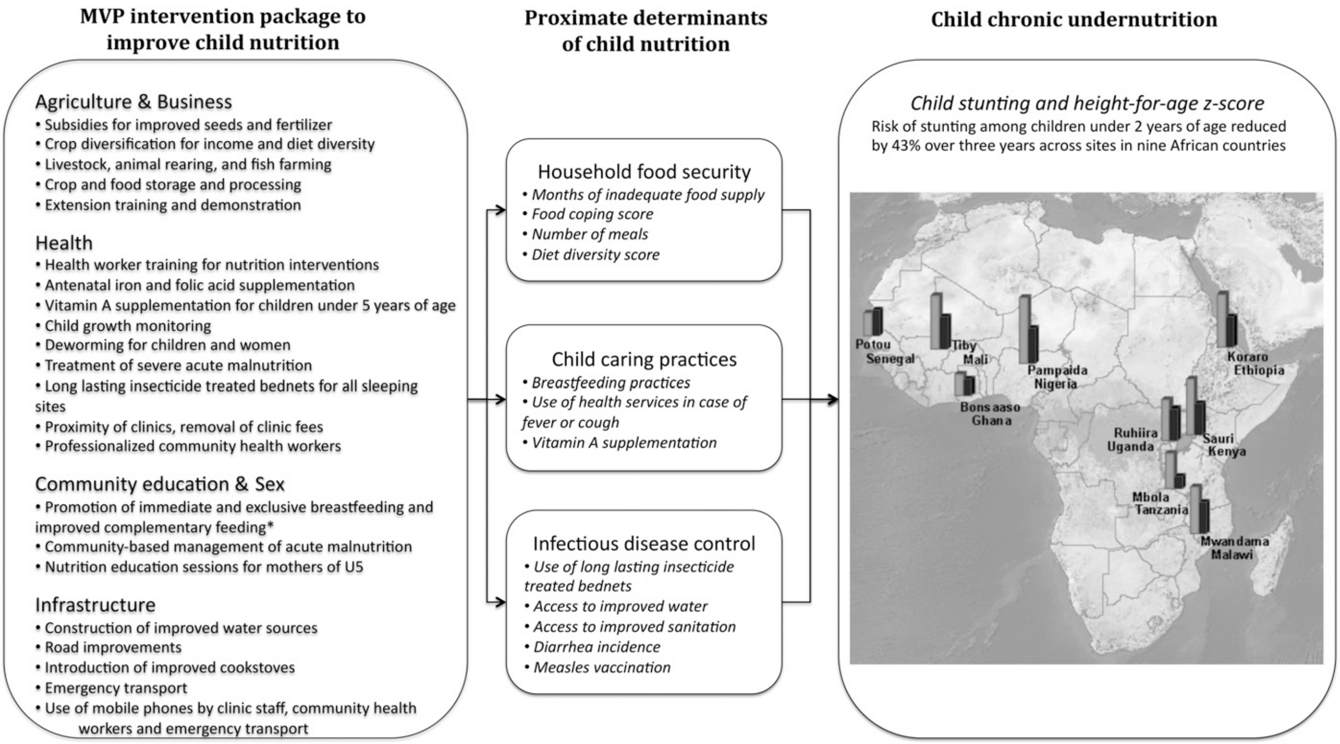

FIGURE 1. Overview of project interventions for improving nutrition and the overall study approach including proximate determinants of child nutrition and anthropometric study outcomes. Study indicators are indicated in italics. Bars show site locations and represent the prevalence of stunting at baseline (gray) and year 3 (black) across project sites in 9 African countries. Study-outcome indicators and results are shown in Tables 2 and 3. *With regard to improved complementary feeding, the intervention was to use locally grown and sourced foods that were culturally acceptable for the communities and mothers but that also provided improved nutrition with a focus on increasing protein, essential fatty acids, and micronutrients as opposed to staple grain porridge. In some sites, there was also home-based fortification of complementary foods (eg, in Mali) and biofortified staple crops (eg, in Uganda). MVP, Millennium Villages Project; U5, children <5 y old.

Anthropometric measurements were taken by using standard best practices (22). Child recumbent length (0–24 mo) was read twice to the nearest 0.1 cm with either a steel tape attached to a wooden board with a footplate and sliding head block or a length mat (Shorr Productions). Body weight was obtained in 2 separate measures with an electronic balance (Seca) or on a hanging spring scale (Salter Ltd) and read to the nearest 0.1 kg. Anthropometric indexes were calculated with Stata (StataCorp) macros provided by the WHO with the use of growth references (23). Extreme *z* scores (less than −6 or >6 for height-for-age; less than −6 or >5 for weight-for-age; less than −5 or >5 for weight-for-height) were excluded as suggested by the WHO protocol (23). Stunting, underweight, and wasting were defined, respectively, as a HAZ, weight-for-age *z* score, and weight-for-height *z* score less than −2 (23).

National data

National data for stunting in children <2 y of age were obtained from the WHO Nutrition Landscape Information System (26) to evaluate long-term national trends across countries included in this study.

Data quality control

Survey data were collected by enumerators who underwent 3 wk of field training. Daily field supervision took place by site-based senior program staff with overall supervision and guidance provided by an international team of epidemiologists, nutritionists, and statisticians. Accepted best practices for field-level quality control were followed (22, 27). Systematic repeat data entries were done for all anthropometric data. Postanalysis quality checks compared SDs of anthropometric data by site to WHO standards and other studies for children <2 y of age (27, 28). Data from questionnaires were double entered with CSPro software (US Census Bureau) and cleaned for structural and logical errors in both the CSPro (US Census Bureau) and Stata (version 10, StataCorp) software programs.

Statistical analysis

The analysis examined changes in nutritional outcomes and pathway variables from baseline to year 3. A multilevel regression analysis was used to account for clustering of observations within sites; a linear model was used for continuous outcomes, and a logistic model was used for binary outcomes (29). The independent variable of interest was a binary indicator for time period (year 3 or baseline). The coefficient for this indicator represented the estimated changes from baseline to year 3 in nutritional outcomes and key pathway variables. For continuous variables, the estimated change was the difference in mean outcomes between the 2 time periods; for binary outcomes, the estimated change from baseline was the log OR. When fittingthe multilevel model, the intercept (mean outcomes) and year coefficient (change over time) were allowed to vary randomly across sites.

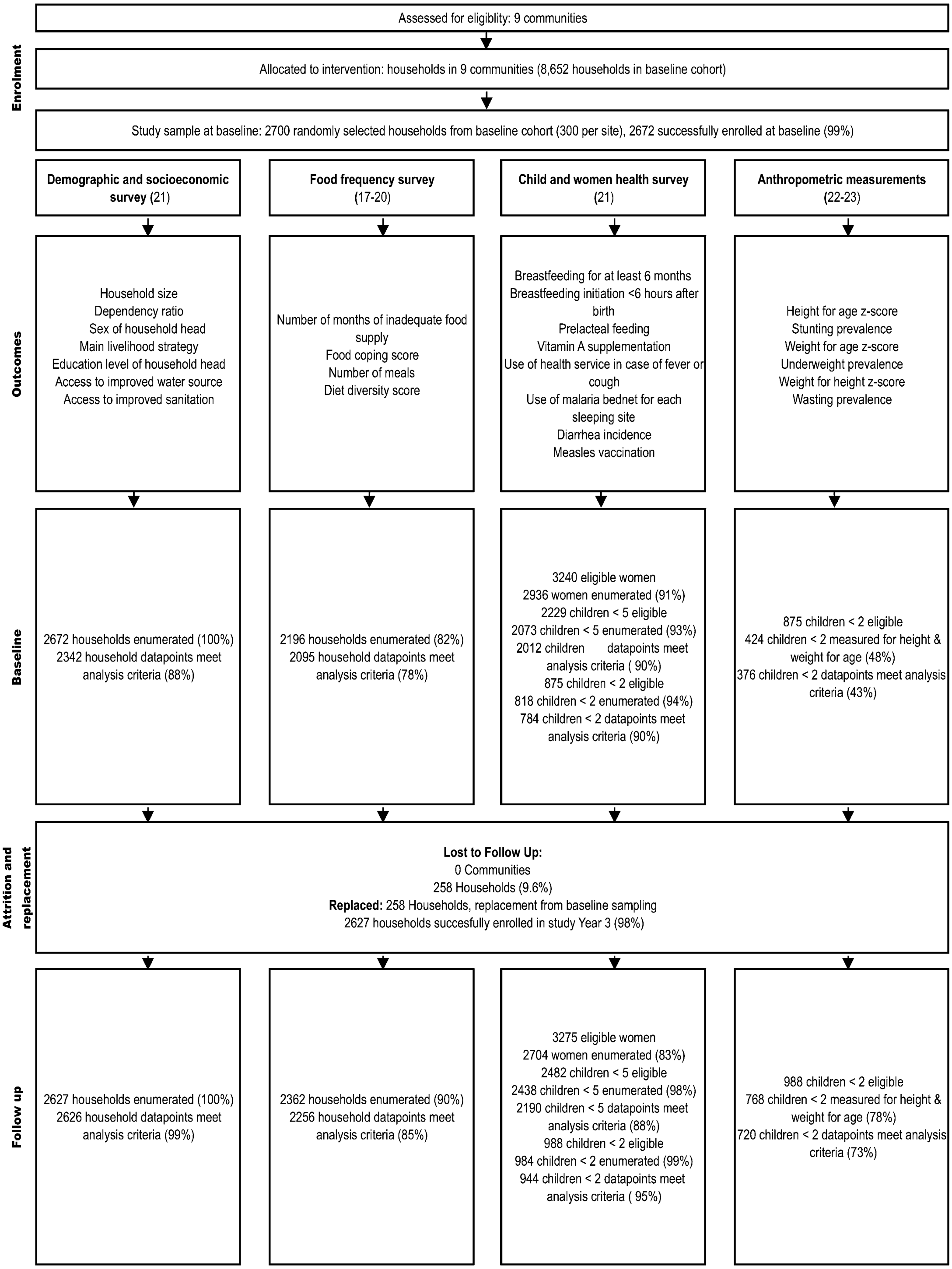

FIGURE 2. Target population and samples at baseline and year 3.

To strengthen the plausibility that between-year changes in outcomes were attributable to the intervention, we adjusted for possible confounding in 2 ways, depending on the outcome measure. For pathway outcomes, the following set of household and child characteristics was added to the multivariate regression model: child's age and sex, household size, sex of household head, and the main household livelihood strategy and dependency ratio (the ratio of children and elderly to adult household members). For nutritional outcomes (ie, HAZ and stunting), before the adjusted regression model was estimated, data were preprocessed by using propensity score matching (30, 31). This procedure was used to account for imbalances in sociodemographic characteristics of children in the anthropometric sample as previously described. Propensity score matching was conducted as follows. First, each child in the anthropometric sample at baseline was matched within site to the most similar child in the

TABLE 2
Outcomes of study indicators at baseline and year 3 across 9 study sites

	No. of subjects		Values[1]					
Study outcome and indicator	Baseline	Year 3	Baseline	Year 3	OR (95% CI)	Adjusted OR (95% CI)[2]	Absolute change (95% CI)	Adjusted absolute change (95% CI)
Proximate determinants								
Household food security								
Months of inadequate food supply (0–12 mo)	2095	2256	3.95 ± 1.86	1.72 ± 1.64	0.36 (0.24, 0.54)	0.36 (0.24, 0.54)	—	—
Food-coping score (0–11)	2095	2256	4.4 ± 2.43	2.42 ± 2.17	0.35 (0.26, 0.46)	0.35 (0.26, 0.46)	—	—
No. of meals	2095	2256	2.55 ± 0.69	2.85 ± 0.62	1.31 (1.12, 1.53)	1.30 (1.11, 1.52)	—	—
Diet-diversity score (0–12)	2139	2242	8.62 ± 1.86	9.2 ± 1.68	1.25 (1.01, 1.55)	1.25 (1.02, 1.52)	—	—
Adequate child care (%)								
Breastfeeding for ≥6 mo	602	668	83 ± 0.38	96 ± 0.19	4.1 (2.88, 10.7)	4.0 (2.87, 10.6)	—	—
Breastfeeding initiation <6 h after birth	792	944	49 ± 0.50	76 ± 0.43	3.35 (1.56, 7.19)	3.29 (1.53, 7.21)	—	—
Prelacteal feeding	828	944	49 ± 0.50	30 ± 0.46	0.36 (0.25, 0.36)	0.36 (0.25, 0.36)	—	—
Use of health service in case of fever or cough	454	989	47 ± 0.49	74 ± 0.44	2.56 (1.31, 3.01)	1.49 (1.11, 2.21)	—	—
Vitamin A supplementation	602	668	59 ± 0.49	73 ± 0.50	3.61 (2.77, 4.44)	3.09 (2.55, 3.63)	—	—
Infectious-disease control (%)								
Use of long-lasting insecticide-treated bed net	3995	3098	8 ± 0.27	54 ± 0.48	11.7 (5.78, 23.7)	11.5 (5.76, 23.5)	—	—
Access to improved drinking water	2012	2190	18 ± 0.38	63 ± 0.41	38.0 (12.4, 117.1)	38.0 (12.4, 117.1)	—	—
Access to improved sanitation	2063	2042	6 ± 0.24	36 ± 0.43	15.3 (9.52, 218.4)	15.2 (9.51, 218.3)	—	—
Diarrhea incidence	2012	2190	24 ± 0.43	22 ± 0.41	0.93 (0.66, 1.32)	0.93 (0.65, 1.34)	—	—
Measles vaccination	421	440	64 ± 0.48	75 ± 0.43	2.32 (1.21, 4.43)	2.09 (1.57, 2.61)	—	—
Anthropometric outcomes								
Height-for-age z score	376	720	−1.93 ± 1.91	−1.05 ± 2.01	—	—	0.88 (0.52, 1.23)	0.56 (0.25, 0.87)[3]
Weight-for-age z score	401	675	−1.05 ± 1.69	−0.73 ± 1.57	—	—	0.32 (0.1, 0.53)	−0.03 (−0.28, 0.23)[3]
Weight-for-height z score	388	664	0.10 ± 1.59	−0.19 ± 1.53	—	—	−0.28 (−0.61, 0.05)	−0.42 (−0.87, 0.03)[3]
Stunting (%)	376	720	52 ± 0.48	32 ± 0.46	0.45 (0.29, 0.71)	0.57 (0.38, 0.83)[3]	—	—
Underweight (%)	401	675	24 ± 0.42	17 ± 0.37	0.66 (0.47, 0.91)	1.18 (0.71, 1.96)[3]	—	—
Wasting (%)	388	664	7 ± 0.25	8 ± 0.27	1.18 (0.75, 1.86)	1.39 (0.73, 2.64)[3]	—	—

[1] Values are means ± SDs.
[2] Adjusted for household size, dependency ratio, sex of household head, and main household livelihood strategy.
[3] Propensity score matching was used to account for differences in demographic and socioeconomic variables between groups at baseline and year 3.

year-3 sample by using one-to-one optimal matching (32) with all nonmatched children in the year-3 sample excluded from further analysis. For the purposes of matching, similarity was defined by using a propensity score on the basis of child age, sex, and household size, and the household's dependency ratio (ie, the ratio of number of people aged 0–14 and ≥65 y over the number of people aged 15–64 y). The adjusted change in anthropometric outcomes was then estimated by fitting the multilevel regression to the sample of matched children, with the set of child and household characteristics controlled for. Propensity matching was not necessary for pathway outcomes because the sample was balanced between survey rounds.

Ethical review

The study was approved by institutional review boards at Columbia University (AAAA-8202) and in all partner countries. Community consent was obtained before each survey round in each village. Informed consent was obtained from individuals or parents for all survey procedures.

RESULTS

Data on the 3 proximal determinants of chronic undernutrition and child anthropometric measures were assessed in a cohort of 2700 households (Figure 2). The major results of the evaluation are summarized in Table 2.

At baseline, in 70% of households, the per capita income was <$1/d. The average household size was 5.9 individuals, and the dependency ratio 107. Just 16% of adults had completed primary school, and farming was the main livelihood strategy for >95% of households.

For household food security, consistent improvements were observed both in household food availability (ie, the decrease in number of months in a year of inadequate food supply, increase in number of meals in a day, and decrease in food-coping score) and diet diversity (increase in diet-diversity score). Improvements in diet diversity included a greater intake of animal-source foods and legumes, which are important sources of proteins and micronutrients (data not shown). Adjustment for household demographic and socioeconomic indicators did not change these results.

Most indicators of adequate child-caring practices also improved over time. There was increased coverage with vitamin A supplementation, improved breastfeeding practices, and higher levels of the appropriate use of health services in case of a fever or cough.

Changes in indicators of infectious-disease control were mixed. Coverage with measles vaccination underwent a modest increase from relatively high baseline levels. Long-lasting insecticide-treated bed nets were distributed to every sleeping site at the onset of the program alongside educational campaigns, which resulted in major increases in levels of use. Although access to improved drinking water and improved sanitation facilities increased in project sites, diarrhea incidence remained unchanged.

A total of 1096 children <2 y old were assessed for height-for-age, weight-for-age, and weight-for-height (Table 2). After differences in demographic and socioeconomic variables were adjusted for, lower levels of stunting were observed at year 3 relative to at baseline (adjusted OR: 0.57; 95% CI: 0.38, 0.83). There was a concurrent improvement in the average HAZ with an increase in the absolute value by 0.56 (95% CI: 0.25, 0.87) across project sites. A reduction in underweight prevalence from 24% to 17% (OR: 0.66; 95% CI: 0.47, 0.91) was also observed, but CIs include unity in the adjusted analysis after propensity-score matching. For wasting, there was no statistically significant difference between time periods. Because levels of wasting were at an average level of 7%, our sample size did not provide sufficient power to detect changes in this outcome.

Corresponding national data on levels of stunting in children <2 y of age are presented in **Figure 3**. The average trend line for countries included in this study indicated that stunting prevalence had remained largely unchanged between 1990 and 2008.

Site-specific results for primary outcomes are shown in **Table 3**. SDs of HAZ per site indicated data quality similar to other studies that reported on HAZs of children <2 y of age (9, 28, 33). Stunting prevalence at baseline ranged from 25% to 77%. There was a significant (at $\alpha = 0.05$) reduction in stunting prevalence at 5 of the sites and a nonsignificant reduction in 3 additional sites.

DISCUSSION

This study assessed the effects of an integrated, multisector rural-development program on the prevalence and determinants of child stunting across MVP sites in 9 sub-Saharan African countries. After 3 y of program exposure, improvements were observed in household food security and diet diversity, alongside most measures of child-caring practices and disease control. Furthermore, children <2 y of age had a 43% lower risk of being stunted than before project initiation. Information derived from national data sources suggested childhood stunting in countries included in this study has remained largely unchanged between 1990 and 2008 (26; Figure 3).

Gains in household food security and dietary diversity were strong and consistent. Previous research from the project sites suggested a near tripling of agricultural yields after the introduction of improved seeds, fertilizer, and extension training for farmers (34–36). Observed gains were potentially enhanced by complementary efforts to promote crop, livestock, and dietary diversification and improve access to markets (25). In relation to reductions in child stunting, these findings are supported by recent analyses of national and subnational data that document associations between agricultural growth and lower underweight (37, 38) and stunting prevalence (when Indian states were excluded as outliers) (38). However, although the potential for community-based interventions to enhance local food production has been demonstrated in areas as diverse as Bangladesh (39, 40), Kenya (41), and Iran (42), few previous studies have examined their potential contribution toward the reduction of levels of child stunting (7, 12, 13, 43, 44).

Changes in coverage with child care and disease-control interventions with the potential to influence stunting were less consistent and more complex to interpret. After 3 y, children were more likely to sleep under insecticide treated bed nets for malaria protection, live in households with access to improved water and sanitation facilities, be appropriately breastfed and use clinic services, and receive vitamin A supplementation and basic vaccinations. Although previous studies on the association between malaria and child stunting are conflicting (45–48), pooled estimates suggest that bed-net use during pregnancy is associated with a 23% reduction in

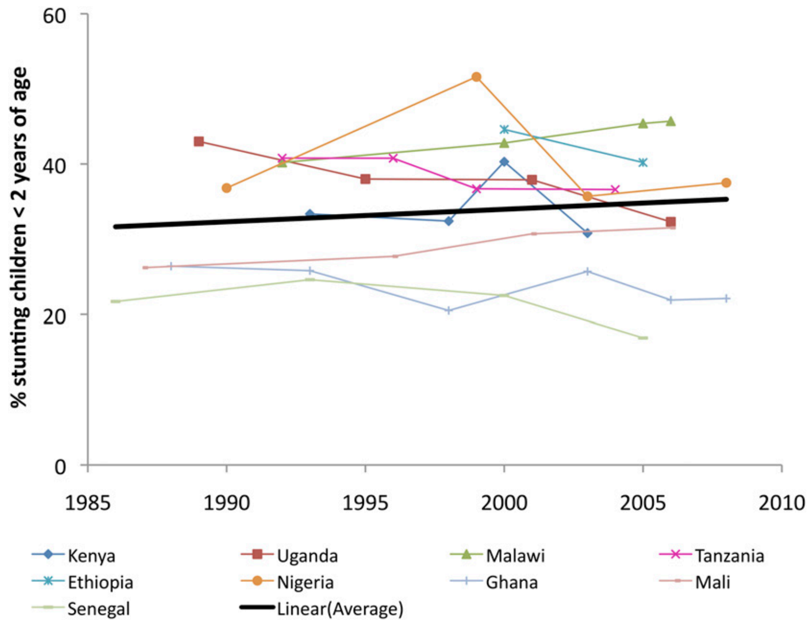

FIGURE 3. National prevalence of stunting for children <2 y of age from 1988 to 2008. Data were obtained from the WHO Nutrition Landscape Information System (26).

risk of delivering a low-birth-weight baby (7). There is strong evidence that among infectious diseases, chronic diarrhea is most strongly associated with nutritional deficiencies and stunting (49, 50). Although the incidence of diarrhea remained unchanged in this study, access to improved drinking water and sanitation may have longer-term effects on the frequency or duration of diarrheal episodes, neither of which were measured in our assessment. With respect to vitamin A, previous studies have shown reductions in all-cause mortality by 24% (7); however, the effect of supplementation on anthropometric measures is expected to be minimal (7). Finally, despite the large number of studies that show health promotion could increase levels of breastfeeding (7, 51, 52), the few studies that assessed nutritional status have not conclusively shown increased weights or lengths of infants (7).

The findings suggest that the observed reductions in child stunting are likely related to interactions between several drivers of change that vary across sites. Although there is limited previous evidence from programs in sub-Saharan Africa, potential synergies between interventions have been suggested in the Good Start to Life Program in Peru (53), where reductions in stunting from 54% to 37% were associated with the delivery of an integrated package that includes nutrition, hygiene, and health interventions (7), combined with participatory processes that mobilize human, economic, and organizational resources.

The evaluation described in this study had several limitations that are important to underscore. First, the use of an observational design limited the ability to make causal statements. The plausibility that reductions in stunting were influenced by program exposure is enhanced by observing changes in the stunting outcome alongside key pathway variables. Further, the timing of changes was consistent with the introduction of a range of community-level interventions, and changes exceeded those predicted by secular trends drawn from national data sets. Potential confounding was addressed by adjustment for covariates at the household level. At the country level, the effect of factors such as economic, policy, or program shifts and climate or disease

TABLE 3
Primary outcomes per site

Site	Baseline (n = 376) Height-for-age z score[1]	Baseline (n = 376) Stunting prevalance[2]	Year 3 (n = 720) Height-for-age z score[1]	Year 3 (n = 720) Stunting prevalance[2]	P value for percentage at baseline compared with year 3	P value for z score at baseline compared with year 3
Koraro, Ethiopia	−2.34 ± 1.91	62 ± 48	−0.96 ± 2.45	36 ± 48	0.001	0.001
Bonsaaso, Ghana	−1.04 ± 1.61	25 ± 43	−0.81 ± 1.57	20 ± 40	0.235	0.288
Sauri, Kenya	−2.46 ± 1.94	62 ± 48	−1.18 ± 2.51	38 ± 48	0.002	0.014
Mwandama, Malawi	−2.11 ± 1.82	55 ± 50	−1.49 ± 1.64	37 ± 48	0.029	0.038
Tiby, Mali	−2.47 ± 2.25	63 ± 48	−1.19 ± 1.86	38 ± 48	0.006	0.078
Pampaida, Nigeria	−2.75 ± 1.57	78 ± 42	−1.63 ± 2.17	42 ± 49	0.038	0.020
Potou, Senegal	−1.25 ± 1.86	30 ± 46	−0.78 ± 2.41	31 ± 46	0.161	0.656
Mbola, Tanzania	−1.52 ± 1.89	42 ± 49	−0.52 ± 1.67	15 ± 36	0.001	0.002
Ruhiira, Uganda	−1.48 ± 2.38	49 ± 50	−1.25 ± 1.78	38 ± 49	0.268	0.189

[1] Values are means ± SDs.
[2] Values are percentages ± SDs.

endemnicity were somewhat mitigated by the observation of effects across a diverse range of sites where the confounding structures of the population were likely to differ.

Second, survey instruments had limited precision for the measurement of some pathway variables. Although current bednet usage is an indicator that describes intervention coverage, changes in parasitologic and clinical malaria may be more relevant. Access to improved (protected) water sources may not measure possible contamination in the home and insufficiently capture the quantity of water used for basic hygiene. Third, assessment tools did not capture variables such as amounts of zinc supplementation for diarrhea or conduct a detailed assessment of infant and young-child feeding practices. Notably, persistent barriers in the supply of zinc across all project sites have been difficult to overcome in the first 3 y of the project. Finally, definitive statements regarding the specific mechanisms through which observed reductions in stunting occurred were difficult to make because of the multifactorial determinants of stunting and the uniqueness of project settings. Unraveling site-specific pathways and interactions between factors will be the subject of future research efforts. Variability in outcomes between sites will also allow opportunities to investigate why certain strategies to reduce undernutrition work well in some settings but not in others, such as limited reductions in the Senegal site, where cash-crop production rather than staple food–crop production is the principal agricultural livelihood strategy. Despite these limitations, the diverse agroecological contexts and the range of implementation experiences across project sites have the potential to generate important lessons for a wider application to policy and program development.

With just 5 y remaining to the 2015 deadline of reaching MDGs, the persistent scale of global hunger remains an inexcusable unfinished agenda. Although the complex determinants of child undernutrition have been suggested for decades (4, 54), the optimal mix of interventions to reduce stunting is much less clear, particularly in regions such as sub-Saharan Africa. This research provides encouraging evidence that, by combining proven health-sector interventions with efforts to enhance food and livelihood security, rapid gains toward reducing stunting can be achieved in a relatively short time even in some of the world's most diverse, challenging, and deeply impoverished settings.

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