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DÉTERMINANTS DE RETARD DE CROISSANCE EN AFRIQUE DE L'EST

DETERMINANTS OF STUNTING IN EAST AFRICA

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DÉTERMINANTS DE RETARD DE CROISSANCE EN AFRIQUE DE L'EST - THÈSE DE DOCTORAT PAR JAMES P WIRTH

1. Introduction

Le retard de croissance et une mauvaise croissance linéaire chez les enfants de moins de cinq ans peuvent entraîner une augmentation de la morbidité et de la mortalité de l'enfant, une diminution des performances cognitives, une capacité d'apprentissage et une productivité amoindries, ainsi que des effets nocifs sur la santé à long terme [1]. En 2012, l'Assemblée mondiale de la Santé (AMS) a inscrit une réduction de 40 % des enfants présentant un retard de croissance parmi les six objectifs mondiaux de nutrition à atteindre en 2025 [2]. Dans ses objectifs de développement durable (ODD), l'ONU a également identifié le retard de croissance comme un indicateur de développement clé, utile à l'évaluation des progrès accomplis en vue d'éradiquer la famine [3]. Bien que la prévalence d'enfants présentant un retard de croissance ait considérablement diminué à l'échelle mondiale, elle n'a que faiblement reculé en Afrique subsaharienne. En réalité, compte tenu de l'accroissement démographique, le nombre absolu d'enfants présentant un retard de croissance en Afrique subsaharienne est en augmentation [4].

Malgré le vaste corpus de documents étudiant les différents facteurs déterminants des retards de croissance, nombre de pays ne disposent pas de données suffisantes relatives à ces facteurs ni d'une bonne compréhension de l'efficacité des programmes. En raison des différents éléments qui influencent le développement de l'enfant, une analyse des facteurs des retards de croissance à l'échelle nationale est nécessaire pour permettre aux décideurs politiques d'élaborer des programmes efficaces. Selon Stewart *et al.* [5], « les recherches, programmes et politiques devraient être élaborés sur la base d'une évaluation minutieuse des facteurs contextuels des retards de croissance, afin de concevoir des approches complètes et pluridisciplinaires pour promouvoir une croissance et un développement sains ».

La présente thèse se compose de quatre manuscrits étudiant les facteurs déterminants des retards de croissance chez les enfants d'Afrique de l'Est, à l'aide de données issues d'Éthiopie et de Tanzanie. Si tous les quatre considèrent le retard de croissance ou le rapport taille-âge (z-score TA) comme les principaux indicateurs d'intérêt, chacun aborde le sujet d'une perspective différente. Dans tous les manuscrits, la prévalence d'enfants présentant un retard de croissance a été définie comme la proportion mesurée d'enfants enregistrant un z-score de plus de deux écarts types en dessous de la médiane. Certains prennent également en compte le rapport poids-taille (z-score PT) et l'émaciation (c.-à-d. z-score PT < -2 écarts types) en tant qu'indicateurs de l'état nutritionnel et covariantes du retard de croissance.

Le premier manuscrit (chapitre 1) contient une analyse documentaire des textes concernant le retard de croissance, ainsi qu'une application à l'échelle nationale du cadre d'interventions de l'OMS en Éthiopie [6]. Le deuxième (chapitre 2) étudie les facteurs déterminants des retards de croissance en Éthiopie à l'aide de données nationales regroupées, issues de trois séries d'enquêtes démographiques et de santé (EDS). Les facteurs ont été examinés séparément selon trois groupes d'âge (0–5, 6–23 et 24–59 mois) pour déterminer les vecteurs de risque spécifiques à chaque stade infantile et pendant la petite enfance. Le troisième manuscrit (chapitre 3) présente les résultats d'une analyse écologique, au cours de laquelle la diminution de la prévalence des retards de croissance à l'échelle infranationale en Éthiopie entre 2000 et 2015 a été comparée à l'évolution des programmes de santé publique [7]. Enfin, le quatrième (chapitre 4) expose les résultats d'une étude de cas-témoins réalisée dans le nord de la Tanzanie, qui s'intéresse aux corrélations entre inflammation, indicateurs d'entéropathie environnementale et croissance de l'enfant.

2. Résumé des méthodes

2.1 Évaluation du cadre d'interventions de l'OMS avec une étude de cas en Éthiopie

Le premier manuscrit étudie les particularités du pays pour chaque facteur mentionné dans les parties « Causes » et « Contexte » du cadre (voir schéma 1), qui sont les principaux responsables des retards de croissance et des problèmes de santé, avec des conséquences économiques et en matière de développement.

Afin de recenser un maximum de facteurs de risque liés au retard de croissance, une analyse documentaire approfondie a été menée sur les principaux rapports rédigés sur ce thème en Éthiopie [8,9], ainsi que sur des examens au niveau mondial sur la santé maternelle et infantile et sur la nutrition [5,10–12]. Une analyse des références de ces articles a été réalisée pour identifier les sources initiales. Bien que notre analyse se fonde principalement sur des sources validées par les pairs, nous avons également étudié des documents parallèles fiables, tels que des rapports d'EDS, des documents de travail et des thèses académiques, lorsqu'ils se révélaient pertinents.

Pour étoffer ce corpus, nous avons effectué une recherche structurée de mots clés sur les sites Web of Science, PubMed et Google Scholar, afin d'identifier les articles relatifs aux facteurs déterminants des retards de croissance publiés entre l'an 2000 et février 2015.

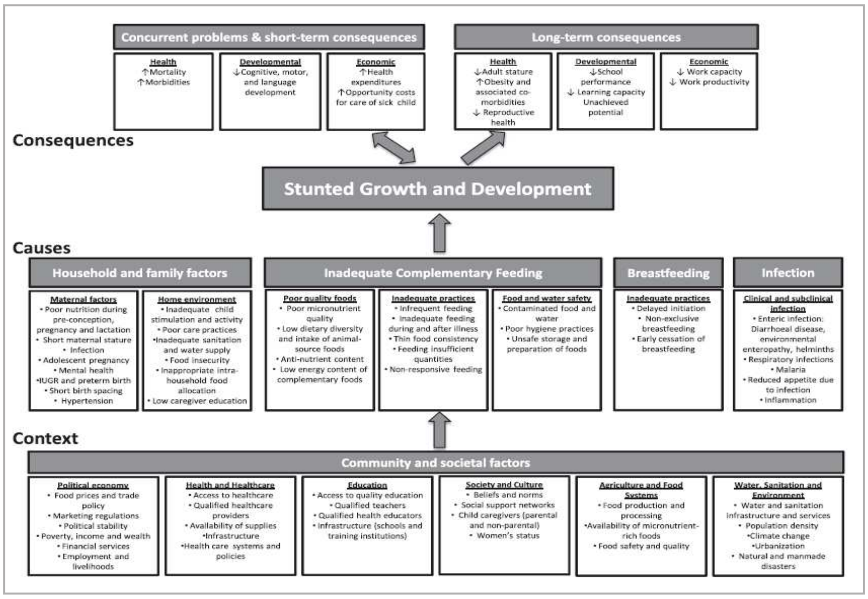

Schéma 1 Cadre d'interventions de l'OMS contre le retard de croissance

2.2 Facteurs déterminants des retards de croissance en Éthiopie de 2000 à 2011

Le deuxième manuscrit se fonde sur des données regroupées issues de trois enquêtes démographiques et de santé (EDS) menées en Éthiopie en 2000, 2005 et 2011. À l'issue du regroupement des données, nous avons appliqué le cadre d'interventions de l'OMS [5] pour déterminer l'ensemble le plus complet de facteurs potentiellement liés aux retards de croissance. À l'aide de ce cadre, nous avons examiné en profondeur les ensembles de données EDS issus des trois enquêtes, afin de sélectionner les variables des EDS pouvant être considérées comme des facteurs potentiels de réduction de la prévalence des retards de croissance en Éthiopie. Au total, nous avons relevé 83 facteurs potentiels. Outre les valeurs présentées dans les fichiers de données EDS, nous avons calculé un nouvel indice de richesse des ménages sur la base des données regroupées issues de toutes les séries d'enquêtes, analysant les principaux éléments de variables identiques utilisées dans le calcul EDS original [13]. Cela nous a permis d'évaluer les tendances de la richesse des ménages entre 2000 et 2011.

L'analyse des données se composait de trois étapes. Tout d'abord, nous avons réalisé une analyse à deux variables sur les données regroupées issues des trois EDS, afin de déterminer celles qui étaient associées au z-score TA en Éthiopie. Les variables continues et catégoriques furent respectivement étudiées à travers des analyses de régression linéaire et de la variance, puis comparées au z-score TA, considéré comme le résultat continu.

Nous avons ensuite mené une analyse de régression linéaire à plusieurs variables à l'échelle nationale, sur la base des données regroupées issues des trois enquêtes. Des modèles séparés ont été élaborés pour les enfants âgés de 0 à 5 mois, de 6 à 23 mois et de 24 à 59 mois, puisque les facteurs de risque potentiels et les pratiques d'alimentation chez les jeunes enfants diffèrent significativement selon l'âge et les EDS recueillent des ensembles de données différents sur des enfants d'âge divers. Chaque modèle comprenait des variables qui, statistiquement, étaient étroitement liées au z-score TA dans l'analyse à deux variables et étudiées dans les trois enquêtes.

Enfin, nous avons entrepris une analyse des tendances des variables dans chaque modèle définitif, afin d'identifier les variables ayant connu un changement considérable entre les trois EDS et qui, ainsi, pourraient avoir contribué à la diminution de la prévalence des retards de croissance en Éthiopie entre 2000 et 2011. Les valeurs moyennes (pour les variables continues) ou taux de prévalence (pour les valeurs catégoriques) pondérés ont été comparés entre les trois EDS.

2.3 Évolution des programmes de nutrition et de santé en Éthiopie et leur corrélation avec la réduction du nombre d'enfants présentant un retard de croissance

Le troisième manuscrit présente une analyse écologique qui a comparé la réduction de la prévalence des retards de croissance à l'échelle infranationale et le nombre de cas (c.-à-d. le nombre d'enfants présentant un retard de croissance) avec le renforcement des programmes de nutrition et de santé publique en Éthiopie. Nous avons utilisé les données issues des trois EDS ainsi que des chiffres démographiques nationaux afin de connaître les régions et les périodes où le nombre d'enfants présentant un retard de croissance a évolué au fil du temps. Les changements infranationaux ont été examinés sous deux approches. Tout d'abord, nous avons mesuré la prévalence des retards de croissance à l'échelle nationale, selon le statut urbain/rural et la région. Les statistiques démographiques régionales issues de l'Office central de statistique d'Éthiopie [14–16] et la prévalence régionale tirée des trois EDS furent incluses dans le calcul du nombre total d'enfants présentant un retard de croissance par région et par année. Ensuite, en nous fondant sur le changement régional du nombre d'enfants présentant un retard de croissance sur deux périodes différentes (2000–2005 et 2005–2011), nous avons attribué la proportion de réduction nationale des retards de croissance à chaque région spécifique, en tenant compte de l'évolution de la prévalence des retards de croissance et de la taille de la population.

Nous avons dressé l'inventaire de tous les programmes de santé, de nutrition et de sécurité alimentaire de grande envergure, examiné les données relatives à leur couverture et à leur impact puis comparé ces données aux réductions de nombre d'enfants présentant un retard de croissance observées dans les EDS. L'évolution du contexte politique, économique et démographique en Éthiopie a également été étudiée, afin de détecter d'autres corrélations entre les tendances à long terme et l'évolution de la prévalence des retards de croissance.

2.4 État de croissance, inflammation et entéropathie chez les jeunes enfants en Tanzanie

Le quatrième manuscrit présente les résultats d'une étude de cas-témoins comparant les biomarqueurs d'inflammation et d'entéropathie environnementale (EE), ainsi que les caractéristiques sociodémographiques, d'hygiène et de santé entre les enfants présentant un retard de croissance (cas) et les enfants présentant une croissance normale (témoins) vivant dans des communautés identiques. Cette étude a été imbriquée dans l'évaluation finale de l'impact du projet Creating Homestead Agriculture for Nutrition and Gender Equity (CHANGE, Création d'exploitation agricole pour la nutrition et l'égalité des sexes) – une étude menée par l'association Helen Keller International et l'Institut international de recherche sur les politiques alimentaires, afin de mesurer l'influence d'un ensemble varié d'actions intégrées dans le domaine de la nutrition (telles que les micronutriments en poudre ou la production agricole) sur l'anémie et la croissance infantiles [17].

En janvier et février 2016, l'étude de cas-témoins a inclus tous les enfants vivant dans les 10 shehias (la plus petite unité administrative) du district de Sengerema, dans la région des lacs de Tanzanie, qui avaient fourni des échantillons sanguins au cours de l'évaluation finale du projet CHANGE.

Un questionnaire approfondi a été présenté, dans le cadre de l'étude du CHANGE, aux parents et tuteurs des enfants concernés. Ce questionnaire comprenait des informations sur les variables démographiques des ménages et individuelles (telles que l'âge ou le sexe), la sécurité alimentaire des ménages, les pratiques et installations en matière d'eau, assainissement et d'hygiène (EAH), la santé maternelle et le contexte éducatif, ainsi que les pratiques d'alimentation des nourrissons et des jeunes enfants. La taille et le poids de tous les enfants ont été mesurés à l'aide d'un mètre en bois portable et d'un pèse-personne.

Des échantillons sanguins ont été prélevés par ponction capillaire sur le majeur ou l'annulaire de chaque enfant par des infirmières qualifiées. À l'issue du prélèvement sanguin, les infirmières ont fourni des récipients pré-étiquetés pour les échantillons de selles, une cuillère en plastique propre et un morceau de papier à placer sous l'enfant au moment de la défécation, s'il ne portait pas de couche. Une chaîne du froid rigoureuse a été établie pour les échantillons de sang et de selles.

Nous avons mesuré trois marqueurs d'inflammation systémique dans le sérum : la protéine C-réactive (CRP), l'alpha-1-glycoprotéine acide (AGP, ou orosomucoïde) et les anticorps IgG spécifiques au noyau de l'endotoxine (EndoCAb). Trois biomarqueurs d'entéropathie ont été examinés dans les échantillons de selles : la néoptérine (NEO), l'alpha 1-antitrypsine (AAT) et la myéloperoxydase (MPO).

À l'aide des biomarqueurs de l'entéropathie, nous avons défini une note d'entéropathie environnementale (EE) selon l'approche détaillée par Kosek et al. [18]. Avec une approche identique, nous avons établi une note d'EE élargie en utilisant les indicateurs d'EE et d'inflammation (AGP et EndoCAb).

3. Résultats

3.1 Évaluation du cadre d'interventions de l'OMS avec une étude de cas en Éthiopie

À l'issue de l'examen des différents composants et indicateurs décrits dans le cadre d'interventions de l'OMS contre le retard de croissance, nous avons identifié des corrélations systématiques entre une mauvaise croissance linéaire et les indicateurs de taille à la naissance, de taille de la mère et d'éducation, ainsi que d'hygiène et d'assainissement dans les ménages. Nous avons également distingué d'autres indicateurs, tels que l'exposition à la fumée en milieu fermé, étroitement liés aux retards de croissance, mais qui n'avaient pas été pris en compte dans le cadre d'interventions de l'OMS.

Taille à la naissance

Le lien entre la taille à la naissance et la croissance de l'enfant découle des facteurs in utero affectant le développement de l'enfant et le retard de croissance a plusieurs fois été associé au retard de croissance intra-utérine et aux accouchements prématurés en Afrique [19–21]. Cependant, les données sur le poids et la longueur à la naissance ne sont pas systématiquement recueillies ou enregistrées, et les enquêtes démographiques et de santé (EDS) interrogent les mères uniquement sur la taille perçue de l'enfant à la naissance pour en tirer un indicateur approximatif. Bien que cette mesure ait ses limites, une analyse plurirégionale d'EDS (dont l'enquête éthiopienne de 2000) a permis de déceler une probabilité accrue de retard de croissance chez l'enfant, avec une probabilité de « très faible » et « plus faible que la moyenne » [22].

Maladies récentes

En ce qui concerne les maladies récentes, bien que le retard de croissance ait été plusieurs fois associé à des diarrhées [23] et des infections respiratoires aiguës (IRA) [24] récentes, peu d'études ont montré de telles corrélations en Éthiopie. Une seule a identifié un lien étroit entre la diarrhée et le retard de croissance chez les enfants de moins de cinq ans [25], et aucune donnée n'a permis d'établir une corrélation entre les infections respiratoires aiguës et le retard de croissance en Éthiopie. Aucun lien entre le paludisme et le retard de croissance n'a été mentionné dans l'étude menée à Jimma, dans la région d'Oromia [26].

Caractéristiques maternelles

Les études menées en Éthiopie ont à plusieurs reprises montré une forte corrélation entre la taille et le poids de la mère et le retard de croissance chez l'enfant [8,27,28], à l'exception de Fentaw et al. [29], qui n'a constaté aucun lien entre l'indice de masse corporelle de la mère (IMC) et le retard de croissance chez l'enfant. La grossesse à l'adolescence influence fortement la nutrition de l'enfant et revêt une importance particulière en Éthiopie, où le phénomène est courant. Une étude, réalisée dans le nord-ouest de l'Éthiopie par Haidar et al. [30], montre que les enfants nés d'adolescentes de moins de 15 ans sont beaucoup plus exposés au risque de retard de croissance. Une analyse multinationale comprenant l'Éthiopie a également mis en évidence des taux de retard de croissance nettement supérieurs chez les enfants de mères adolescentes [31]. En Éthiopie et dans beaucoup d'autres pays en voie de développement, un intervalle de naissance de moins de 24 mois est associé à un taux de prévalence du retard de croissance significativement supérieur [22,32]. Umeta et al. [33] ont constaté que dans la région d'Oromia, les enfants de 5 à 11 mois consommant un lait maternel à faible teneur en zinc présentaient plus souvent un retard de croissance que ceux recevant un lait maternel normalement dosé en zinc.

La faible éducation maternelle a également été associée à des niveaux plus élevés de retard de croissance chez les enfants de 6 à 23 mois dans le sud de l'Éthiopie [34] et parmi les enfants de 0 à 59 mois dans une analyse des données d'EDS de 2000 et 2005 [35]. L'analyse distincte des données regroupées issues des EDS réalisées en Éthiopie en 2000, 2005 et 2011 n'a pas permis d'établir une corrélation entre l'éducation maternelle et le z-score TA des enfants de 0 à 23 mois. Toutefois, l'éducation maternelle est étroitement liée au développement des enfants de 24 à 59 mois et les progrès réalisés en matière d'éducation des mères depuis l'an 2000 ont entraîné une diminution de la prévalence du retard de croissance dans ce groupe d'âge [36].

Allaitement et alimentation de complément

La corrélation entre l'allaitement exclusif et la croissance de l'enfant est floue en Éthiopie. Dans la Région des nations, nationalités et peuples du Sud (RNNP), Fikadu et al. [37] ont constaté que les enfants de 24 à 59 mois exclusivement nourris au sein pendant les six premiers mois étaient moins susceptibles de présenter un retard de croissance que ceux recevant une alimentation mixte. En revanche, Jones et al. [38] ont analysé les enquêtes démographiques et de santé (EDS) réalisées en Éthiopie en 2005 et ont observé un z-score TA sensiblement inférieur chez les enfants exclusivement nourris au sein de 0 à 6 mois, par rapport à ceux recevant une alimentation mixte.

En ce qui concerne l'alimentation de complément, Ali et al. [39] ainsi que Jones et al. [38] ont observé des corrélations entre le retard de croissance et la diversité alimentaire minimale ainsi que le régime acceptable minimal, respectivement, chez les enfants éthiopiens de 6 à 23 mois. Pourtant, l'analyse des données regroupées issues des EDS réalisées en Éthiopie en 2000, 2005 et 2011 n'a pas permis d'établir de lien avec la diversité alimentaire minimale ou le régime acceptable minimal, mais a mis en évidence la forte corrélation entre la consommation de lait et le z-score TA des enfants de 6 à 23 mois et de 24 à 59 mois [36]. Les enfants d'Afrique sont fortement exposés aux aflatoxines et plusieurs études ont démontré que cette exposition entravait la croissance de l'enfant [40–43]. En Éthiopie, les mycotoxines se retrouvent dans diverses céréales [44] et une concentration élevée d'aflatoxines a plusieurs fois été constatée dans les arachides [45], mais aucune étude n'a examiné le lien entre la croissance linéaire et l'exposition aux aflatoxines dans le pays.

Assainissement dans les ménages et les communautés

En Éthiopie, le retard de croissance est souvent associé aux indicateurs de qualité de l'eau et d'assainissement dans les ménages. Medhin et al. [46] ainsi qu'Outes et Porter [47] ont observé d'importantes corrélations entre le retard de croissance et les indices composites comprenant la source d'eau potable et le type de toilettes des ménages. Dans une analyse économétrique multinationale (incluant l'Éthiopie) des données d'EDS, Spears [48] a conclu que la défécation à l'air libre jouait un rôle important dans les variations internationales de la taille des enfants. En Éthiopie, deux analyses séparées des données regroupées issues d'EDS ont montré qu'une prévalence réduite de la défécation à l'air libre entraînait une diminution des retards de croissance [36,49]. En outre, une réduction du nombre d'enfants présentant un retard de croissance a été constatée à la suite de la mise en œuvre d'un projet d'acheminement de l'eau, d'assainissement et d'hygiène dans le nord de l'Éthiopie, dans lequel la promotion du lavage des mains au savon comptait parmi les interventions clés [50].

Lacunes de données en Éthiopie

Nous avons constaté d'importantes lacunes dans la documentation relative au retard de croissance en Éthiopie. Nous n'avons trouvé aucune étude éthiopienne évaluant les biomarqueurs d'entéropathie environnementale et envisageant leur corrélation avec la croissance de l'enfant. Étant donné les liens étroits entre la croissance linéaire et l'assainissement dans les ménages et les communautés d'Éthiopie, des études supplémentaires analysant cette relation seraient appropriées. Au vu des preuves de contamination par les aflatoxines dans les aliments de consommation courante en Éthiopie, d'autres études examinant la corrélation entre la croissance de l'enfant et l'exposition aux aflatoxines sont également recommandées.

3.2 Facteurs déterminants des retards de croissance en Éthiopie de 2000 à 2011

Enfants de 0 à 5 mois

En ce qui concerne les enfants de 0 à 5 ans, les principaux indicateurs de z-score TA étaient le sexe, l'âge, la taille estimée à la naissance, le z-score PT, la taille de la mère et la richesse du ménage. Le z-score TA moyen était considérablement supérieur chez les filles et diminuait significativement à mesure que l'âge augmentait. La taille estimée à la naissance était fortement associée au z-score TA et montrait une relation dose-réponse : plus la mère estime son enfant petit à la naissance, plus le z-score TA est faible. Le z-score PT d'un enfant semblait inversement proportionnel à son z-score TA. La taille de la mère et la richesse du ménage semblaient fortement et positivement liées au z-score TA.

Parmi les facteurs inclus dans les modèles à plusieurs variables définitifs pour les enfants de moins de six mois, seuls la taille estimée à la naissance et l'indice de richesse du ménage ont considérablement changé entre les trois enquêtes. Toutefois, pour les deux variables, aucune tendance claire n'a été observée à partir des enquêtes.

Enfants de 6 à 23 mois

Pour les enfants de 6 à 23 mois, les principaux indicateurs de z-score TA étaient les caractéristiques de l'enfant et de son alimentation, ainsi que les facteurs maternels et du ménage. Le z-score TA était supérieur chez les filles, les plus jeunes enfants, ceux dont la taille à la naissance était estimée la plus grande, ceux qui enregistraient un z-score PT inférieur et ceux dont les mères étaient les plus grandes. Le z-score TA était encore meilleur chez les enfants nés à des intervalles plus importants, ceux qui buvaient du lait non humain, ceux dont la mère affichait un IMC élevé, ceux dont la mère utilisait un moyen de contraception, ceux dont la mère avait un partenaire sans emploi, ceux vivant dans un ménage patriarcal et ceux vivant dans les ménages les plus riches.

D'importantes différences entre ces variables indépendantes ont été relevées dans les tendances pour la période 2000-2011. La seule tendance constante apparue dans les trois enquêtes était le taux d'utilisation par la mère de moyens contraceptifs modernes, qui a augmenté de 6,5 % en 2000 à 24,4 % en 2011. À l'instar des enfants de 0 à 5 mois, la proportion d'enfants de 6 à 23 mois dont la taille à la naissance avait été estimée comme très grande ou très petite a augmenté entre 2000 et 2011. D'autres facteurs comme le z-score PT moyen de l'enfant, la proportion d'enfants ayant consommé du lait non humain au cours des dernières 24 heures, l'IMC moyen de la mère et l'indice de richesse moyen du ménage ont augmenté entre 2000 et 2005, puis diminué de 2005 à 2011.

Enfants de 24 à 59 mois

Les principaux indicateurs de z-score TA comprenaient les caractéristiques de l'enfant et de son alimentation, les maladies récentes, ainsi que les facteurs maternels, du ménage et de la communauté. La taille estimée à la naissance montrait encore une fois une relation dose-réponse avec le z-score TA, où les enfants les plus petits enregistraient un score inférieur et où le z-score TA moyen était supérieur chez les enfants qui n'avait pas connu de récentes fièvres ou diarrhées. Les enfants ayant consommé du lait non humain au cours des dernières 24 heures présentaient un z-score TA supérieur. La taille de la mère, l'IMC et l'éducation étaient positivement liés au z-score TA, ce qui indiquait que les mères les plus grandes, les mieux nourries et bénéficiant de la meilleure éducation avaient des enfants plus grands. Cependant, la plupart des différences entre les z-scores TA selon l'éducation de la mère sont apparues entre les mères ayant reçu un enseignement primaire et celles avec un niveau d'éducation plus avancé. Une différence relativement modeste a été constatée dans les z-scores TA entre les mères sans éducation et celles ayant reçu un enseignement primaire. Parmi les facteurs de composition du ménage, seul le coefficient de dépendance du ménage a montré une corrélation négative avec le z-score TA, suggérant que la nutrition de l'enfant est négativement affectée dans les ménages présentant une forte proportion de dépendance. La richesse du ménage était positivement liée au z-score TA, ce qui indiquait une diminution des retards de croissance à mesure de l'augmentation de la richesse du ménage. Bien que d'importantes corrélations ont été relevées, aucun lien clair n'a été observé entre la proportion de ménages où les défécations se font à l'air libre dans chaque groupe et le z-score TA et les scores moyens spécifiques aux catégories variaient de -2,42 à -2,18. L'année d'enquête a montré que le z-score TA moyen augmentait régulièrement au fil du temps.

Parmi les facteurs explicatifs du z-score TA, nous avons relevé une tendance importante et constante en ce qui concerne les diarrhées et fièvres récentes, ainsi qu'au niveau de l'éducation de la mère. S'agissant du modèle global, nous avons également remarqué une tendance claire au changement en ce qui concerne la défécation à l'air libre. De 2000 à 2011, la prévalence de diarrhées cumulée à deux semaines est passée de 18,8 % à 9,6 %, tandis que celle de la fièvre a chuté de 25,4 % à 14,5 % sur la même période. L'éducation de la mère a connu une amélioration constante, avec une augmentation de la proportion de mères ayant reçu un enseignement primaire de 12,6 % en 2000 à 26,1 % en 2011. La défécation à l'air libre au niveau communautaire a considérablement diminué : en 2000, 52 % des enfants de 24 à 59 mois vivaient dans des communautés où 100 % des ménages la pratiquaient, tandis qu'en 2011, seuls 5,2 % des enfants de cette tranche d'âge vivaient dans de telles communautés.

3.3 Évolution des programmes de nutrition et de santé en Éthiopie et leur corrélation avec la réduction du nombre d'enfants présentant un retard de croissance

Tendances du retard de croissance à l'échelle nationale et infranationale

Les données d'EDS recueillies en 2000, 2005 et 2011 montrent une réduction régulière de la prévalence du retard de croissance examinée à l'échelle nationale et selon que l'enfant habite en zone urbaine ou rurale en Éthiopie. Sur la même période, le nombre global de cas d'enfants présentant un retard de croissance a diminué à l'échelle nationale, malgré l'augmentation de la population d'enfants de moins de cinq ans, qui est passée de 10,3 millions en 2000 à 12,6 millions en 2011.

Entre 2000 et 2005, nous avons constaté une réduction de 6,9 points de pourcentage des retards de croissance au niveau national. Cette diminution pourrait être principalement attribuée à la réduction du nombre d'enfants présentant un retard de croissance dans la région d'Oromia, dans la RNNP et dans le Tigré. De 2005 à 2011, la diminution de 6,8 points de pourcentage de la prévalence nationale des retards de croissance pourrait être attribuée à la réduction du nombre d'enfants présentant un retard de croissance dans les régions d'Amhara et d'Oromia, dans la RNNP et dans le Somali.

Actions relatives à la nutrition et programme de vulgarisation sanitaire

Si de nombreux projets à petite échelle en matière de santé et de nutrition existaient en Éthiopie dans les années 90 et au début des années 2000, des programmes de grande envergure n'ont vu le jour qu'en 2003 et 2004, avec le lancement du programme de vulgarisation sanitaire (PVS), de la stratégie de communication renforcée (SCR), du programme d'alimentation de complément ciblée (ACC) et du programme de prise en charge communautaire de la malnutrition aiguë (PCCM).

Établi en 2003 et rendu opérationnel en 2004 [51], le programme de vulgarisation sanitaire en Éthiopie a été élaboré dans le but d'améliorer l’accès à un ensemble universel de services de santé, en mettant l'accent sur la prévention des maladies et affections [52]. Nous assistons à un élargissement régulier de la couverture des services de santé locaux depuis l'an 2000. Comme l'explique l'UNICEF [53], le nombre de postes créés dans le domaine de la santé a constamment augmenté, passant de 1 311 en 2001 à 6 191 en 2005 et à 14 192 en 2011. Cette hausse montre que la couverture du secteur de la santé éthiopien a régulièrement augmenté en ce qui concerne les infrastructures de soins de santé primaires et a presque atteint l'objectif du PVS, fixé à 15 000 postes de santé opérationnels et occupés par des agents de vulgarisation sanitaire en 2011. Les programmes de nutrition à grande échelle (tels que la SCR et la PCCM) ont été intégrés au PVS en 2008.

La stratégie de communication renforcée (SCR) a été lancée en 2004 en Éthiopie et a permis de fournir une supplémentation semestrielle en vitamine A aux enfants de 6 à 59 mois ainsi que des traitements vermifuges aux enfants de 12 à 59 mois à l'occasion des Journées pour la santé des enfants éthiopiens. Dans les districts exposés à la sécheresse, les enfants ont été examinés en mesurant la circonférence du bras ; ceux présentant un état de malnutrition aiguë sévère ont été dirigés vers le programme thérapeutique ambulatoire du PCCM, et ceux présentant un état de malnutrition aiguë modérée, vers le programme ACC.

Lancé en 2005, le programme de protection sociale fondé sur des activités productives (PPSAP) en Éthiopie représente le plus important programme de protection sociale et de sécurité alimentaire d'Afrique. Mis en œuvre dans les districts d'insécurité alimentaire, le PPSAP apporte son aide aux ménages en insécurité alimentaire pendant les périodes de famine, afin de leur éviter de vendre leurs biens et de stabiliser les modèles de consommation [54].

Le programme pour l'accès universel (PAU) a été établi en 2005 et définit les objectifs de capacité en matière d'accès à des sources d'eau potable et des installations d'assainissement adéquates. Les données d'EDS montrent une augmentation de la proportion de ménages ruraux disposant d'un meilleur accès à une source d'eau potable, qui est passée de 14 % en 2000 à 26 % en 2005 et à 42 % en 2011 [55]. Bien que la proportion de ménages disposant d'un meilleur accès à des installations d'assainissement soit restée relativement basse (seulement 8 % en 2011), celle des ménages pratiquant la défécation à l'air libre est passée de 82 % en 2000 à 38 % en 2011 [55].

Effets tangibles du programme sur le retard de croissance

Très peu d'analyses d'impact examinent les effets des actions à grande échelle en matière de santé et de nutrition sur les retards de croissance et les rares qui existent présentent des résultats contradictoires. L'évaluation du programme de nutrition communautaire (PNC) et du programme d'alimentation de complément ciblée (ACC) comprenait différentes enquêtes transversales initiales, médianes et finales. Les enquêtes initiales ont été réalisées avant le lancement du PNC et les groupes d'intervention et témoins ont été établis de facto, sur la base de la mise en œuvre effective du programme. Entre 2008 et 2010, les groupes d'intervention ont connu une plus grande amélioration des contacts avec les agents de santé, de l'alimentation des nourrissons et des jeunes enfants (p.ex. la diversité du régime alimentaire et le régime acceptable minimal), ainsi qu'une plus forte diminution de la prévalence des retards de croissance que dans les groupes témoins [56]. Une réduction des retards de croissance a été constatée tant dans les zones d'intervention visées par le programme ACC que dans celles non concernées, et ce, quelle que soit l'intensité du PNC à l'échelle des communautés. Bien que cette évaluation suggère que le programme de nutrition communautaire (PNC) – avec ou sans programme d'alimentation de complément ciblée (ACC) – était associé à la réduction des retards de croissance, les résultats pourraient être faussés par le fait que les zones initiales où le PNC a été lancé en 2008 étaient classées comme « exposées à la sécheresse » ; impliquant ainsi la mise en œuvre des programmes de stratégie de communication renforcée et d'alimentation de complément ciblées au même endroit.

L'évaluation de l'impact nutritionnel du programme de protection sociale fondé sur des activités productives (PPSAP) et du programme de nutrition communautaire (PNC) n'a montré « aucune corrélation fiable et statistiquement significative entre le PPSAP et la participation ou la durée du PNC et les z-scores TA ou le retard de croissance, après examen des caractéristiques de l'enfant, de la mère, du ménage et de la localisation [57] ». Ces récents résultats corroborent les précédentes recherches liées au PPSAP suggérant que, même si certains bénéficiaires du PPSAP avaient connu des progrès en matière de sécurité alimentaire des ménages, ces avancées ne se sont pas traduites par une amélioration de l'état nutritionnel et de santé de l'enfant [58].

Tendances à long terme

Outre les programmes à grande échelle, certaines tendances à long terme pourraient avoir contribué aux améliorations au niveau du statut nutritionnel et de la croissance linéaire de l'enfant. Au cours des 20 dernières années, l'Éthiopie a connu une importante hausse de son PIB et enregistré une diminution notable de la part de sa population vivant sous le seuil de la pauvreté (moins d'1,25 dollar par jour). Entre 2000 et 2005 notamment, la proportion de personnes vivant dans la pauvreté a diminué de 16 points de pourcentage, passant de 54,6 % à 38,9 % [59].

La croissance économique n'a toutefois pas entraîné d'augmentation de la richesse des ménages à l'échelle nationale en Éthiopie [36,55]. Bien que le PIB aurait pu entraîner des répercussions positives, les crises alimentaires récurrentes suggèrent que la croissance économique n'a pas amélioré la sécurité alimentaire des populations vulnérables. Les crises alimentaires de 2002 et 2011 n'ont pas toujours été associées à une augmentation de la prévalence des cas de retard de croissance dans les trois régions les plus affectées : Afar, Oromia et Somali. Entre 2000 et 2005, la prévalence du retard de croissance a diminué dans ces trois régions, mais le nombre de cas a augmenté dans la région Somali. Entre 2005 et 2011, la prévalence du retard de croissance s'est uniquement accentuée dans la région d'Afar, mais le nombre de cas a augmenté à Afar et Oromia. En particulier, malgré la réduction de 17,7 points de pourcentage dans la prévalence du retard de croissance dans la région Somali entre 2005 et 2011, le nombre de cas n'a diminué que faiblement. La forte hausse de la population éthiopienne associée à une urbanisation relativement lente pourrait avoir « dilué » les progrès économiques réalisés ; par conséquent, le nombre d'enfants exposés à la malnutrition en cas de crise alimentaire pourrait rester inchangé.

3.4 État de croissance, inflammation et entéropathie chez les jeunes enfants en Tanzanie

Dans le cadre de l'étude de cas-témoins menée dans le nord de la Tanzanie, un questionnaire complet, ainsi que des données concernant l'anthropométrie, les biomarqueurs sanguins et les biomarqueurs des selles, ont été mis à disposition pour 310 enfants. Parmi eux, 52 % présentaient un retard de croissance avec un z-score TA moyen de -2,82 (écart type ± 0,61). En outre, les enfants présentant une croissance normale ont enregistré un z-score TA moyen de -1,22 (écart type ± 0,56). Le z-score PT était beaucoup plus faible (p=0,016) chez les enfants présentant un retard de croissance.

Corrélations entre le retard de croissance et l'inflammation ainsi que l'entéropathie

Aucune différence notable n’a été relevée entre les concentrations médianes de CRP et d'AGP chez les enfants présentant un retard de croissance et chez les enfants à la croissance normale. De même, aucune différence significative n'a été constatée dans les concentrations médianes d'EndoCab, NEO, AAT et MPO. Bien qu'aucune différence importante dans la concentration d'hémoglobine n'ait été observée entre les groupes, la prévalence de l'anémie était considérablement supérieure (p=0,016) chez les enfants présentant un retard de croissance. Nous n'avons relevé aucune différence dans la prévalence du paludisme et des diarrhées et fièvres récents entre les différents groupes d'enfants.

En ce qui concerne l'hygiène des mains, presque tous les parents et tuteurs ont déclaré laver les mains de leurs enfants au moins une fois par jour et aucune différence significative n'a été observée entre les enfants présentant un retard de croissance et les autres. Les pratiques d'hygiène les plus couramment mentionnées étaient le lavage des mains de l'enfant avant le repas (83,9 % chez les enfants présentant un retard de croissance et 78,5 % chez les autres) et après la défécation (respectivement 53,5 % et 47,1 %). Seulement 7,1 % des parents et tuteurs d'enfants présentant un retard de croissance ont déclaré laver fréquemment les mains de leurs enfants pendant la journée, contre 5 % pour les autres. Aucune pratique particulière n'a été associée de manière pertinente au retard de croissance.

Alors que 72 % des ménages disposaient de l'une ou l'autre installation d'assainissement, seuls 7 % des ménages étaient dotés d'installations sanitaires « améliorées ». Aucune différence statistiquement significative dans les proportions de tous types d'installations d'assainissement ou d'installations améliorées n'a été constatée entre les enfants présentant un retard de croissance et les autres. Plus de la moitié des ménages possédaient du savon, avec une fréquence beaucoup plus importante dans les ménages dont les enfants ne présentaient pas de retard de croissance ($p=0,033$). La possession de savon était également considérablement associée à une diminution du risque de retard de croissance (OR = 0,61 ; 95 % CI : 0,38, 0,96). Toutefois, il est important de noter que seuls 2,3 % des ménages disposaient d'une station fixe pour le lavage des mains et qu'aucune différence statistique n'a été relevée entre les groupes.

Les infections aux *Ascaris lumbricoides* étaient très rares et ont touché uniquement quatre enfants qui présentaient tous un retard de croissance. Environ 25 % des enfants avaient été alimentés avec l'eau de leur bain au cours des derniers mois, et 40 % à au moins un moment de leur vie avant un an. Nous n'avons constaté aucune différence statistiquement significative dans les proportions d'enfants présentant un retard de croissance et d'enfants à la croissance normale alimentés avec l'eau de leur bain.

Étant donné que les sujets d'étude ont été sélectionnés parmi les participants à un essai de micronutriments, presque tous les enfants

(96,7 %) avaient reçu des micronutriments en poudre au cours des six mois précédant l'étude, sans aucune différence importante en matière de consommation chez les enfants présentant un retard de croissance et les autres. Près de la moitié des enfants recevaient une alimentation modérément diversifiée et la proportion d'enfants à la croissance normale (54,4 %) recevant une alimentation modérément diversifiée était considérablement supérieure à celles des enfants présentant un retard de croissance (42,5 % ; p=0,037). Environ 40 % des ménages étaient classés comme ayant connu une insécurité alimentaire « sévère » au cours des derniers mois, mais aucune différence statistiquement significative n'a été observée entre les ménages avec des enfants présentant un retard de croissance et les autres. Près de 4 % des ménages avaient connu une famine sévère et le phénomène était statistiquement bien plus courant (p=0,045) dans les ménages avec des enfants présentant un retard de croissance.

Les corrélations par paires entre le z-score TA et tous les biomarqueurs d'inflammation et d'entéropathie montrent que seul l'AGP, un marqueur à long terme de l'inflammation systémique, était statistiquement et négativement associé au z-score TA. En d'autres termes, des concentrations moindres en AGP entraînent de meilleurs z-scores TA.

Corrélations entre les facteurs de risque d'inflammation ou d'entéropathie et les notes d'entéropathie

Lors de l'examen des potentiels facteurs de risque d'inflammation ou d'entéropathie environnementale (EE), nous avons constaté que les marqueurs d'inflammation et d'EE n'étaient pas associés de manière statistiquement significative aux caractéristiques de santé, d'alimentation et d'hygiène. Nous avons également mesuré les corrélations entre des facteurs de risque similaires et les indicateurs individuels d'inflammation et d'entéropathie (CRP, AGP, AAT, NEO et MPO) et avons observé des concentrations nettement plus élevées en : a) AGP (p=0,015) et EndoCAb (p=0,018) chez les enfants vivant dans des ménages ne possédant pas de savon ; b) AGP (p=0,028) chez les enfants ayant souffert de fièvre au cours des deux dernières semaines ; c) NEO (p=0,031) chez les enfants ne suivant pas un régime alimentaire à la diversité minimale ; et d) MPO (p=0,039) chez les enfants alimentés avec l'eau de leur bain au cours des derniers mois.

4. Discussion

La présente thèse a permis d'identifier une myriade de facteurs déterminants du retard de croissance ainsi que de facteurs associés à une réduction des retards de croissance, notamment chez les enfants de 6 à 59 mois. Pour les enfants de 0 à 5 mois, un nombre restreint de facteurs de risque étaient associés à la croissance de l'enfant. De manière générale, notre analyse de l'Éthiopie a révélé plusieurs pistes pour de potentielles interventions visant à prévenir les retards de croissance dans cette tranche d'âge. Néanmoins, la forte corrélation entre le z-score TA et la taille à la naissance ainsi que la taille maternelle – des indicateurs en lente évolution du statut nutritionnel des femmes à l'échelle de la population – suggère que les interventions maternelles et prénatales pourraient favoriser le développement fœtal et ainsi entraîner de plus grandes tailles à la naissance et une meilleure croissance linéaire pendant les premiers mois de l'enfant, voire plus tard au cours de sa vie.

Certains facteurs de risque de retard de croissance sont facilement « modifiables » et pourraient être traités à court terme, tandis que d'autres, tels que l'éducation maternelle, demanderaient beaucoup plus de temps avant de connaître une amélioration significative. Cependant, certains facteurs de risque, tels que l'âge et le sexe de l'enfant, ainsi que l'âge et le sexe du ménage, ne sont pas modifiables et ne peuvent donc pas être traités.

4.1 Facteurs de risque modifiables à court terme

La situation en matière d'hygiène et d'assainissement à l'échelle du ménage et de la communauté représente un facteur de risque important et les progrès réalisés dans ce domaine sont associés à des niveaux plus bas de retards de croissance. Ces constatations sont semblables à celles d'autres pays. Presque toutes les sections du cadre d'interventions de l'OMS contre le retard de croissance mentionnent les facteurs EAH et les infections liées, ce qui illustre les nombreuses façons dont les conditions EAH peuvent nuire au développement de l'enfant.

Bien que la prévalence de la défécation à l'air libre ait significativement diminué en Éthiopie depuis l'an 2000, la majorité des latrines du pays sont des toilettes sèches à fosse sans dalle, qui ne comptent pas parmi les installations améliorées définies par l'OMS et UNICEF [60]. Ce phénomène démontre qu'une transition de la défécation à l'air libre vers des installations sanitaires *non améliorées* peut réduire les retards de croissance, mais suggère également qu'une augmentation d'envergure des installations d'assainissement améliorées pourrait permettre d'autres réductions de la prévalence du retard de croissance en limitant les diarrhées et entéropathies environnementales.

La promotion de l'utilisation de savon dans les ménages est également une stratégie viable pour réduire les retards de croissance, car elle limite l'exposition des enfants aux pathogènes. Dans l'étude de cas-témoins menée en Tanzanie, la présence de savon dans les ménages constituait le seul indicateur d'hygiène et d'assainissement étroitement lié au retard de croissance, aux inflammations et aux marqueurs d'EE (AGP et EndoCAb). Ces résultats s'expliquent vraisemblablement par le fait qu'un lavage régulier des mains au savon peut prévenir la contamination des aliments et la transmission des pathogènes [61]. Si les réductions des retards de croissance en Éthiopie sont en lien avec les programmes EAH promouvant le lavage des mains au savon [50], peu de données s'intéressent aux liens entre le lavage des mains et l'entéropathie environnementale. Une récente étude menée au Bangladesh a montré que les enfants de 0 à 30 mois étaient plus susceptibles de présenter des niveaux élevés de calprotectine fécale – un marqueur d'inflammation de l'intestin – lorsque leurs parents ou tuteurs s'occupaient d'eux avec les mains visiblement sales [62]. Une récente étude menée en Inde montre également un risque de retard de croissance significativement moindre chez les enfants de 0 à 23 mois dont les parents ou tuteurs avaient déclaré se laver les mains au savon avant les repas ou après la défécation [63].

Outre les programmes EAH, des actions destinées à améliorer l'état nutritionnel et de santé de la mère pourraient s'avérer utiles à court terme pour réduire les retards de croissance en améliorant le développement fœtal et les pratiques de soin aux nourrissons et petits enfants.

Il convient de noter que les variables modifiables peuvent être liées à l'âge et nous avons constaté que les facteurs de risque du retard de croissance évoluaient avec l'âge [36]. Ainsi, les responsables de la planification et de la gestion des programmes devraient prendre en considération le fait que les actions peuvent avoir des effets sur certains groupes d'âge et pas sur d'autres.

4.2 Facteurs de risque modifiables à long terme

L'éducation maternelle et l'accès aux soins de santé ont à plusieurs reprises été qualifiés de facteurs de risque de retard de croissance et l'amélioration de ces éléments pourrait se révéler être une stratégie efficace à long terme pour réduire la prévalence des retards de croissance.

Notre analyse de l'Éthiopie a démontré que l'éducation maternelle influençait le développement de l'enfant et d'autres études réalisées dans le pays ont fait la preuve d'un lien entre l'éducation des parents et des tuteurs et le retard de croissance [34,35]. Étant donné qu'une faible éducation maternelle est susceptible de contribuer au retard de croissance en affectant les pratiques en matière de soins aux enfants [5], l'élargissement de l'accès des femmes à l'enseignement primaire et secondaire pourrait aider à réduire les retards de croissance à long terme en modifiant les pratiques de soins. L'accès des filles à l'enseignement primaire dans toute l'Éthiopie s'est amélioré à la suite de la suppression des frais de scolarité pour l'école primaire en 2002 [64]. Cet investissement dans l'éducation pourrait ainsi avoir contribué à la diminution des retards de croissance, notamment chez les jeunes femmes. Cependant, en ce qui concerne les enfants de 24 à 59 mois, nous avons observé de plus hauts z-score TA chez les enfants de mères ayant reçu un enseignement plus avancé (école secondaire ou supérieure). Ainsi, les politiques publiques qui améliorent l'accès des filles à l'enseignement primaire et secondaire à court terme peuvent contribuer à la future réduction des retards de croissance.

Notre analyse en Éthiopie a démontré que l'utilisation de moyens de contraception modernes était associée à une réduction des retards de croissance. Le programme de vulgarisation sanitaire étant le principal fournisseur de services de contraception en Éthiopie [65], l'utilisation de moyens contraceptifs pourrait refléter le taux d'accès et de recours à ce programme, qui fournit également d'autres soins de santé et de nutrition qui pourraient avoir joué un rôle dans la diminution des retards de croissance [7]. En outre, l'élargissement de la portée du programme de vulgarisation sanitaire et le développement des différentes actions en matière de nutrition dans les régions d'Amhara, d'Oromia et de RNNP sont associés à des réductions des retards de croissance à l'échelle régionale entre 2005 et 2011 [7], avant que le programme ne soit entièrement mis en œuvre. De plus, l'utilisation de moyens de contraception modernes pourrait entraîner des intervalles de naissance plus espacés et une réduction de la parité. L'élargissement du programme de vulgarisation sanitaire en Éthiopie s'est déroulé sur une période de 10-15 ans et un développement semblable des services de santé et de nutrition dans d'autres pays devrait être considéré comme une approche à long terme pour l'amélioration de l'accès aux soins de santé et la diminution des retards de croissance.

5. Conclusions

Afin d'atteindre les objectifs de réduction des retards de croissance dans le monde, les décideurs politiques et les responsables de la planification des programmes doivent tout d'abord recenser les facteurs déterminants du retard de croissance spécifiques au pays, s'ils n'ont pas déjà été révélés. Des analyses supplémentaires des sources de données existantes, telles que les études démographiques et de santé, peuvent souvent être utilisées pour déterminer les facteurs clés des retards de croissance. Par ailleurs, en ajoutant des études élaborées spécifiquement pour examiner les corrélations entre les différents biomarqueurs du retard de croissance, nous pourrions atteindre une certaine compréhension des facteurs contextuels favorisant le retard de croissance. En outre, les responsables de la planification devraient opter pour une approche pluridimensionnelle pour réduire les retards de croissance, puisque les interventions concernant la nutrition à elles seules ne seront sûrement pas suffisantes. Il est nécessaire d'élaborer des programmes visant à améliorer les installations et les pratiques EAH, notamment, car les conditions EAH peuvent, dans de nombreux contextes, contribuer à la réduction des retards de croissance. En outre, les interventions EAH seront susceptibles d'obtenir de meilleurs bénéfices à court terme et pourraient participer à la réduction de la prévalence ainsi que du nombre de cas de retards de croissance au cours des 8–13 prochaines années, quand les objectifs mondiaux fixés par l'OMS et les objectifs de développement durable de l'ONU seront évalués.

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CHAPTER 1
Assessment of the WHO Stunting Framework using Ethiopia as a case study

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ABSTRACT

Poor linear growth in children <5 years old, or stunting, is a serious public health problem particularly in Sub-Saharan Africa. In 2013, the World Health Organization (WHO) released a conceptual framework on the Context, Causes and Consequences of Childhood Stunting (the "WHO conceptual framework") that identifies specific and general factors associated with stunting. The framework is based upon a global review of data, and we have applied it to country-level analysis where health and nutrition policies are made and public health and nutrition data are collected. We reviewed the literature related to sub-optimal linear growth, stunting, and birth outcomes in Ethiopia as a case study. We found consistent associations between poor linear growth and indicators of birth size, recent illness (e.g. diarrhea and fever), maternal height and education, and household sanitation. Other factors listed as causes in the framework such as inflammation, exposure to mycotoxins, and inadequate feeding during and after illness have not been examined in Ethiopia, and the existing literature suggests that these are clear data gaps. Some factors associated with poor linear growth in Ethiopia are missing in the Framework, such as exposure to indoor smoke and physical violence against women during pregnancy. Examination of the factors included in the WHO framework in a country setting helps identifying data gaps helping to target further data collection and research efforts.

INTRODUCTION

Poor linear growth in children <5 years old, or stunting, is associated with increased morbidity and mortality; reduced neurocognitive function, decreased learning capacity and productivity; and poor long-term health outcomes (Black et al., 2013). The World Health Assembly in 2012 defined the reduction of stunting by 40% as one of six global nutrition targets to be achieved by 2025 (World Health Organization, 2012). The United Nations Sustainable Development Goals have also identified stunting as a key development indicator used to measure progress toward its goal to end hunger (Sustainable Development Solutions Network, 2015).

Released in 2013, the WHO conceptual framework on the Context, Causes and Consequences of Childhood Stunting (Figure 1) presents numerous factors contributing specifically to stunted growth and development (Stewart et al., 2013), in contrast to the UNICEF Framework for malnutrition (UNICEF, 1990) which presents the causes of malnutrition in general. The WHO framework was based on a review of global data. As health and nutrition policies and public health and nutrition data are collected at the country-level, applying the framework to specific country contexts is critical.

Exploring the factors associated with poor linear growth in Ethiopia provides an opportunity to test the application of the WHO Stunting Framework at the country level. Ethiopia is one of the 34 countries with the highest burden of stunting and has more than 5 million stunted children (United Nations Children`s Fund et al., 2014). While Ethiopia reduced child stunting by 13% between 2000 and 2011 (UNICEF, 2013, de Onis et al., 2013), the specific factors that led to this decline require further elucidation. By exploring the relevance and applicability of the WHO Stunting Framework to Ethiopia, we hope to support the data collection and analysis efforts of policy makers in Ethiopia and other countries affected by stunting.

This paper aims to apply the WHO Stunting Framework to Ethiopia as a case study to assess a) the current evidence-base related to stunting risk factors in Ethiopia, b) factors irrelevant to stunting in Ethiopia, and c) risk factors missing in the WHO Stunting Framework. This exercise also provides a critical assessment of the comprehensiveness and level of detail of the WHO Stunting Framework`s implicit pathways (Figure 1). An important caveat to this assessment is that we focus our analysis on child growth/stunting, whereas the WHO framework addresses both stunted growth and development.

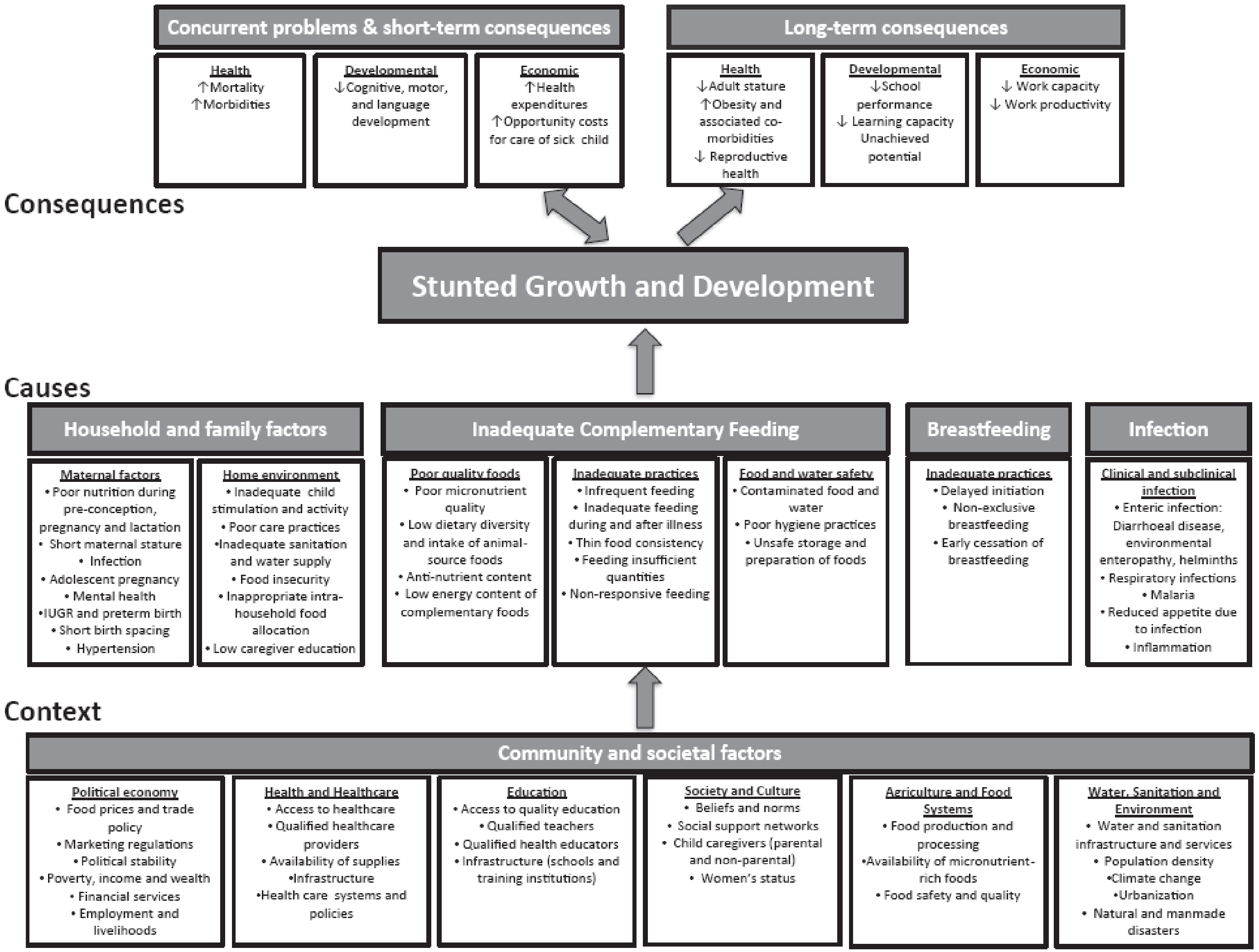

Figure 1. WHO conceptual framework on Childhood Stunting: Context, Causes, and Consequences (reprinted with permission from the World Health Organization)

METHODS

The WHO Stunting Framework is structured in three levels: the "context" (i.e. community and societal factors), proximate "causes", and short- and long-term "consequences" of stunting. As this review is concerned with the determinants of poor linear growth, we do not discuss indicators of the consequences of stunting; these have been reviewed extensively by others (Stewart et al., 2013, Hoddinott et al., 2013, Black et al., 2013, Dewey and Begum, 2011).

To identify as many risk factors related to stunting as possible, an extensive literature review was conducted using key reports of stunting in Ethiopia (Shrimpton, 2011, Silva, 2005) and global reviews of maternal and child health and nutrition (UN Standing Committee on Nutrition, 2011, Meeks, 2012, Stewart et al., 2013, Black et al., 2008). A review of the references in these articles was used to identify initial source material. To augment this literature, a structured key-word search in Web of Science, PubMed and Google Scholar was conducted to identify articles related to the determinants of stunting which were published from 2000 until February 2015. The search used the following word combinations: (stunting AND Ethiopia) OR (determinants AND stunting) OR (stunting AND reduction). Research conducted in Ethiopia was prioritized but we also included meta-analyses and studies from other countries because the applicable literature from Ethiopia is not extensive.

We have limited our assessment of the WHO Stunting Framework in several ways. First, we focused on studies investigating linear growth, often measured by height for age z-score (HAZ) or the prevalence of stunting (i.e. proportion of children with HAZ < −2 standard deviations). Thus, we focus on "growth" as the main outcome rather than "growth and development", which would include mental and psychosocial development. Second, we focus on individual, household, community and societal factors associated with stunting. Thus, multi-country ecologic studies that identify national-level factors (e.g. gross domestic product, Gini index, etc.) were excluded. Last, individual studies and trials examining the link between vitamin and mineral supplements and stunting were also excluded due to the variability between the dosage and content of supplements used in studies. In contrast, the findings of meta-analyses of supplementation studies have been included.

RESULTS

Maternal and household factors

The WHO Stunting Framework includes sub-sections on maternal and home environment factors affecting stunting. Maternal factors influence stunting through two distinct pathways: *in utero* and postnatal.

Factors influencing *in utero* growth include maternal infection, adolescent pregnancy, maternal short stature and short birth spacing. Poor nutrition during pre-conception and pregnancy is not a discrete and measurable factor, but represents a wide range of potential indicators. Gluckman & Pinal (2003) and Darnton-Hill & Mkparu (2015) conclude that deficiencies of vitamin A, vitamin E, zinc, calcium, and iodine *in utero* likely have adverse consequences but we found no studies in Ethiopia examining these deficiencies on birth outcomes. A study in Malawi observed that children born to HIV+ and vitamin A-deficient mothers were shorter and lighter at two years of age (Semba et al., 1997), and a study in Tanzania found children born to vitamin D deficient mothers were more likely to be stunted and suffer from cough (Finkelstein et al., 2012). Despite the plausible link between maternal iron deficiency anemia (IDA) and stunting (Black et al., 2013), little is known about the effects of maternal IDA during pregnancy on infant and young child growth.

Maternal infection with malaria, helminths and HIV may lead to intrauterine growth restriction and later stunted growth in the infant (Stewart et al., 2013). No studies from Ethiopia could be found directly linking malaria or helminth infections during pregnancy with later child stunting. Globally, few studies have investigated the association between infection during pregnancy and birth outcomes or stunting in early childhood. Some studies have examined the impact of antihelminthics administration during pregnancy, but a Cochrane review found only three randomized controlled trials (Haider et al., 2009) and concluded that provision of antihelminthics did not result in significant improvements in maternal anemia or the perinatal outcomes of low birthweight, preterm birth, and perinatal deaths.

Adolescent pregnancy has a well-established link with nutrition outcomes and is of particular importance in Ethiopia where teenage pregnancy is common. In a study from northwestern Ethiopia, Haidar et al (2005) show that children born to girls <15 years old were significantly more likely to be stunted. A multi-country analysis which included Ethiopia also showed markedly higher rates of stunting in children of teenage mothers (Finlay et al., 2011). In

Ethiopia and many other developing countries, a birth spacing interval of < 24 months is associated with significantly higher stunting prevalence (Maleta et al., 2003, Mukuria et al., 2005).

While stunting associated with poor birth outcomes, such as intra-uterine growth retardation and preterm birth are common in African countries (Mamiro et al., 2005, Chopra, 2003, Adekanmbi et al., 2013), data on birth weight and birth length are not routinely collected or recorded. As a proxy measure for these indicators, DHS surveys ask a child's mother about the perceived size of the child at birth which is recorded as very small, smaller than average, average, larger than average, or very large. While this measure has limitations, a multicounty review of DHS surveys (including the Ethiopian 2000 survey) found an increased likelihood of stunting in children characterized as "very small" and "smaller than average"(Mukuria et al., 2005).

Maternal factors influencing postnatal child growth include poor nutrition during lactation and mental health. Umeta et al (2003) found that Ethiopian children 5 – 11 months of age whose mothers' milk had low concentrations of zinc were more stunted than children of mothers with normal levels of breastmilk zinc. Studies investigating the association between self-reported common mental disorders (CMDs;(WHO, 1994) and stunting in Ethiopia, Peru, India, Vietnam, and Bangladesh found significant associations in the Asian countries but not in Peru or Ethiopia (Harpham et al., 2005, Nguyen et al., 2014).

Short maternal stature and other anthropometric measures are common proxies of maternal nutritional status, which can affect *in utero* and postnatal growth. Studies from Ethiopia have repeatedly shown significant associations between maternal height and weight and child stunting (Mulugeta et al., 2010, Silva, 2005, Gibson et al., 2009), with the exception of Fentaw et al (2013) who found no association between low maternal body mass index (BMI) and child stunting.

Maternal hypertension is included in the WHO Stunting Framework due to its influence on birth outcomes, such as pre-term birth, still birth, and low birth weight (Thangaratinam et al., 2012). While no studies on maternal hypertension and subsequent stunting could be identified, maternal hypertension has been associated with low birthweight and still birth in northwest Ethiopia (Adane et al., 2014). These findings are supported by a systematic review showing consistent associations between chronic hypertension and preterm delivery and low birthweight (Bramham et al., 2014).

The “home environment” sub-section includes six factors: 1) inadequate child stimulation and activity, 2) poor care practices, 3) inadequate sanitation and water supply, 4) food insecurity, 5) inappropriate intra-household food allocation, and 6) low caregiver education. There is only limited evidence linking inadequate child stimulation with poor child growth, and no studies investigating the topic in Ethiopia were identified. While multiple studies have shown that psychosocial stimulation can improve mental and motor development (Grantham-McGregor et al., 1991, Hamadani et al., 2006, Walker et al., 2007), no studies found an independent effect of psychosocial stimulation on growth. There are few data on care practices to prevent or treat a child illness, and the data found examines stunting among children who have been immunized. In Ethiopia, Medhin et al. (2010) found that children who were not immunized within the first 2 months were less likely to be stunted at the age of 6 months. In a multi-country analysis (including Ethiopia), Mukuria et al. (2005) found no difference in the prevalence of stunting between vaccinated and non-vaccinated Ethiopian children 0-35 months of age. However, in other countries, a lower stunting prevalence was found in children vaccinated for measles.

Household water and sanitation indicators typically include the safety and distance of the drinking water source and the type of toilet used. Both have been repeatedly identified as risk factors for stunting and are often included in causal models separately or as composite indices. In Ethiopia, Medhin et al. (2010) and Outes and Porter (2013) showed a significant relationship between stunting and composite indices containing both drinking water source and type of toilet. Using Ethiopia 2000 DHS data, Silva (2005) found no associations between household water source and growth, only the water quality was significantly associated with underweight at the community level. Yimer (2000) and Woodruff et al (2015) also failed to find an association between household water source and stunting. Haidar et al. (2005) observed a positive association between the distance from a household to its water source and the prevalence of stunting. It is unclear, however, if distance to a water source affects child nutrition due to diminished child care or use and consumption of unsafe water by children or is merely a indicator for some other contributing indicator.

Food security is frequently measured using the household food insecurity access scale (HFIAS), household dietary diversity score (HDDS), and food consumption score (FCS). Using data from Ethiopia’s Tigray and SNNPR regions, Ali and colleagues (2013) found that children from severely food insecure households (measured using HFIAS) were significantly more likely to be stunted; the authors found similar results in Bangladesh as part of the same study. In Ghana, Saaka and Osman (2013) compared all three aforementioned measures of food security with child nutritional status and found no association between HFIAS and stunting, wasting, or underweight, but a significant association between the HDDS and FCS and stunting. Household food insecurity can plausibly influence stunting via two pathways: 1) by contributing to poor *in utero* growth by affecting maternal dietary intake during pregnancy (Ivers and Cullen, 2011), and 2) by limiting a child's dietary intake and diet quality (of breast milk and/or complementary foods) and thus restricting growth.

The risk of undernutrition is unequally distributed among members of the same household (Lindtjørn and Alemu, 1997) in Ethiopia. It was hypothesized that this is due to the socio-cultural context (Kaluski et al., 2002), for example providing adolescent boys with a greater proportion of the household food compared to adolescent girls in food insecure households (Hadley et al., 2008). However, a recent literature review did not find strong evidence for a disadvantage of girls in terms of food allocation based on energy intake versus requirements (Berti, 2012).

Our pooled analysis of Ethiopian DHS data shows that maternal education was significantly associated with child growth in children 24-59 months, and improvements in maternal education since 2000 were associated with reductions in stunting for this age group (Woodruff et al., 2015). Results were mixed for parental literacy. While Fentaw et al. (2013) observed that the proportions of stunted, wasted, and underweight children were higher in households with illiterate parents (either mother or father), no association between maternal literacy and child stunting was observed by Beyene (2012).

Inadequate Complementary Feeding

The Framework divides complementary feeding into three sub-sections related to poor quality foods, inadequate feeding practices, and food and water safety.

Inadequate nutrient intake during early childhood is recognized as a causal factor of growth failure, but evidence on specific nutrients other than zinc and protein is limited and mixed (Branca and Ferrari, 2002). In Ethiopia's SNNPR region, a study assessing nutrient intake from weighed food records for children 6-23 months of age found that while caloric intake was significantly lower in stunted children 6-8 months of age, no difference in caloric intake between stunted and non-stunted children in other age groups and no significant difference in micronutrient intake of stunted and non-stunted children were observed (Gibson et al., 2009). With respect to consumption of multi-micronutrient supplements, a meta-analysis from African and Asian studies has shown a relationship between micronutrient supplementation and growth (Ramakrishnan et al., 2004). To date, Ethiopia does not have policy guidance on the use of multiple micronutrient supplements.

WHO (2008) and many other international agencies have standardized infant and young child feeding indicators, including dietary diversity and consumption of iron-rich and iron-fortified foods. Using Ethiopia's 2005 DHS, Ali et al (2013) and Jones et al (2014) found associations between stunting and dietary diversity and minimum acceptable diet, respectively. Our analysis of pooled data from Ethiopia's DHS in 2000, 2005, and 2011 identified only milk consumption as significantly associated with HAZ in children 6-23 and 24-59 months of age (Woodruff et al., 2015). A wide range of compounds, such as phytate, polyphenols, inhibitors of trypsin and chymotrypsin, lectins (Roos et al., 2013), hemaglutinins, goitrogens, saponins, and oxalates (Melese, 2013b) have been identified in the global nutrition literature as anti-nutrients. In Ethiopia, these anti-nutrients are present in complementary foods and regularly consumed by Ethiopian children (Melese, 2013a). Unfortunately no studies could be found examining the effect of consumption of these compounds on child growth in Ethiopia. We could also not identify data specific to Ethiopia that investigated energy content and thin consistency of complementary foods in association with stunting.

While the Framework identifies "poor micronutrient quality" in foods, it does not include child anemia and micronutrient status. While anemia and micronutrient status can be viewed as co-outcomes of stunting rather than causal factors at the same level as low food intake or poor quality foods, we explored the literature examining the association between anemia and selected micronutrient deficiencies (i.e. iron, iodine, vitamin A, zinc) and child growth to determine if there is indeed a gap in the Framework. In a small study (n=300) in Debre Zeit in the Oromiya Region of Ethiopia, a significant association between anemia and stunting was found, but not between iron deficiency and stunting (Good, 2009), a finding consistent with the results of studies carried out outside Ethiopia (Siegel et al., 2006, Ramakrishnan et al., 2004). To our knowledge there are no data on the association between iodine deficiency and growth faltering among Ethiopian children <5 years of age. While epidemiologic studies have shown a relationship between vitamin A status and child growth (Sempertegui, 2001), no relationship between vitamin A and anthropometric status was observed in Ethiopia's 1990 national vitamin A deficiency survey (Wolde-Gebriel et al., 1991). This was confirmed in a meta-analysis of 14 vitamin A supplementation studies from developing countries which showed no improvements in linear or ponderal growth in children (Ramakrishnan et al., 2004). The prevalence of zinc deficiency in Ethiopia is unknown; however, there are studies of zinc's relationship to stunting. Umeta et al (2000) showed a significant increase in growth in both stunted and non-stunted Ethiopian children 6 – 12 months of age receiving daily supplementation with 10 mg zinc. The effect was much greater in stunted children, which is consistent with results from studies conducted outside Ethiopia (Brown et al., 1998).

With regard to inadequate feeding practices, feeding frequency is correlated with energy intake from complementary foods in two cross-sectional studies in rural Ethiopia, where feeding fewer than 3 times a day was associated with increased risk for stunting (Umeta et al., 2003, Teshome et al., 2009).

Regarding caloric and nutrient density of food (i.e. thin food consistency), no specific data from Ethiopia could be identified. As an indirect measure, Teshome and colleagues (2009) compared stunting prevalence among children fed by spoon, hand and bottle. Those fed by bottle were more likely to be stunted than those fed by hand or spoon, which could potentially be explained by the food density or infections from compromised hygiene in bottle feeding. No studies linking feeding insufficient quantities to stunting could be found in Ethiopia. Because of varying approaches to measuring responsive feeding, its impact on stunting remains inconclusive, although there are data suggesting that better nutritional status where responsive feeding is practiced (Bentley et al., 2011). This statement is to some extent supported by recently published results from a cluster-randomized trial from India (Vazir et al., 2013).

Although not explicitly mentioned in the WHO Stunting Framework, a strong and consistent predictor of stunting in Ethiopia is the child's age when complementary food is introduced (Teshome et al., 2009, Yimer, 2000, Mulugeta et al., 2010). A higher prevalence of stunting has been detected when children started complementary feeding after 6 months (Yimer, 2000) or 12 months (Teshome et al., 2009) of age. Umeta and colleagues (Umeta et al., 2003) reported that children with a high meal frequency (i.e. >3 meals per day) were less likely to be stunted than their peers. Other measures of complementary feeding, such as dietary diversity and overall dietary acceptability, have also been investigated in Ethiopia's SNNPR region;

however, no differences between stunted and non-stunted children were observed (Tessema et al., 2013). We could not find information about feeding during and after illness and subsequent child growth in Ethiopia or elsewhere.

In the context of complementary feeding, food and water safety relates most directly to exposure to mycotoxins, the most well-known example of which is aflatoxin, and handwashing (discussed above). The exposure of children living in Africa to aflatoxin is known to be high and has been shown to limit growth in several studies (Shouman et al., 2012, Gong et al., 2002, Gong et al., 2004, Khlangwiset et al., 2011). In Ethiopia, mycotoxins have been found in multiple cereal grains (Ayalew et al., 2006) and high aflatoxin concentrations are repeatedly found in groundnuts (Guchi, 2015).

In Northern Ethiopia, a reduction of stunting was observed following the implementation of a water, sanitation and hygiene (WASH) project where hand washing was a key intervention (Fenn et al., 2012). Though independent associations between stunting and hand washing were not assessed in this Ethiopian study, systematic reviews (Curtis and Cairncross, 2003), multi-country reviews (Dangour et al., 2013, Huttly et al., 1997), and a pooled analysis of several studies (Bhutta et al., 2008) show a decreased risk of diarrhea following hand washing promotion interventions. This suggests that improved practices could reduce child diarrhea and may thus lead to improvements in growth.

Breastfeeding

The breastfeeding section of the WHO Stunting Framework includes three well-defined indicators of inadequate breastfeeding practices: delayed initiation, non-exclusive breastfeeding, and early cessation of breastfeeding.

In Ethiopia, 52% and 80% of the newborns are put to breast within the first hour and one day after birth, respectively (Central Statistical Agency [Ethiopia] and ICF International, 2012). While no studies could be identified on the association of delayed breastfeeding initiation with stunting (or HAZ), a small study from Northern Ethiopia showed that children not given colostrum were twice as likely to be stunted as children who received it (Teshome et al., 2009). Evidence from nearby Uganda indicates that delayed breastfeeding initiation may influence wasting but is not associated with stunting (Engebretsen et al., 2007). Fifty-two percent of Ethiopian children <6 months are exclusively breastfed (UNICEF, 2013). In Ethiopia, Fikadu et al (2014) found that children 24-59 months of age who were exclusively breastfed for the first six months of life were less likely to be stunted than children exclusively breastfeed for <6 months. Exclusive breastfeeding has not been associated with stunting in numerous other studies in Ethiopia, including our analysis of pooled DHS data (Woodruff et al., 2015). Regarding early cessation of breastfeeding, WHO recommends that children be breastfed up to 2 years of age or beyond (2008). In Ethiopia, Teshome et al. (2009) observed increased prevalence of stunting when breastfeeding was continued past 12 months, but the consequences of early cessation of breastfeeding were not reported. It should be noted however that breastfeeding confers developmental benefits by supplying essential fatty acids and has been associated with increased IQ (Brion et al., 2011).

Infection

The infection section of the WHO Stunting Framework includes factors related to both clinical and subclinical infection, including enteric infections (e.g. diarrheal disease, environmental enteropathy, helminths), respiratory infections, malaria, reduced appetite from infection, and inflammation.

Data describing diarrhea's association with stunting in Ethiopia are scarce; we found only one cross-sectional study conducted in the West Gojam Zone, Northern Ethiopia, showing that reporting diarrhea during the two weeks prior to the study was strongly associated with stunting in children less than five years of age (Teshome et al., 2009). For environmental enteropathy, we could find no studies from Ethiopia that measured environmental enteropathy biomarkers and explored their association with child growth. Globally, evidence linking environmental enteropathy to growth is limited to a handful of studies (Humphrey, 2009, Campbell et al., 2003, Lin et al., 2013). Intestinal helminth infections affect a large proportion (~52%) of Ethiopian school-aged children (Abera et al., 2013), but no recent studies of helminth burden in preschool children could be found. A study investigating the intestinal parasitic burden in children <5 years of age in Southern Ethiopia reported that mothers identified loss of appetite as a key symptom of parasitic infections (Nyantekyi et al., 2010). A program evaluation of Ethiopia's Enhanced Outreach Strategy (EOS) screening program, which includes the provision of anti-helminthic drugs, has been shown to reduce stunting (Skau et al., 2009). Our ecologic analysis of program coverage and reductions in stunting has also identified a relationship between increased coverage of the EOS program and reductions in the prevalence of stunting (Wirth et al., 2015).

Acute lower respiratory infections (ARI) are common among Ethiopian children; the 2011 DHS observed that the mothers of 7% of children reported

ARI in the past two weeks (Central Statistical Agency [Ethiopia] and ICF International, 2012). Okiro and colleagues (2008) found an association between severe stunting and respiratory syncytial virus pneumonia as well as between moderate to severe stunting and lower respiratory tract infection of any origin.

No correlation between malaria and stunting was reported from a study conducted in Oromiya's Jimma Zone (Deribew et al., 2010), however, recent fever history has been associated with stunting in Uganda (Wamani et al., 2006) and Bangladesh (Jesmin et al., 2011). To our knowledge, no studies in Ethiopia have examined the link between markers of sub-clinical inflammation and stunting.

Community and societal factors

The WHO Stunting Framework labels community and social factors as contexual and categorizes them into six groups: 1) political economy, 2) health and healthcare, 3) education, 4) society and culture, 5) agriculture and food systems, and 6) water, sanitation and environment. The current evidence for association between these factors and stunting is limited (Stewart et al., 2013). Moreover, many of the contextual factors included in the WHO Stunting Framework (e.g. population density, per-capita national income, level of democracy (Smith and Haddad, 1999, Pridmore and Hill, 2009)) are calculated at the national level and are thus not applicable for analysis of the causes of stunting at household or community level.

Of the "political economy factors" identified in the WHO Stunting Framework, food prices and community-level wealth differentials are two that have been explored in relation to stunting. In Ethiopia, Christiansen and Alderman (Christiaensen and Alderman, 2001) show mixed associations in a regional analysis of commodity prices and child stunting; "higher teff, kerosene, and charcoal prices are associated with shorter children… [and] …higher maize, sorghum, beef, and milk prices on the other hand are associated with taller children". In our analysis of Ethiopia's pooled DHS data (Woodruff et al., 2015), wealth index quintiles were not associated with stunting. Wealth quintile, however, was significantly associated.

Of the community health and healthcare factors identified in the WHO Stunting Framework, access to health care is the only one shown to be associated with stunting in Ethiopia. In Afar region, Fentaw et al. (2013) observed that stunted children lived about 2 kilometers farther away from the nearest health clinic than non-stunted children. The same relationship was observed in South Africa with distance measured in time (Chopra, 2003). Factors related to education quality and infrastructure are not readily applicable to sub-national analyses related to child growth or stunting. UNESCO (2009) compiled more than 40 education indicators, the vast majority of which are calculated at the national level.

Cultural beliefs, norms and social support networks are posited as contextual factors which contribute to poor feeding and dietary patterns. Women's status in particular is seen as a cultural factor that can influence child health, and it is frequently assessed using data on household decision-making relating to cooking, purchase of food and household items, ability to take short trips to market or relatives' homes, etc.. In Ethiopia, women with high decision making autonomy are less likely to have a low BMI themselves (Tebekaw, 2011). In addition, Shroff et al. (2009) showed that women from Andhra Pradesh, India, with "access to money and the freedom to choose to go to the market are significantly less likely to have a stunted child". In a multi-country review of DHS data, Smith et al. (2003) assessed the association between HAZ and two indices of women's status: relative decision-making power and societal gender equality. They find that while both indices have a positive effect on children's HAZ in South Asian countries, positive effects on children's HAZ in sub-Saharan African countries (not including Ethiopia) are restricted to relative decision-making power only.

Regarding agriculture and food systems factors, Stewart et al. cite the effects of programmatic interventions, such as agricultural extension, biofortification and production of livestock (Stewart et al., 2013). A recent analysis in Ethiopia shows that household ownership of cows in rural areas is associated with increased milk consumption and reduced prevalence of stunting (Hoddinott et al., 2014) but the effects are weaker in communities with good access to markets. In addition, Sadler et al. (2012) found that the provision of livestock support of pastoral communities in Ethiopia (Somali Region) prevented growth faltering in children <5 years old during the dry season.

Water, sanitation, and environmental factors have recently emerged in the literature as important influences on children's nutrition status. In particular, the practice of open defecation in the community – measured as the percentage of households in each survey cluster reporting open defecation – has been identified as a potential cause of child stunting. In a multi-country (including Ethiopia) econometric analysis of DHS data, Spears (2013) concludes that the practice of open defecation significantly explains international variations in child height. In Ethiopia, two separate pooled analyses of DHS showed that reduced prevalence of open defecation is associated with a reduction in stunting (Woodruff et al., 2015, Headey, 2014).

DISCUSSION

Ethiopia findings

In reviewing available evidence, we find that the WHO Stunting Framework includes many of factors found to be important determinants of stunting in Ethiopia. The strongest and most consistent associations with stunting were found with indicators of birth size, recent illness (e.g. diarrhea, respiratory infection), maternal height and education, and household sanitation. Nonetheless, there are several indicators for which data are lacking. Despite the Framework's focus on infection, sanitation, and hygiene, few studies in Ethiopia or elsewhere comprehensively examine associations between these factors and stunting. In particular, there is no data found assessing the relationship between stunting and exposure to mycotoxins in Ethiopia, despite evidence mycotoxin-contaminated groundnuts and cereal grains. There are also no data from Ethiopia showing that inadequate feeding during and after illness is associated with sub-optimal growth. Few of the Framework's community and societal factors can be readily measured at sub-national level in Ethiopia.

Framework assessment

The WHO Stunting Framework includes both specific and general factors. Given the myriad factors that can cause sub-optimal growth, the use of general factors is indeed appropriate. Nonetheless, greater detail in some areas of the Framework would be useful for national and sub-national researchers and policy makers. Specifically, "poor micronutrient quality" could be described in more detail to identify which micronutrients are most important to support linear growth. Evidence from Ethiopia suggests that while there is an association between zinc status and growth, there is no association between iron and vitamin A status and growth. In addition, more detailed description of complementary feeding factors such as "low caloric and nutrient density", "feeding insufficient quantities", and "poor hygiene practices", would help researchers apply the Framework to specific populations and situations.

WASH factors and infection occurs in nearly all sections of the Framework. Recurrence of WASH factors illustrates the multiple pathways by which poor WASH conditions impair child growth; this is supported by strong evidence linking stunting and WASH at maternal, household, community levels in Ethiopia. We find that only a relatively small number of community and societal variables have been examined in non-ecologic studies related to stunting. Notably, the factors identified all showed either a moderate or strong association with stunting, suggesting that the exploration of community-level factors and, concurrently, data collection, should be explored further.

In contrast, although factors such as "poor nutrition during pre-conception, pregnancy, and lactation" influence both *in utero* and postnatal growth, they are not further elaborated on in the Framework. A notable feature is its acknowledgement that a specific factor can influence child growth at various times.

Stewart et al (2013) do not explicitly define poor care practices but rather cite Imdad (2011) and Semba (2008) as examples of how "low caregiver education shows a strong and consistent relationship with poor child nutrition outcomes, and likely drives other caring practices associated with stunted development and growth". Imdad's study, which looks predominantly at maternal education, is discussed elsewhere in this review. Semba's study uses child vitamin A supplementation, vaccination, household use of iodized salt, latrine use, family planning methods, and visits to local health posts in the past year as proxies for parental caregiving practices. While family planning, visits to local health posts, and vitamin A supplementation/immunization represent practices that are available to Ethiopian households, and thus can be attributed to inadequate care, other practices, identified by Semba, (i.e. iodized salt use, and latrine use) which are not accessible to all households cannot be attributed only to inadequate care in Ethiopia.

The Framework also does not specify which factors are associated with linear growth and which are associated with child developmental. To illustrate, the global evidence suggests that exclusive breastfeeding is more strongly associated with child development outcomes than linear growth. Optimal breastfeeding is consistently associated with reduced mortality, reduced morbidity (Black et al., 2008), and increased IQ (Horta et al., 2015). Optimal breastfeeding is not associated, however, with linear growth in Ethiopia (Woodruff et al., 2015, Marriott et al., 2012) and several other countries (Kramer and Kakuma, 2012). The Framework can thus be enhanced by clarifying which factors are associated most strongly with stunted growth, development, or both. This clarification could greatly assist programme planners at the national level by elucidatory the plausible outcomes achievable by modifying specific factors.

Missing indicators

The Framework does not include two groups of factors that have been shown to be associated with child growth: household characteristics and the experience of physical violence during pregnancy. While there is a sub-section dedicated to home environment, it does not include specific factors associated with stunting and poor birth outcomes in studies in Ethiopia and elsewhere, such as low household socio-economic status (Gibson et al., 2009, Assefa et al., 2012), dwelling quality (Gibson et al., 2009, Mukuria et al., 2005), exposure to indoor smoke due to low quality cooking fuel (Mishra and Retherford, 2007), number of children <5 years (Yimer, 2000, Fentaw et al., 2013), dependency ratio (Fentaw et al., 2013), family size (Fentaw et al., 2013), and female sex of the household head (Fentaw et al., 2013, Haidar et al., 2005). It is plausible, however, that these missing household factors may affect stunting via the pathways already described in the Framework. To illustrate; 1) household socio-economic status may highly correlate with a household's food security, and 2) the number of children <5 years of age may correlate with short birth spacing. Nonetheless, given the multiple household-level factors that have shown significant associations with stunting, an expansion of the Framework's "home environment" factors may be considered.

In Ethiopia's Oromiya Region, women experiencing physical violence during pregnancy were at higher risk of having a low birthweight child (Assefa et al., 2012). While physical violence against women could be classified under the Framework's "women's status" in the community and societal factors, routine DHS data collection related to domestic violence suggests that physical violence during pregnancy may be better included as one of the "household and family factors" of stunting.

CONCLUSION

Despite reductions in the prevalence of stunting globally, this form of malnutrition remains a serious public health concern, particularly in Sub-Saharan Africa where the number of stunted children is rising. The WHO Stunting Framework provides the first internationally-endorsed causative model which focuses on stunting and identifies many factors associated with child growth. In applying the Framework to available evidence in Ethiopia, we find that it presents a useful guide for identifying potential stunting determinants, but that some factors are missing while others may be extraneous. Also, few of the contextual factors of stunting are relevant or can be easily measured for sub-national analyses. Applying the WHO Stunting Framework to national literature can identify consistent risk factors for stunting and pinpoint national data gaps.

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CHAPTER 2

Determinants of stunting reduction in Ethiopia 2000 – 2011

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ABSTRACT

The prevalence of stunting in Ethiopia declined from 57% in 2000 to 44% in 2011, yet the factors producing this change are not fully understood. Data on 23,999 children 0-59 months of age from three Demographic and Health Surveys (DHS) from 2000, 2005, and 2011 were analyzed to assess the trends in stunting prevalence, mean height-for-age z-scores (HAZ) and the associations between potential factors and HAZ. Associations were determined separately using three separate generalized linear models for children age less than 6 months, 6-23 months, and 24-59 months of age. Significant variables were then analyzed to determine if they showed an overall trend between the 2000 and 2011 surveys. In children < 6 months of age, only mother's height was both a significant predictor of HAZ and showed a progressive increase from 2000 to 2011. In children 6-23 months of age, only mother's use of modern contraception showed substantial changes in a direction consistent with improvement in HAZ, but improvements in maternal nutrition status were observed from 2000 to 2005. For children 24-59 months of age a consistent and progressive change is seen in child's diarrhea, fever, mother’s education, and the occurrence of open defecation. Our analysis demonstrated that factors associated with HAZ vary by child’s age and the dominant livelihood practice in the community. Variables that could have contributed to the decline of stunting in Ethiopia in children less than 5 years of age include markers of child health, mother's nutritional status, mother's educational level, and environmental hygiene.

INTRODUCTION

Stunting, or suboptimal growth by age in children < 5 years old, is associated with adverse short- and long-term health outcomes. In the short-term, the consequences of stunting include an increased risk of infectious diseases and poor psychomotor and mental development (Abubakar et al., 2010, McDonald et al., 2012). In the long term, childhood stunting has been linked to obesity and diabetes (Bhargava et al., 2004) and lower human capital in adulthood (Victora et al., 2008)

Reducing the prevalence of stunting is one of the World Health Assembly's Nutrition Targets for 2025 (40% reduction in the number of under five children stunted) (WHO, 2012). Globally, stunting has declined by 1.8% annually between 1995 and 2010, with some countries observing annual reductions of 3.9% or higher in this time period (de Onis et al., 2013). In Ethiopia, stunting has declined on average by 1.2% per year since 2000. Though the annual rate of stunting reduction in Ethiopia is below the global average, Ethiopia's stunting reduction is noteworthy as it is one of the few African countries to substantially reduce the prevalence and the number of stunted children in the past two decades (de Onis et al., 2013). According to UNICEF (2013a), child stunting in Ethiopia was reduced by more than 20 percentage points in the past 20 years. As measured in a series of Demographic and Health Surveys (DHS) using comparable methodologies, the prevalence of stunting declined from 57% in 2000 to 51% in 2005 and 44% 2011 (Central Statistical Authority [Ethiopia] and ICF International, 2012). Nonetheless, the prevalence of stunting in Ethiopia remains somewhat higher than the regional prevalence of 40% in east and southern Africa (UNICEF, 2013b).

This analysis has been conducted to understand the reasons for the reduction in stunting between 2000 and 2011 in Ethiopia. It identifies factors which are associated with HAZ overall and which have changed during this time period. These results may be useful in identifying factors for future intervention to further reduce the prevalence of stunting in Ethiopia. In addition, the methods used in this analysis could be used in other sub-Saharan countries to identify factors contributing to stunting in order to design and adjust programs addressing stunting.

METHODS

Data sources

Ethiopia's three nationwide DHS, conducted in 2000, 2005, and 2011, served as the main source of data for this analysis. These surveys are representative at both the national and regional level; the design of these DHS is presented in further detail elsewhere (Central Statistical Authority [Ethiopia] and ORC Macro, 2001, 2006, 2012).

In each DHS, anthropometric measurements were taken on children 0-59 months. In the 2000 and 2011 DHS, all children in all selected households were recruited for measurement. In the 2005 survey, children were recruited for measurement only in a randomly selected subsample of ½ of the recruited households. Hence, the number of children with weight and height measurements is much smaller in the 2005 survey than in the other two DHS. Length and height measurements of children were made using standard procedures, and using length/height, weight, and age information from children in all rounds, length/height-for-age z-scores (HAZ) and weight-for-height z-scores (WHZ) using the WHO Child Growth Standard were calculated (WHO Multicentre Growth Reference Study Group, 2006).

Stunting was defined as having a HAZ less than -2.0; children with HAZ ≥ -2.0 are considered non-stunted. Children without valid measurements of length or height or age were excluded from all analyses. As widely recommended, children with HAZ less than -6.0 or greater than +6.0 were excluded from all analyses.(SMART, 2006).

Enumeration areas (EA) were assigned to livelihood zones so that results could be presented according to four sub-national groups: urban, rural-agricultural, rural-agro-pastoral, and rural-pastoral. EAs were classified as urban based on DHS classifications, and rural areas were sub-divided based on the governmental classification (USAID and Government of Ethiopia, 2011).

Selection of factors potentially associated with growth

The recently-published WHO conceptual framework on childhood stunting (Stewart et al., 2013) was used to identify the most comprehensive set of factors potentially associated with stunting. Using this framework, the three DHS datasets, DHS reference materials, dataset maps, and the data collection forms were thoroughly reviewed in order to select variables included in the DHS which may be considered potential contributory factors to a stunting reduction in Ethiopia. A literature review examining existing knowledge of the contributors to child stunting in Ethiopia and indicators available in the DHS was also conducted to identify additional potential contributory factors (Wirth et al., 2013). WHZ, although not included in the WHO conceptual framework, was included in the analysis because, in addition to wasting sharing risk factors with stunting, there is some evidence that wasting itself may be a direct and independent cause of stunting (Khara and Dolan, 2014).

In total, 83 potential factors were identified. In addition to values provided directly in the DHS data files, a new household wealth index was calculated on pooled data from all survey rounds using principal component analysis of the same variables used in the original DHS calculation (Rutstein and Johnson, 2004). This allowed assessment of trends in household wealth between 2000 and 2011.

Data analysis

Data analysis was conducted in three phases. First, a bivariate analysis using pooled data from all three DHS was conducted to identify those variables which were associated with HAZ in Ethiopia. Continuous and categorical variables were analyzed using linear regression and ANOVA, respectively, against HAZ as a continuous outcome. Linear data analysis techniques were used because associations using continuous data generally have more statistical precision than analysis of a categorized form of a continuous variable. Pooled data was used to maximize the number of children included in each bivariate analysis, thus increasing the precision and likelihood of detecting an association with statistical significance. Sampling weights were not used in this bivariate analysis.

Second, a national-level multivariate linear regression analysis was conducted on the pooled data from all three surveys. Separate models were constructed for three different age groups – children <6 months of age, children 6-23 months of age, and children 24-59 months of age – because potential risk factors and feeding patterns in young children differ substantially by age and DHS collect different data on children of different ages. Each model included variables that were statistically significantly associated with HAZ in the bivariate pooled analysis and were measured in all three surveys. Factors identified in a literature review of stunting determinants in Ethiopia (Wirth et al., 2013) strongly related to stunting in Ethiopia as well as variables of high interest, such as exclusive breastfeeding, child age, and child sex, were also included in the initial models regardless of the apparent strength of their association with HAZ in the bivariate analysis. In addition, survey year was included in the model to represent unmeasured factors not captured by the other explanatory variables that could have changed over time. Using the national-level model, backward elimination was used to remove variables which did not make a statistically significant ($p<0.05$) contribution. Those variables remaining in the final, most parsimonious national model were then included in separate models for each livelihood zone. Removal of WHZ from regression analyses did not change resulting regression coefficients.

Third, a trends analysis of variables in each final model was undertaken to identify variables that significantly changed between the three DHS and may thus have contributed to the decline in stunting in Ethiopia from 2000 – 2011. The weighted mean values (for continuous variables) or weighted prevalence (for categorical values) were compared among the three DHS. Statistical difference was determined using ANOVA or adjusted chi square.

In all phases, statistical significance was defined as a p value less than 0.05. All analyses except the initial bivariate analyses used sampling weights already contained in the DHS databases. Calculation of all estimates of precision (e.g. p values, confidence intervals, etc.) took into account the complex sampling used in DHS, including cluster sampling and stratification. All statistical analyses were conducted using SPSS version 21.

Table 1. Selected information about the three DHS included in our data analysis

Survey	Dates of data collection	Number of households	Children 0-59 months of age	Number of children with valid HAZ*	HAZ*	National prevalence of stunting	
		n (% response)	n	n	mean	(%)	P-value
DHS 2000	February – May 2000	14,072 (96.1%) of 14,642 selected households	9,513	9,417	-2.08	57.7	
DHS 2005	April – August 2005	13,721 (93.7%) of 14,645 selected households	4,455†	4,141†	-1.78	50.8	<0.001
DHS 2011	Dec 2010 – June 2011	16,702 (93.7%) of 17,818 selected households	10,480	10,441	-1.61	44.3	
Total	**n/a**	**n/a**	**24,448**	**23,999**	**n/a**	**n/a**	

* Height-for-age z-score
† Children were weighed and measured in only one-half of selected households.
n/a = not applicable

Results

Trends in stunting

Table 1 shows the dates of data collection and the number of households and children included in the analyses in each DHS. In total, 98.2% of children less than 5 years of age had weight, height, and age measurements resulting in a valid HAZ. The mean HAZ in all children increased by 0.47 standard deviations between 2000 and 2011.

In each DHS, the mean HAZ differs significantly by age group; children <6 months of age had the highest mean HAZ and children 24-59 months old had the lowest mean HAZ. Mean HAZ also improve from 2000 and 2011 in all age groups. The total increase in HAZ during this time period was slightly greater in children 0-5 months of age and children 6-23 months of age (0.66 and 0.65 z-scores, respectively) than in children 24-59 months of age (0.49 z-scores). By 2011, the mean HAZ for the youngest age group was -.06; close to a distribution with the mean of 0.

Bivariate analyses

The results of the unweighted bivariate analysis of the association between various factors and HAZ are shown in a supplementary table 1. Many variables are statistically significantly associated with HAZ. Some variables, however, were not collected in all three surveys or were not collected in a standardized fashion allowing comparison among the three surveys. Such variables were excluded from subsequent data analysis.

Multivariate and trend analyses – Children <6 months of age

Table 2 presents the regression results for all children < 6 month of age. The residuals for this model are normally distributed and not correlated with the predicted HAZ (results not shown). This model accounts for 27.8% of the variability in HAZ in this age group (R^2 = 0.278). Significant predictors of HAZ include child sex, age, estimated birth size, WHZ, mother’s height, and household wealth. Mean HAZ is significantly lower in boys than girls, and HAZ declines significantly with increased age. Although estimated birth size is a crude measure of birth weight, it is strongly associated with HAZ and shows a dose-response relationship; the smaller the mother's estimate of birth size, the lower the HAZ. A child's WHZ is significantly inversely related to that child's HAZ. Mother's height and household wealth show a significant and positive association with HAZ.

Livelihood-specific models account for a similar or higher variability in HAZ as the overall model, with the pastoral model accounting for nearly 49.7% of the variance in HAZ. Moreover, the importance of each independent variable varies among the livelihood-specific models. The sex difference in mean HAZ is much lower in urban and agro-pastoral areas than in rural-agricultural and rural-agro-pastoral communities; however, in some livelihood groups, a relatively small number of children may make estimates somewhat imprecise. Child's age was much less strongly related to HAZ in agro-pastoral and pastoral communities. Unlike child's age and sex, estimated birth size remained statistically significant in all models. Although the association between HAZ and child's WHZ and mother's height was not statistically significant in all models, the beta coefficients indicated a comparable strength of association. On the other hand, household wealth showed a substantially weaker strength of association in agricultural households than in other livelihood groups.

Of the factors included in the final multivariate models for children less than 6 months of age, only estimated birth size and household wealth index show significant changes between the three surveys, but for both variables, no clear trend between the surveys is observed.

Multivariate and trend analyses – Children 6-23 months of age

Table 3 presents the model results for children 6-23 months of age. The residuals for this model are normally distributed and show no association with predicted values of HAZ derived from the regression equation (results not shown). The overall regression explains 20.4% of the variation in HAZ (R^2=0.204), and significant predictors of HAZ include child characteristics (sex, age, birth order, estimated size at birth, WHZ), child feeding characteristics (child drank non-human milk in past 24 hours), maternal factors (height, BMI, partner's occupation, use of a modern form of contraception), and household factors (sex of household head, household wealth). As with children less than 6 months of age, HAZ was higher in girls than in boys, younger children, larger estimated birth sizes, lower WHZ, and greater mother's height. HAZ was greater in children with lower birth order, children who drank non-human milk, children whose mothers had a greater BMI, children whose mothers used contraception, children whose mothers' partner had no occupation, children in male-headed households, and children in wealthier households.

The livelihood models explained from 19.7 – 31.7% of HAZ's variability. Unlike in younger children, child age is statistically significantly associated with HAZ in all models. Estimated birth size is significantly associated with HAZ in all but the agro-pastoral models; however, there is no clear dose-response relationship in urban or pastoral areas. Non-human milk consumption is only marginally associated with HAZ in urban areas and does not contribute to the model with statistical significance in agro-pastoral or pastoral children. Mother's height was found to be a significant and positive predictor in all livelihoods zones expect pastoral, whereas maternal BMI was only significantly associated with HAZ in urban areas. In urban populations, the average HAZ was very similar between children whose mothers used contraception and whose mothers did not. On the other hand, maternal use of contraception was significantly associated with HAZ in agricultural and agro-pastoral areas. Although the contribution to the model of mother's partner's occupation was only of marginal or insignificant relevance in all livelihood-specific models, children whose mother's partner had no occupation were still taller in all rural populations.

The sex of the household head is only significant in agricultural areas. Household wealth index shows a significant and positive association with HAZ in urban and agricultural models, and although the beta coefficient is relatively high in agro-pastoral areas, indicating an association, the p value is not significant. This association is much weaker in pastoral areas.

There are substantial differences in the trends between 2000 and 2011 among these independent variables. The only consistent trend shown in the three surveys is mother’s use of modern contraceptive methods, which increased from 6.5 in 2000 to 24.4% in 2011. Similar to children <6 months of age, the proportion of children 6-23 months of age with both very large and very small estimated birth size increased between 2000 and 2011. Other factors, such as average child’s WHZ, proportion of children having consumed non-human milk in the past 24 hours, average BMI of mothers, and average household wealth index, increased from 2000 to 2005, and then decreased from 2005 to 2011.

Multivariate and trend analyses – Children 24-59 months of age

Table 4 presents the model results for children 24-59 months of age. The overall regression explains 12.2% of the variation in HAZ (R^2= 0.122), and the models' residuals are normally distributed and not associated with predicted values of HAZ (results not shown). Significant predictors of HAZ include child characteristics (birth order, estimated size at birth, WHZ), recent disease (diarrhea and/or fever in past 2 weeks), feeding characteristics (child drank non-human milk in past 24 hours), maternal factors (height, BMI, education), household factors (mother’s number of living children, number of children <5 year old in the household, age of household head, dependency ratio, household wealth), and community factors (percent of households in cluster practicing open defecation). Estimated size at birth again shows a dose-response relationship with HAZ with smaller children having a lower HAZ, and mean HAZ is higher in children without recent fever and diarrhea. Children consuming non-human milk in the past 24 hours have higher HAZ. Mother’s height, BMI, and education are positively associated with HAZ, indicating that taller, better-nourished, and more-educated mothers have taller children; however, most of the difference in HAZ by mother's education appears between mother with primary education and those with more advance education. There is relatively little difference in HAZ between mothers with no education and with only primary education. Among household composition factors, only dependency ratio shows a negative association with HAZ, suggesting that child’s nutrition is adversely affected in households with a higher proportion of dependants. Household wealth is positively associated with HAZ, indicating that as household wealth increases, stunting decreases. Although significant associations were found, no discernible pattern between the proportion of households in each cluster openly defecating and HAZ is observed, and category-specific mean HAZ ranges from -2.42 to -2.18. Survey year shows that mean HAZ increases steadily over time.

The livelihood-specific models explain between 10.7 and 30.1% of the variability in HAZ, with the best fit in the pastoral model. Estimated size at birth and WHZ is significantly associated with HAZ in all livelihood zones except agro-pastoral, yet there is no clear trend in the mean HAZ by for each sub-group of perceived birth size. WHZ is negatively associated with HAZ. Recent morbidity are significantly associated with HAZ in agricultural (both fever and diarrhea) and agro-pastoral (diarrhea only) models; the mean HAZ for children with recent illness in these areas is significantly lower than in non-ill children. Recent consumption of non-human milk in the past 24 hours is significantly associated with HAZ in agricultural areas. Mother’s height and BMI are significant and positive predictors of HAZ in nearly all livelihood models. Child HAZ is higher in more educated mothers in all models except pastoral, where the association is not significant. HAZ increases as household wealth increases; however, this increase in HAZ with household wealth is lower and not statistically significant in agricultural households.. At the community level, the practice of open defecation is significantly associated with HAZ in agro-pastoral and pastoral communities; however, there is no clear dose-response relationship between sub-groups with different level of open defecation. Lastly, survey year significantly associated with all models except the pastoral model; in models where a significant association is found, mean HAZ increases steadily over time.

Amongst the various explanatory factors associated with HAZ, there is a significant and consistent trend in recent diarrhea, fever, and mother’s education. For the overall model, there is also a clear trend in the change in open defecation. From 2000 to 2011 the 2-week cumulative prevalence of diarrhea decreased from 18.8 to 9.6%, and the 2-week cumulative prevalence of fever declined from 25.4 to 14.5% in the same time period. Mother’s education consistently improved, with the proportion of women with a primary education increasing from 12.6% in 2000 to 26.1% in 2011. Open defecation at the community level decreased dramatically: in 2000 52% of children 24-59 months of age lived in communities where 100% of households practiced open defecation, whereas in 2011 only 5.2% of these children were in communities where open defecation was exclusively practiced.

Table 2. Linear regression model with HAZ as outcome which includes only children <6 months of age and only variables collected in all three DHS, applied to each of four livelihood zone categories, national.

Variable	National (n=2,031; R^2=0.278)		Urban (n=304; R^2=0.365)		Agricultural (n=1,399; R^2=0.269)		Agro-pastoral (n=153; R^2=0.318)		Pastoral (n=136; R^2=0.497)		Comparison of survey results			
	β coeff-icient†	P value†	β coeff-icient†	P value†	β coeff-icient†	P value†	β coeff-icient†	P value†	β coeff-icient†	P value†	2000	2005	2011	p value
Child's sex ‡		.006		0.093		0.021		0.807		0.119				0.700
Male	-0.25		-0.39		-0.23		-0.42		-0.44		52.3%	56.0%	52.7%	
Female	referent		referent		referent		referent		referent		47.7%	44.0%	47.3%	
Child's age (in months) §	-0.22	<.001	-0.20	0.030	-0.25	<.001	0.003	0.969	0.06	0.519	2.79	2.99	2.80	0.179
Child's estimated size at birth ‡		<.001		<.001		<.001		0.073		0.630				<.001
Very large	0.84		1.11		0.91		1.30		0.66		3.0%	16.0%	18.1%	
Larger than average	0.62		0.86		0.57		1.12		0.62		18.9%	3.3%	11.7%	
Average	0.60		0.89		0.57		0.85		1.02		35.3%	45.1%	34.4%	
Smaller than average	-0.07		-1.24		0.04		0.19		0.46		34.9%	9.7%	10.2%	
Very small	referent		referent		referent		referent		referent		7.9%	25.9%	25.7%	
Child's weight-for-height z-score §	-0.43	<.001	-0.34	<.001	-0.43	<.001	-0.23	0.152	-0.55	<.001	-0.25	-0.10	-0.42	0.092
Mother's height (in cm) §	0.04	<.001	0.04	0.066	0.04	<.001	0.11	0.003	0.10	0.071	156.0	156.3	156.5	0.464
Household wealth index §	0.17	<.001	0.27	0.007	0.07	0.532	0.34	0.210	0.91	0.132	-0.276	-0.025	-0.073	<.001
Survey ‡		<.001		0.040		0.002		0.112		0.001				
2000	-0.42		-0.43		-0.40		-0.26		-1.24					
2005	0.01		0.30		0.02		0.25		-0.52					
2011	referent		referent		referent		referent		referent					

* p value for comparison the mean HAZ in each subgroup to the referent subgroup
† p value for variable's contribution to overall model
‡ Categorical variable
§ Continuous variable

Table 3. Linear regression model with HAZ as outcome which includes only children 6-23 months of age and only variables collected in all three DHS, applied to each of four livelihood zone categories, national.

	National (n=6,154; R^2=0.203)		Urban (n=966; R^2=0.315)		Agricultural (n=4,364; R^2=0.196)		Agro-pastoral (n=380; R^2=0.229)		Pastoral (n=346; R^2=0.206)		Comparison of survey results			
Variable	β (beta) coeff-icient[†]	P value[†]	β (beta) coeff-icient[†]	P value[†]	β (beta) coeff-icient[†]	P value[†]	β (beta) coeff-icient[†]	P value[†]	β (beta) coeff-icient[†]	P value[†]	2000	2005	2011	p-value
Child's sex ‡		<.001		0.032		<.001		<.001		0.144				0.527
Male	-0.41		-.32		-0.43		-0.96		0.33		51.1%	48.6%	50.8%	
Female	referent		referent		referent		referent		referent		48.9%	51.4%	49.2%	
Child's age (in months) §	-0.10	<.001	-0.11	<.001	-0.10	<.001	-0.04	0.033	-0.10	<.001	14.34	13.75	13.98	0.052
Child's estimated size at birth ‡		<.001		0.001		<.001		0.998		0.026				<.001
Very large	0.61		1.45		.587		.032		1.002		4.7%	22.4%	17.6%	
Larger than average	0.47		.05		.520		.003		.641		22.6%	9.2%	11.6%	
Average	0.37		.46		.350		-.082		.929		36.2%	38.8%	39.2%	
Smaller than average	0.12		-.19		.121		.005		.741		30.2%	6.7%	9.2%	
Very small	referent		referent		referent		referent		referent		6.4%	22.9%	22.3%	
Child's weight-for-height z-score §	-0.07	0.022	-0.02	0.720	-0.08	0.026	-0.02	0.879	-0.21	0.037	-0.92	-0.66	-0.73	<.001
Child drank non-human milk ‡		0.002		0.044		<.001		0.734		0.085				<.001
No	-0.19		-0.30		-0.24		0.09		0.41		66.5%	60.6%	78.1%	
Yes	referent		referent		referent		referent		referent		33.5%	39.4%	21.9%	
Mother's height (in cm) §	0.05	<.001	0.06	<.001	0.05	<.001	0.06	<.001	0.04	0.093	156.6	156.7	156.4	0.509
Mother's BMI §	0.04	0.006	0.07	0.002	0.03	0.126	0.10	0.090	0.01	0.848	19.9	20.2	20.1	0.003
Mother uses contraception		0.014		0.851		0.037		0.033		0.210				<.001
No	-0.22		0.03		-0.25		-0.88		-0.34		93.5%	87.0%	75.6%	
Yes	referent		referent		referent		referent		referent		6.5%	13.0%	24.4%	

Mother's partner's occupation ‡		0.015		0.570		0.085		0.041		0.345				<.001
None	0.68		.225		.602		1.746		.357		0.2%	1.2%	1.0%	
Agriculture/Unskilled	0.10		.23		.018		.025		-.408		85.9%	88.4%	80.1%	
Service/Sales/Prof	referent		referent		referent		referent		referent		13.9%	10.4%	18.9%	
Sex of household head		0.005		0.333		0.002		0.468		0.863				0.831
Male	0.23		0.21		0.28		-0.25		0.10		88.2%	87.9%	87.4%	
Female	referent		referent		referent		referent		referent		11.8%	12.1%	12.6%	
Household wealth index §	0.28	<.001	0.33	<.001	0.30	<.001	0.68	0.127	-0.08	0.713	-.295	.000	-.064	<.001
Survey ‡		<.001		0.151		<.001		0.215		<.001				
2000	-0.56		-.26		-.616		-.520		-.268					
2005	-0.36		-.28		-.429		-.307		1.181					
2011	referent		referent		referent		referent		referent					

* p value for comparison the mean HAZ in each subgroup to the referent subgroup

† p value for variable's contribution to overall model

‡ Categorical variable

§ Continuous variable

Table 4. Linear regression model with HAZ as outcome which includes only children 24-59 months of age and only variables collected in all three DHS, applied to each of four livelihood zone categories, national.

Variable	National (n=9,022; R^2=0.122)		Urban (n=1,229; R^2=0.243)		Agricultural (n=6,587; R^2=0.107)		Agro-pastoral (n=554; R^2=0.139)		Pastoral (n=504; R^2=0.301)		Comparison of survey results			
	β coeff-icient†	P value†	β coeff-icient†	P value†	β coeff-icient†	P value†	β coeff-icient†	P value†	β coeff-icient†	P value†	2000	2005	2011	p-value
Child's birth order §	-0.08	0.001	-0.04	0.522	-0.08	0.001	-0.02	0.763	-0.15	0.040	4.19	4.31	4.02	0.007
Child's estimated size at birth ‡		<.001		0.006		<.001		0.738		0.002				<.001
Very large	.256		.449		.253		.418		.554		5.5%	23.1%	19.8%	
Larger than average	.218		.799		.183		.581		.015		26.7%	11.2%	12.8%	
Average	.192		.532		.178		.271		.137		36.7%	40.1%	39.6%	
Smaller than average	-.031		.442		-.062		.594		.025		25.8%	8.2%	8.5%	
Very small	referent		referent		referent		referent		referent		5.4%	17.5%	19.3%	
Child's weight-for-height z-score §	-0.17	<.001	-0.16	0.023	-0.17	<.001	-0.13	0.221	-0.33	0.001	-.58	-.40	-.44	<.001
Child had diarrhea past 2 weeks ‡		<.001		0.130		<.001		0.029		0.986				<.001
No	0.27		0.29		0.25		0.52		0.01		81.2%	86.4%	90.4%	
Yes	referent		referent		referent		referent		referent		18.8%	13.6%	9.6%	
Child had fever past 2 wks ‡		0.006		0.251		0.001		0.613		0.683				<.001
No	0.15		-0.16		0.21		-0.08		0.08		74.6%	83.6%	85.5%	
Yes	referent		referent		referent		referent		referent		25.4%	16.4%	14.5%	
Child drank non-human milk ‡		<.001		0.062		<.001		0.093		0.182				<.001
No	-0.18		-0.22		-0.22		0.22		0.27		72.9%	62.6%	81.6%	
Yes	referent		referent		referent		referent		referent		27.1%	37.4%	18.4%	
Mother's height (in cm) §	0.05	<.001	0.06	<.001	0.04	<.001	0.04	<.001	0.08	<.001	156.6	157.2	156.8	.086
Mother's BMI §	0.05	<.001	0.04	0.006	0.05	<.001	0.01	0.727	0.13	0.007	20.1	20.4	20.4	.529

Mother's educations group ‡		0.001		0.020		0.024		0.011		0.097				<.001
None	-.406		-.413		-.434		-1.152		-.941		82.4%	78.9%	70.9%	
Primary	-.345		-.151		-.390		-1.089		-1.563		12.6%	17.0%	26.1%	
Secondary	referent		referent		referent		referent		referent		5.0%	4.2%	3.0%	
Number of mother's living children §	0.08	0.003	0.05	0.491	0.09	0.002	-0.06	0.404	0.20	0.050	3.93	4.27	4.01	.001
Number of children <5 yrs in household§	0.07	0.071	-0.09	0.278	0.09	0.056	-0.06	0.442	0.41	0.006	1.81	1.89	1.83	.046
Age of household head §	0.01	<.001	0.01	0.130	0.01	<.00 1	0.01	0.766	0.01	0.552	39.7	39.2	38.2	<.001
Dependency ratio §	-0.10	<.001	0.08	0.303	-0.13	<.001	0.13	0.053	-0.18	0.217	1.49	1.69	1.66	<.001
Household wealth index §	0.20	<.001	0.22	<.001	0.13	0.062	0.49	0.025	0.79	0.001	-.277	-.024	-.099	<.001
Percent households practicing open defecation ‡		0.028		0.929		0.088		0.002		<.001				<.001
<=10%	-.132		.205		-.326		.163		1.299		2.5%	8.4%	10.5%	
11-26%	-.234		.058		-.175		-.471		-.595		4.6%	9.3%	16.8%	
27-43%	-.055		.095		-.021		-.346		-.738		3.2%	9.5%	22.2%	
44-63%	-.082		.195		-.085		-.126		.063		4.3%	9.8%	19.2%	
64-81%	-.234		.053		-.211		-.416		-.267		8.0%	10.6%	17.1%	
82-92%	-.242		.030		-.217		-.345		.664		9.5%	15.0%	6.8%	
93-99%	-.184		.205		-.166		.533		-.897		15.9%	13.1%	2.1%	
100%	referent		referent		referent		referent		referent		52.0%	24.3%	5.2%	
Survey ‡		<.001		<.001		<.001		<.001		0.764				
2000	-.535		-.624		-.535		-.785		.036					
2005	-.287		-.288		-.289		-.239		.171					
2011	referent		referent		referent		referent		referent					

* p value for comparison the mean HAZ in each subgroup to the referent subgroup
† p value for variable's contribution to overall model
‡ Categorical variable
§ Continuous variable

Discussion

Factors associated with HAZ in each age group

Children less than 6 months of age have not typically been included in assessments of nutritional status because they were generally considered protected from malnutrition by breastfeeding. Widespread use of the new WHO Child Growth Standard has refuted this assumption and demonstrated that children in this age group do indeed have both acute and chronic malnutrition (de Onis M et al., 2006). Our analysis adds to the relatively sparse data examining factors related to stunting in this age group. Perhaps the most striking conclusion is that relatively few factors are associated with HAZ. In this age group, HAZ is not statistically significantly related to variables measuring child feeding, child morbidity, perinatal care, mother's health (except height), parent characteristics, household characteristics (except wealth index), or environmental sanitation and hygiene. Specifically, regarding perinatal variables, which might be expected to play a role in stunting, our analysis fails to demonstrate a statistically significant association between HAZ and birth order, mother's smoking, or measures of ante-natal care. Feeding variables, including exclusive breastfeeding, are not statistically significantly related to HAZ. This finding is consistent with other published studies (Kramer and Kakuma, 2002, Vesel et al., 2010). In general, this analysis reveals few direct points for intervention to prevent future stunting in this age group. Nonetheless, the strong association between HAZ and birth size and maternal height – slowly-changing indicators of women's nutritional status at the population level – may indicate that maternal and ante-natal interventions could increase fetal growth and thus lead to higher birth weight and greater linear growth in the first half of infancy and perhaps later in a child's life.

Although more factors are associated with linear growth in children 6-23 months of age, the age of maximum growth faltering in Ethiopia and other developing countries, the factors that are modifiable by public health interventions are consumption of non-human milk, mother's use of modern contraception, and mother's height and BMI. In Ethiopia, milk consumption by young children, particularly during the lean season, has been shown to prevent stunting and wasting (Sadler et al., 2012). The use of modern contraceptives has also been associated with stunting, perhaps by increasing the space between births and by increasing overall knowledge of maternal and child health issues (Finlay JE, 2012). In Ethiopia, because the Health Extension Program is the major provider of contraceptive services (Medhanyie et al., 2012), the use of contraception may reflect access to and use of this program which provides other health and nutrition services which may have played a role in ameliorating stunting (Wirth et al., 2015). Thus, the apparent association between contraceptive use and HAZ may be due to confounding by participation in these other parts of the Health Extension Program. Maternal height and BMI have also been associated with stunting in previous studies in Ethiopia (Gibson et al., 2009, Fentaw et al., 2013), illustrating that maternal height and nutrition status are closely associated with child growth in Ethiopia. Many other direct measures of child feeding behaviors, however, did not exhibit a statistically significant association with HAZ, including ever breastfeeding, early initiation of breastfeeding, drinking from a bottle with a nipple, dietary frequency, dietary adequacy, eating vitamin A rich foods, and consumption of iodized salt. Compared to younger children less than 6 months of age, more household factors are associated with HAZ, including mother's partner's educational level, sex of the household head, and household wealth.

In children 24-59 months of age, the list of variables significantly associated with HAZ is even longer than in younger children. Like younger children estimated size at birth, child's WHZ, and mother's height and BMI remain significantly associated with HAZ. On the other hand, unlike in younger children, various measures of child morbidity and household composition are associated with HAZ. Diarrhea and respiratory infections result in stunting, as shown by prospective studies in other developing countries (Checkley et al., 2008, Adair and Guilkey, 1997, Kossmann et al., 2000), but we found only one other published study from Ethiopia reporting a significant relationship between recent diarrhea and child growth (Teshome et al., 2009). In addition, mother's educational level becomes associated with HAZ in this age group. The association between mother's education and child's health and nutritional status is well documented in other countries (Adekanmbi et al., 2013, Muhangi et al., 2013). Because the direct effect of diarrheal disease on HAZ is accounted for in the linear regression model, the decline in the prevalence of open defecation has an independent effect on HAZ. Open defecation at the community level has recently been identified as a potential cause of child stunting (Spears, 2013), and its significance only in children 24-59 months, may be due to the fact that these children are more mobile, and thus have more “contact” with the environment outside the home than younger children.

Overall, only a few variables are associated with HAZ in all age groups; these include child's WHZ, child's estimated size at birth, mother's height, and household wealth index. Most of these variables are, however, not *modifiable* by short-term public health interventions. Modifiable variables may be age-specific. Thus, program planners and managers should be sensitive to the fact that interventions may have effects on some age groups and not others.

Factors associated with HAZ in each livelihood zone

Our analysis finds that the factors associated with child growth are quite consistent between urban and rural areas. There are few factors that were significant only in either urban or rural areas but not both. More frequently, there are differences in the association between HAZ and a given factor in the three rural livelihood zones, which is likely due to the diversity of culture and livelihoods in rural areas of Ethiopia. For example, recent consumption of milk in children 6-23 months of age is associated with higher HAZ in urban and agricultural areas, but not agro-pastoral or pastoral. This may be due to the fact that milk is more frequently consumed by pastoral communities than agrarian communities, and milk consumption in pastoral areas is constant except during dry seasons and droughts (Sadler et al., 2012). Mother's use of modern contraception is significantly associated with HAZ in agricultural and agro-pastoral communities, but not urban or pastoral areas. If use of modern contraception is considered a proxy of health care coverage, the lack of variability in health care coverage in these subpopulations (nearly universal in urban areas and nearly inaccessible in nomadic populations) may preclude measurement of associations with this variable. Similarly, the statistically significant association between measures of child morbidity and HAZ seen in agricultural areas, but not in urban or pastoral areas, may reflect universal access or lack of access in urban and pastoral areas. In agricultural areas, there may be great variability in access so that more effective and timely treatment for child illness somewhat ameliorates the nutrition effects of such illness.

Other factors showed consistent relationships in the livelihood models. In particular, maternal factors, e.g. height, BMI and education, are consistently associated with improvement in older child growth irrespective of livelihood zone.

Trends in factors and contribution to stunting reduction

Although the multivariate analysis described above identified several variables which were statistically significantly associated with HAZ in one or more age groups, whether or not a given variable contributed to the decline in the prevalence of stunting seen in Ethiopia between 2000 and 2011 depends on the trend in that variable. Even if a factor is associated with HAZ, if the level of that factor did not substantially change during this time period, it probably did not contribute. In fact, many of the factors remaining in the final age-specific and livelihood zone-specific multivariate models did not substantially change between 2000 and 2011.

Of course, certain demographic variables, such as age and sex distribution in children and sex of the household head, can be expected to be relatively constant during this short time period. Indeed, these variables did not change with statistical significance in Ethiopia. Other demographic variables, such as birth order, mother's educational level, number of mother's living children, and household wealth, did change and could therefore be contributors to the decline in stunting prevalence. Regarding maternal education, Ethiopia's elimination of school fees for primary education in 2002 and the increased public funding for education have expanded the access to primary education to girls throughout Ethiopia by reducing households' opportunity costs of sending girls to school (Oumer, 2009), and thus may have contributed to the reduction in stunting observed. Some behavioral factors such as mother's use of contraceptives and child's consumption of milk were both associated with HAZ and changed in the expected direction during this time period. Maternal nutritional indicators, such as mother's height and BMI, were either unassociated with HAZ or did not change during this time period in many age- and livelihood-specific groups. Interestingly, the only potentially contributory nutritional or dietary variable which might respond in the short-term to nutrition programming is child's consumption of milk. On the other hand, indicators of child morbidity were both associated with HAZ and changed, at least in the oldest age group. Possible targets of more general health intervention, such as birth weight and child morbidity may also have an effect on stunting prevalence.

Interventions to address stunting in Ethiopia

The failure of our analysis to identify various dietary factors as potentially contributing to the decline of stunting in Ethiopia may be due to the inexact nature of the indicator measurements or other reasons. A similar lack of association between complementary feeding indicators and stunting has been found in several countries in Africa and elsewhere (Onyango et al., 2014). Nonetheless, further diversification of complementary feeding diets in children older than 6 months of age may contribute to additional reductions in stunting prevalence as a relationship between the quality of complementary feeding and stunting has been observed in multiple countries (Ruel and Menon, 2002, Arimond and Ruel, 2004). The low proportion of children in the 2011 DHS with a minimally acceptable diet highlights the need for specific interventions to improve complementary feeding. In addition, our analysis found that though consuming non-human milk has a protective effect in children 6-23 months old, there is a consistent decline since 2000 in the proportion of children consuming milk. Further research is warranted to determine which other dietary programs targeted to which age groups might be effective. And finally, encouraging girls' education to produce better educated mothers can be expected to further reduce stunting.

Programs improving child health, especially those preventing and/or treating diarrhea and fever, should result in further decline in the prevalence of stunting. Although the prevalence of open defecation has substantially declined in Ethiopia since 2000; however, the majority of latrines used in Ethiopia are pit latrines without slabs, which are classified by as *unimproved* by WHO and UNICEF (2015). Thus, increased coverage of *improved* sanitation facilities may result in additional reductions in stunting prevalence by further preventing diarrhea and environmental enteropathy. In addition, programs that improve mother's health, nutrition, and education status may reduce stunting by improving fetal growth and care giving practices during infancy and early childhood.

Limitations

Although DHS data were the only data available in Ethiopia to undertake this analysis, DHS data have several limitations and thus can provide neither a complete picture of factors contributing to stunting in Ethiopia nor all the factors responsible for its reduction since 2000.

Notably, the three DHS were done in somewhat different seasons, and thus, any outcomes showing seasonal variation may show differences among the three surveys solely because the measurement was done at different times of the year. In addition, DHS data does not include direct measures of household food security or children's dietary intake which are major putative risk factors for stunting. Although the household wealth index and children's dietary diversity may serve as proxies for food security and dietary intake, respectively, they are at best indirect measures.

DHS data also contain no assessment of participation of selected households in any of the many nutrition and health programs existing in Ethiopia, although some factors (e.g. use of contraception) can potentially serve as proxies for primary health care coverage. In general, the effect of these potentially important programs cannot be measured in our analysis. Because such nutrition and health programs may mitigate the effect of possible risk factors included in our analysis, we may be underestimating the contribution of such risk factors to stunting in the absence of interventions.

Similar to other studies from Ethiopia (Gibson et al., 2009, Assefa et al., 2012), our analysis found consistent associations between household wealth index and child HAZ. Although household wealth index is routinely calculated, because it is a composite measure, significant findings are difficult to ascribe to any specific household characteristic. To illustrate, household wealth index includes a household's durable goods (e.g. radio, television, watches, tools), dwelling construction (e.g. material used for floors, walls, and roof), household sanitation (e.g. latrine type), and ownership of livestock; and all of these factors have the potential to influence child growth. However, when included separately in the age-specific models, none of the sub-factors were significant at the household level.

Regarding data quality, some heaping of the decimal in height measurements in the 2000 and 2005 DHS were observed. There was no heaping of age on whole years, but there is an uneven distribution of age in children less than 5 years of age. Standard recommendations state that a standard deviation of greater than 1.3 for HAZ reflects excessive random variation in either height measurements or age estimates. The standard deviation of HAZ in the three DHS greatly exceeds this threshold for data quality; however, this recommendation is based on the use of the old NCHS:CDC:WHO reference population. There is evidence that standard deviations for HAZ greater than 1.3 are common in DHS in other countries and may be normal when using the WHO Child Growth Standard (Mei and Grummer-Strawn, 2007). Regardless, the HAZ values were normally distributed in each survey without substantial skewness or kurtosis. If the standard deviation actually reflects imprecise data, it is most likely due to poor age estimates in this largely calendar-illiterate population.

Due to the limitations of DHS, policy makers and program managers in Ethiopia and other countries should use DHS in tandem with evidence from other studies, and should design independent studies to inform key programmatic questions. To address the limitations of this analysis, we recommend that nutrition researchers in Ethiopia examine the determinants of stunting using different study designs. For example, longitudinal cohort studies that examine children at multiple times from birth to five years of age and examine factors often absent from DHS surveys (e.g. household food security, dietary intake, participation in nutrition and health programs, micronutrient and inflammation status) can identify factors directly associated with and preceding growth faltering. Moreover, the greater control inherent in collecting data as part of such a study would reduce random measurement error in key variables, such as feeding indicators.

CONCLUSION

Despite a large reduction in the prevalence of stunting in Ethiopia since 2000, the prevalence of stunting remains unacceptably high. Our analysis finds that factors associated with child growth in Ethiopia vary considerably by age and livelihood zone, with relatively few modifiable factors in children < 6 months of age. In older children 6-59 months old, more factors were associated with HAZ, including some amenable to modification by intervention: recent illness, maternal health and education, and community-level sanitation. Factors that are associated with the decline in the stunting prevalence since 2000 include decreases in the prevalence recent illness and community-level open defecation and improvements in maternal height, BMI, and education. To further accelerate and sustain the reduction in stunting observed in Ethiopia, education and health programs targeted to women should be continued, along with programs to reduce child illness and address community sanitation.

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Supplementary Table 1 – Results of bivariate and trend analyses of potential risk factors for stunting

Not statistically significant ($p > 0.05$) | Variable may not apply to all children | Data not collected in all three surveys

Target group of children	Variable (field name in dataset)	Value	Unwtd number	Bivariate analysis (each factor by HAZ)			
				Weighted mean HAZ	Adj R^2	Stnd beta	P value
All children*	Height-for-age z-score		26,274				
All children	Degree of stunting	Severe Moderate None	5,910 5,573 12,516				
All children	Presence of stunting	Yes No	11,483 12,516				
All children	Size of child at birth (m18)	Very large Larger Average Smaller Very small	2,859 3,684 8,465 3,448 3,530	-1.61 -1.80 -1.75 -2.09 -1.92	.007		.000
Children with known birthwt	Birthweight in kg		1,788		.009	.099	.000
All children	Mother smokes cigarettes (v463a)	No Yes	13,381 77	-1.66 -1.68	.000		.913
All children	Ever had alcohol drink (S1007C)	No Yes	6,331 3,267	-1.50 -1.81	.007		.000
All children	Mom's height (MomHt)		21,953		.030	.174	.000
All children	Mom's BMI (MomBMI)		21,935		.010	.098	.000
All children	Mom's Hb (MomHb)		12,969		.000	.022	.014
Child from last birth	Trouble seeing only at night (NightBlind)	Yes No	482 8,051	-2.03 -1.87	.000		.066
All children†	WHZ		23,999		.006	-.079	.000
All children† >6 mos	Child's Hb (ChildHb)		11,400		.009	.095	.000
Child from last birth	During this pregnancy, given or bought iron tablets/syrup (M45)	No Yes	7,397 1,745	-1.56 -1.41	.001		.002
Child from last birth	Received Vitamin A in first 2 months after this delivery (m54)	No Yes	12,549 2,579	-1.72 -1.63	.000		.024
All children	Mom HIV status (HIVMom)	Negative Positive	12,763 169	-1.67 -1.64	.000		.831
Child from last birth	Trimester first got ANC for this pregnancy (PrenatCare + m13) (PrenatTrimester)	1st 2nd 3d No ANC	1,759 3,098 940 9,303	-1.23 -1.50 -1.67 -1.87	.015		.000
Child from last birth	Number of antenatal visits for pregnancy (m14)		15,086		.019	.136	.000
All children	Place of delivery (DelivPlace)	Home Govt facility Private Other	19,421 2,190 257 158	-1.92 -1.06 -0.59 -2.02	.027		.000
All children	Delivery by caesarian section (m17)	No Yes	21,578 383	-1.83 -0.91	.005		.000
Child from last birth	After birth, health professional checked Mom's health (m50)	No Yes	12,948 1,539	-1.80 -1.26	.008		.000
Last birth if 6-23 months	Min dietary diversity (DietMinDiv)	No Yes	3,617 232	-1.39 -1.07	.002		.002
Last birth if	Min dietary frequency	No	3,209	-1.55	.000		0.45

Target group of children	Variable (field name in dataset)	Value	Unwted number	Bivariate analysis (each factor by HAZ) Weighted mean HAZ	Adj R^2	Stnd beta	P value
6-23 months	(DietMinFreq)	Yes	2,902	-1.59			
Last birth if 6-23 months	Acceptability of diet (DietAccept)	Not accept Acceptable	2,628 93	-1.31 -0.97	.001		**0.06**
Child from last birth	Drank milk last 24 hrs (DrankMilkYN)	No Yes	12,173 5,730	-1.84 -1.59	.004		**.000**
Child from last birth	Ate vit A food last 24 hrs (FoodGrp6VitA)	No Yes	8,292 1,229	-1.47 -1.53	.000		**0.37**
All children	Vitamin A suppl in last 6 months (h34)	No Yes	10,261 11,552	-1.69 -1.93	.005		**.000**
All children	Taking iron pills, sprinkles or syrup (H42)	No Yes	8,690 822	-1.59 -1.82	.001		**.001**
All children	Whether or not HH salt has any iodine (HHSaltIodine)	None Iodized	16,681 6,613	-1.86 -1.78	.000		**.020**
All children	Had diarrhea in past 2 weeks (h11)	No Yes	17,808 4,199	-1.78 -1.99	.002		**.000**
All children	LRI	No Yes	18,856 3,024	-1.78 -2.06	.003		**.000**
All children	Had fever in last two weeks (h22)	No Yes	16,705 5,284	-1.78 -1.96	.002		**.000**
All children	Number of HH members (v136)		22,035		.000	0.011	**0.11**
All children	Wealth index calculated for all surveys together (WealthIndexAll)		21,428		.036	.190	**.000**
All children	HH own crop land (CropLand)	No Yes	5,892 18,099	-1.46 -1.94	.014		**.000**
All children	Tropical livestock units (TLU)		14,577		.000	-.012	**.150**
All children	Mother's current marital Status (v501) (MomMaritalGrp: married now vs. not married now)	Never married Married Living together Widowed Divorced Not living together	131 19,888 604 407 654 351	-1.41 -1.83 -1.47 -1.84 -2.11 -1.71	.002		**.000**
All children	Father alive (hv113)	No Yes	604 23,319	-1.82 -1.82	.000		**0.97**
All children	Partners age (v730)		20,421		.003	-.055	**.000**
All children	Partner's educ. level (v701) (MomPartEduc – combine Secondary and Higher)	None Primary Secondary Higher	12,576 6,415 2,080 646	-2.01 -1.74 -1.24 -0.79	.028		**.000**
All children	Mother's partner's occupational group (MomPartOccupGrp) (use MomPartOccupGrp2)	None Agric Unskilled Services Skilled Sales Prof/clerk	303 16,595 374 512 1,109 1,846 1,037	-1.22 -1.96 -1.66 -1.63 -1.35 -1.46 -1.14	.021		**.000**
All children	Dependency ratio (DepRatio)		23,999		.000	-.014	**.031**
All children	Ever breastfed (BFEver)	No Yes	265 21,661	-1.68 -1.82	.000		**.220**
Last birth if <6 months	Exclusively breastfed (BFExclusive)	No Yes	1,299 838	0.00 -0.34	.008		**.000**
Last birth if <24 months	Currently breastfed, age <24 mos (v404)	No Yes	633 8,001	-1.19 -1.21	.000		**.810**
Child from	Early initiation of	No	3,857	-1.26	.001		**.027**

Target group of children	Variable (field name in dataset)	Value	Unwted number	Bivariate analysis (each factor by HAZ) Weighted mean HAZ	Adj R^2	Stnd beta	P value
last birth	breastfeeding (BFEarly)	Yes	4,664	-1.16			
All children	Drank from bottle with nipple (m38)	No	20,306	-1.89	.018		**.000**
		Yes	1,640	-0.99			
All children	Sex of household head (v151)	Male	18,496	-1.83	.000		**.014**
		Female	3,539	-1.74			
All children	Age of household head (v152)		22,033		.000	-.022	**.001**
All children	Number of children <=5 in HH (v137)		22,035		.001	.037	**.000**
All children	Mom's number of living children (v218)		22,035		.001	-.038	**.000**
All children	Mother alive (hv111)	No	228	-2.15	.000		**0.01**
		Yes	23,744	-1.82			
All children	Mom uses contraceptive now (MomContrYN)	None	18,471	-1.87	.004		**.000**
		Any	3,564	-1.55			
All children	Mom wants more children (MomWantMoreKids)	No	7,540	-1.85	.000		**0.07**
		Yes	13,757	-1.8			
All children	Mom's age at child's birth (MomAgeAtBirth)		22,035		.000	.003	**0.70**
All children	Mom's education combining secondary and higher (MomEducGrp)	None	16,467	-1.96	.025		**.000**
		Primary	4,192	-1.57			
		Secondary	1,376	-0.90			
All children	Mom currently working (v714)	No	13,382	-1.74	.003		**.000**
		Yes	8,635	-1.94			
All children	Mom's occupational group (MomOccupGrp2)	None	10,944	-1.70	.017		**.000**
		Agric	6,394	-2.11			
		Unskilled	187	-2.22			
		Services	147	-1.49			
		Skilled	1,305	-1.88			
		Sales	2,657	-1.72			
		Prof/clerk	291	-0.64			
All children	Child's birth order number (bord)		22,035		.002	-.046	**.000**
All children	Child is twin (b0)	No	21,657	-1.81	.001		**.000**
		Multiple	378	-2.3			
All children	Child lives with whom (b9)	With Mom	22,004	-1.82	.000		**.040**
		Elsewhere	31	-1.22			
All children	Used alcohol or khat (DrugScore)	Last 30 days	3,908	-1.78	.007		**.000**
		Used but not last 30 days	301	-1.30			
		Never used	5,385	-1.50			
All children	Time to get to water Source (v115)		21,081		.001	-.024	**.000**
All children	Drinks safe water (SafeDrink)	Unsafe	11,768	-2.01	.014		**.000**
		Safe	9,728	-1.59			
All children	Adequate latrine (LatrineAdeq)	Not good	20,560	-1.85	.006		**.000**
		OK	1,045	-1.20			
All children	Percent HHs with open defecation (PcntOpenDef)		23,999		.018	-.133	**.000**

Target group of children	Variable (field name in dataset)	Value	Unwted number	Bivariate analysis (each factor by HAZ)			
				Weighted mean HAZ	Adj R^2	Stnd beta	P value
All children	Percent HHs with open defecation (deciles) (PcntOpenDefDeciles)	1 (<10%)	2,478	-1.24	.019		**.000**
		2	2,323	-1.59			
		3	2,472	-1.69			
		4	2,434	-1.77			
		5	2,362	-1.97			
		6	2,098	-1.94			
		7	2,282	-2.04			
		8,9,&10 (100%)	7,550	-2.01			
All children	Degree of exposure to smoke in house (SmokeExpos)	None	372	-0.72	.019		**.000**
		Ventilation	6,389	-1.50			
		Full	6,498	-1.87			
Child from last birth	Baby postnatal check within 2 months (M70)	No	5,314	-1.59	.000		**0.56**
		Yes	265	-1.65			
All children	Child has health card (HealthCardYN)	Never	9,682	-1.85	.000		**0.07**
		Now or in past	12,294	-1.80			
All children	Child got deworming in last 6 months (H43)	No	7,703	-1.54	.005		**.000**
		Yes	1,796	-1.87			
All children	Child ever got measles vaccine (MeaslesVacc)	Never	13,150	-1.72	.005		**.000**
		Yes	8,380	-1.97			
All children	Summary score for HH Decisions (DecisionScore)	0 No decisions	1,349	-1.64	.000		**0.27**
		1	1,319	-1.75			
		2	1,759	-1.62			
		3	2,627	-1.67			
		4 All decisions	5,331	-1.63			
All children	Summary score for reasons child's Mom is beaten (BeatScore)	0 No reason	4,378	-1.58	.006		**.000**
		1	1,831	-1.73			
		2	2,392	-1.86			
		3	2,896	-1.85			
		4	3,228	-1.89			
		5 All reasons	6,588	-1.94			
All children	Mom's husband lives in house (v504)	Yes	18,680	-1.83	0.001		**.001**
		No	1,789	-1.66			
All children	Number of other wives (NumbOtherWives)	None	17,766	-1.81	.000		**.411**
		1	2,118	-1.87			
		2+	533	-1.88			
All children†	Child's sex (b4)	Male	11,124	-1.87	.001		**.000**
		Female	10,911	-1.77			
All children†	Child's age in months (hw1)		22,035		.085	-.291	**.000**
All children†	Type of place of residence (v025)	Urban	3,440	-1.19	.023		**.000**
		Rural	18,595	-1.94			
All children†	Livelihood zone (LZ)	Urban	3,440	-1.9	.027		**.000**
		Agricultural	15,408	-1.98			
		Agro-pastoral	1,486	-1.64			
		Pastoral	1,335	-1.90			

* DHS collect most types of data from only living children resulting from the most recent two births (for DHS 2000) or three births (for DHS 2005 and 2011) to respondent mother. Although mothers with more than three births in the past 5 years are probably rare, any fourth or greater most recent birth, even if that child is less than 5 years of age, would not included in the mother's interview data collection. However, anthropometric and hemoglobin measurements are collected on all children in selected households. In this table, for variables other than anthropometric and hemoglobin measurements, "All children" means the two or three most recent births to a mother who are less than 5 years of age on the day of the interview. Therefore, "All children" does NOT necessarily mean all children in households selected for the survey.

† Includes all children in selected households, not only children of interviewed mothers.

‡ Indicates which model variable is included. Lower case letter (a) is variable dropped during backward elimination. Upper case letter (A) is variable retained after backward elimination.

() Variable names indicated in parentheses include variable names provided in the DHS data files and recoded variables used for the analysis.

CHAPTER 3

Scale up of nutrition and health programs in Ethiopia and their overlap with reductions in child stunting

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Abstract

The prevalence of stunting in Sub-Saharan Africa has changed little since 2000, and the number of stunted children has increased. In contrast, Ethiopia is as example where the national stunting prevalence and number of stunted children has decreased consistently. We compare regional differences and temporal patterns in stunting with large-scale program coverage to identify where and when programs may have led to reductions in stunting. Data from three national demographic and health surveys and population statistics illustrate, at the regional level, where and when the prevalence and number of stunted children changed since 2000. Reports from large-scale nutrition and health programs were used to identify ecologic associations between geographic program coverage and reductions in stunting. From 2000-2005, the decline in the national stunting prevalence was mainly a result of reductions in Oromiya, SNNP, and Tigray. Few nutrition programs had high coverage during this time, and economic growth may have contributed to stunting reduction by increasing household wealth and investments in sanitation. From 2005-2011, declines in stunting prevalence in Amhara, SNNP, Somali, and Oromiya were largely responsible for national reductions. Numerous programs were implemented at scale and could have plausibly improved stunting. While ecologic relationships suggest that economic growth and large-scale programs may have contributed to the reduction in stunting in Ethiopia, stunting did not decrease in all regions despite increased program coverage expansion of the health system. Additional impact evaluations are needed identify the most effective programs to accelerate the reduction in the prevalence and number of stunted children.

INTRODUCTION

Stunting, or chronic malnutrition, in children < 5 years of age, is associated with numerous health and development consequences in childhood and social and economic consequences in adolescence and adulthood (Black et al., 2008). Stunting currently affects 58 million children in Africa, and the number of stunted children in Africa will likely increase due to population growth and a stagnating prevalence of stunting (de Onis et al., 2013). Only a few African countries have successfully reduced the prevalence and number of stunted children in the past two decades.

Ethiopia provides one such example of a Sub-Saharan nation where stunting has decreased. From 1992 – 2011, child stunting declined by 23 percentage points (from 67% to 44%) (UNICEF, 2013); ~14 percentage points of this decline was observed between 2000 and 2011, where the prevalence was measured by three Demographic and Health Surveys (DHS) with comparable designs and methodologies (CSA and ICF International, 2012, CSA and ORC Macro, 2006, CSA and ORC Macro, 2001). This reduction in the national prevalence of stunting occurred during a dynamic period with a significant increase in the total population and the expansion of large-scale health and nutrition programs.

In a separate study, we conducted an analysis to identify the risk factors of stunting and the factors associated with stunting reduction in Ethiopia between 2000 and 2011 using data from Ethiopia's 2000, 2005, and 2011 DHS (Woodruff et al., 2016). As DHS lack detailed information on survey subjects' participation in many health and nutrition programs, our individual-level analysis of DHS data can unfortunately not investigate associations between program coverage and stunting reduction. We present here an ecologic analysis which aims to determine if the reduction in stunting can be – at least partly – ascribed to coverage of large-scale nutrition and health programs.

This paper has two objectives; 1) to present the national and regional stunting trends and identify which regions contributed most to national-level reductions in stunting from 2000-2011, and 2) to draw linkages between the reduction in stunting and health and nutrition programs in Ethiopia in the same time period. By understanding where and when program activities correlated with reductions in stunting, the authors hope to assist national and local authorities determine which programs are effective at reducing stunting.

METHODS

Data from three national DHS surveys and national population figures were used to identify where and when stunting changed in Ethiopia between 2000-2005 and 2005-2011 and which regions contributed most to the changes in prevalence of stunting at the national level. Sub-national changes are investigated using two approaches. First, the prevalence of stunting nationally, by urban/rural status, and by region was calculated using the World Health Organization's (WHO) Child Growth Standards (WHO, 2006). Stunting prevalence is defined as the weighted proportion of children 0-59 months of age with height-for-age z scores (HAZ) below -2 SD; children with HAZ less than -6.0 or HAZ greater than +6.0 were excluded from analysis (SMART, 2006). Regional population statistics[1] from Ethiopia's Central Statistical Agency (CSA) (CSA, 2005, CSA, 2010, CSA, 2013) and regional prevalence from the three DHS were used to calculate the total number of stunted children by region and by year. Second, using the regional change in the number of stunted children for two different time periods, 2000-2005 and 2005-2011, the proportion of the national reduction in stunting was attributed to specific regions, accounting for both changes in stunting prevalence and population size.

An inventory of all large-scale health, nutrition, and food security programs was conducted, and coverage and impact data were examined and overlaid against the reductions of stunting observed by the DHS. The evolution of the political, economic, and demographic context in Ethiopia was also reviewed to further identify associations between secular trends and changes in stunting.

RESULTS

Changes in prevalence and magnitude of stunting, 2000-2011

As shown in Figure 1, there has been a steady reduction in the prevalence of stunting when examined nationally and by urban and rural residence. Similar to national-level analysis, consistent decreases ≥2 percentage points between each DHS were observed in Southern Nations, Nationalities, and Peoples' (SNNP) region, Oromiya, Gambela, and Addis Ababa. The change in stunting prevalence in other regions, however, is less consistent. While the prevalence of stunting declined between 2000 and 2005 in Tigray, Afar, and Benishangul-Gemuz, it increased from 2005-2011, albeit not to 2000 levels. In contrast, the Amhara, Somali, and Harari showed negligible changes or increases in the prevalence of stunting between 2000 and 2005, with reductions in prevalence between 2005

[1] Specific figures used include total population by region by year, and the percent of children 0-4 years old, by region by year.

and 2011. Only in Dire Dawa did stunting increase consistently between 2000 and 2011, though this change is not statistically significant.

Even with a general decline in the prevalence of stunting, the prevalence of stunting measured in 2011 is considered "very high" (≥40%) in six of Ethiopia's 11 regions (Amhara, Tigray, SNNP, Oromiya, Afar, and Benishangul-Gemuz) according to WHO classifications (2010). The prevalence of stunting is considered "high" (30-39%) in Somali and Dire Dawa, and "medium" (20-29%) in Addis Ababa, Gambela, and Harari. In no region is stunting prevalence considered "low" (<20%).

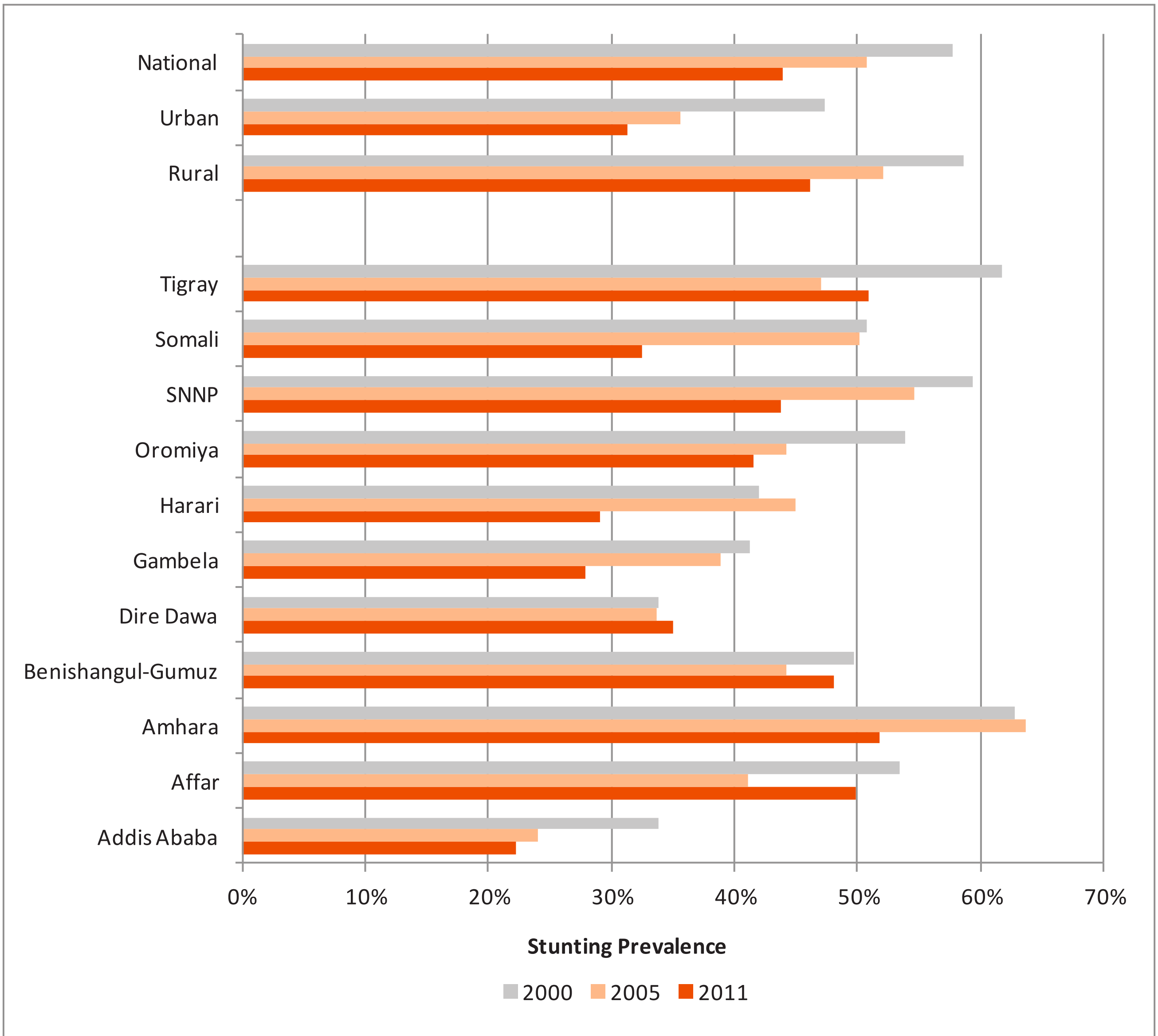

Figure 1. Prevalence of stunting in children < 5 years of age in Ethiopia in 2000, 2005, and 2011 at the national level and by residency and region

Figure 2 presents the total number of stunted children nationally, by urban/rural residence, and by region in 2000, 2005, and 2011 (termed hereafter 'caseloads'). The overall national caseload has declined from 2000 to 2011; while a clear decline in rural children is observed, there was a small increase in caseloads in urban areas. According to population statistics, the number of children <5 years of age increased by nearly 23% from 2000 and 2011, from 10.3 to 12.6 million. The number of stunted children declined from 5.8 to 5.5 million, a change of only 6%, over the same time period. At the region level, the number of stunted children corresponds closely to regional populations, with the three most populous regions, Oromiya, Amhara, and SNNP, containing the largest number of stunted children.

Table 1 and Table 2 present the proportion of the national decrease in the stunting prevalence between two time periods (2000-2005 and 2005-2011) contributed by each region. Between 2000 and 2005 the 6.9 percentage point decrease in stunting nationally is attributed principally to reductions in the number of stunted children in Oromiya, SNNP, and Tigray. Reductions in stunting in Afar and Addis Ababa also contributed to the national reduction in stunting, but to a smaller degree. From 2005-2011, the 6.8 percentage point decrease in the national stunting prevalence is attributed to reductions in the number of stunted children in the Amhara, SNNP, Somali, and Oromiya. The number of stunted children in Addis Ababa, Harari, and Gambela also reduced and contributed to national reductions, but to a smaller extent. As the population of children <5 years old increased in Somali and SNNP between 2005 and 2011, the reduction in the number of stunted children in these regions is due solely to reductions in the prevalence of stunting. In Amhara, however, a reduction in the prevalence of stunting by nearly 12 percentage points was accompanied by a large reduction in the total number of children <5 years. According to Ethiopia's CSA, Amhara has the highest proportion of out-migration and the fastest decrease in the fertility rate (2013), thus, Amhara's contribution to the national reduction in stunting is likely caused both by improvements in child growth a reduced total number of children from migration and lower fertility.

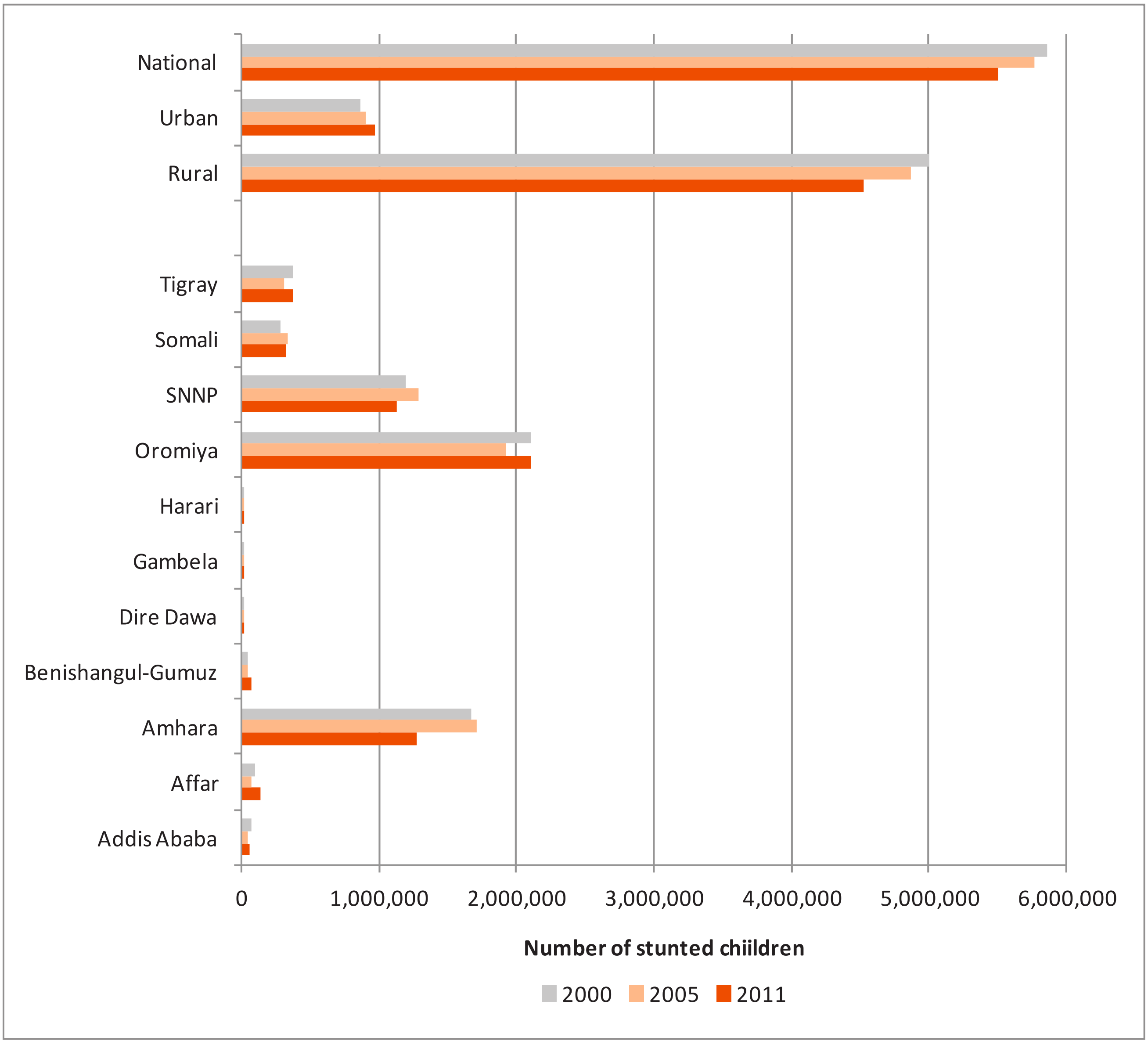

Figure 2. Number of children < 5 years of age with stunting in Ethiopia in 2000, 2005, and 2011 at the national level, by residency and by region

Table 1. Change in stunting and the contribution to national stunting decrease, by region, 2000-2005

Region	Prevalence of stunting 2000	Prevalence of stunting 2005	Change (in percentage points)	Population of children < 5 years (2000)	Population of children < 5 years (2005)	Change in number of stunted children 2000-2005	Weighted decline in stunting prevalence (in percentage points)	Weighted contribution to stunting (as % of national decline)
Addis Ababa	33.8%	24.1%	-9.7	200,375	187,744	-22,480	-0.16	2.8%
Afar	53.5%	41.1%	-12.4	173,689	186,892	-16,111	-0.20	3.5%
Amhara	62.8%	63.7%	0.9	2,653,240	2,679,151	40,384	0.21	-3.7%
Benishangul-Gumuz	49.8%	44.3%	-5.5	84,915	105,485	4,442	-0.05	0.9%
Dire Dawa	33.8%	33.7%	-0.1	41,971	51,493	3,167	0.00	0.0%
Gambela	41.3%	38.9%	-2.4	31,877	34,949	430	-0.01	0.1%
Harari	42.0%	45.0%	3	23,843	26,149	1,753	0.01	-0.1%
Oromiya	53.9%	44.2%	-9.7	3,904,349	4,348,448	-182,430	-3.73	64.0%
SNNP	59.4%	54.6%	-4.8	2,020,698	2,347,289	81,325	-1.00	17.1%
Somali	50.8%	50.2%	-0.6	547,285	678,679	62,676	-0.04	0.6%
Tigray	61.8%	47.1%	-14.7	609,269	659,554	-65,878	-0.86	14.7%
Total	57.7%	50.8%	-6.9	10,291,510	11,305,834	-92,721	-5.83	100.0%

Table 2. Change in stunting and the contribution to national stunting decrease, by region, 2005-2011

Region	Prevalence of stunting 2005	Prevalence of stunting 2011	Change (in per-centage points)	Population of children < 5 years (2005)	Population of children < 5 years (2011)	Change in number of stunted children 2005-2011	Weighted decline in stunting prevalence (in percentage points)	Weighted contribution to stunting (as % of national decline)
Addis Ababa	24.1%	22.2%	-1.9	187,744	235,552	7,046	-0.04	0.5%
Afar	41.1%	49.9%	8.8	186,892	269,958	57,897	0.21	-2.8%
Amhara	63.7%	51.8%	-11.9	2,679,151	2,470,549	-426,875	-2.60	35.1%
Benishangul-Gumuz	44.3%	48.1%	3.8	105,485	158,183	29,356	0.05	-0.7%
Dire Dawa	33.7%	35.1%	1.4	51,493	51,268	642	0.01	-0.1%
Gambela	38.9%	27.9%	-11.0	34,949	49,217	136	-0.05	0.6%
Harari	45.0%	29.1%	-15.9	26,149	28,305	-3,530	-0.04	0.5%
Oromiya	44.2%	41.5%	-2.7	4,348,448	5,062,229	178,811	-1.21	16.3%
SNNP	54.6%	43.8%	-10.8	2,347,289	2,586,806	-148,599	-2.47	33.3%
Somali	50.2%	32.5%	-17.7	678,679	976,195	-23,434	-1.53	20.6%
Tigray	47.1%	51.0%	3.9	659,554	729,057	61,169	0.25	-3.4%
Total	57.7%	50.8%	-6.8	11,305,834	12,617,320	-267,380	-7.41	100.0%

Health, nutrition and food security strategies and program landscape

The number of national policies and large-scale health, nutrition, and food security programs in Ethiopia has increased considerably in the past 20 years. Figure 3 presents the timeline of the various policies and programs implemented from 1995-2015.

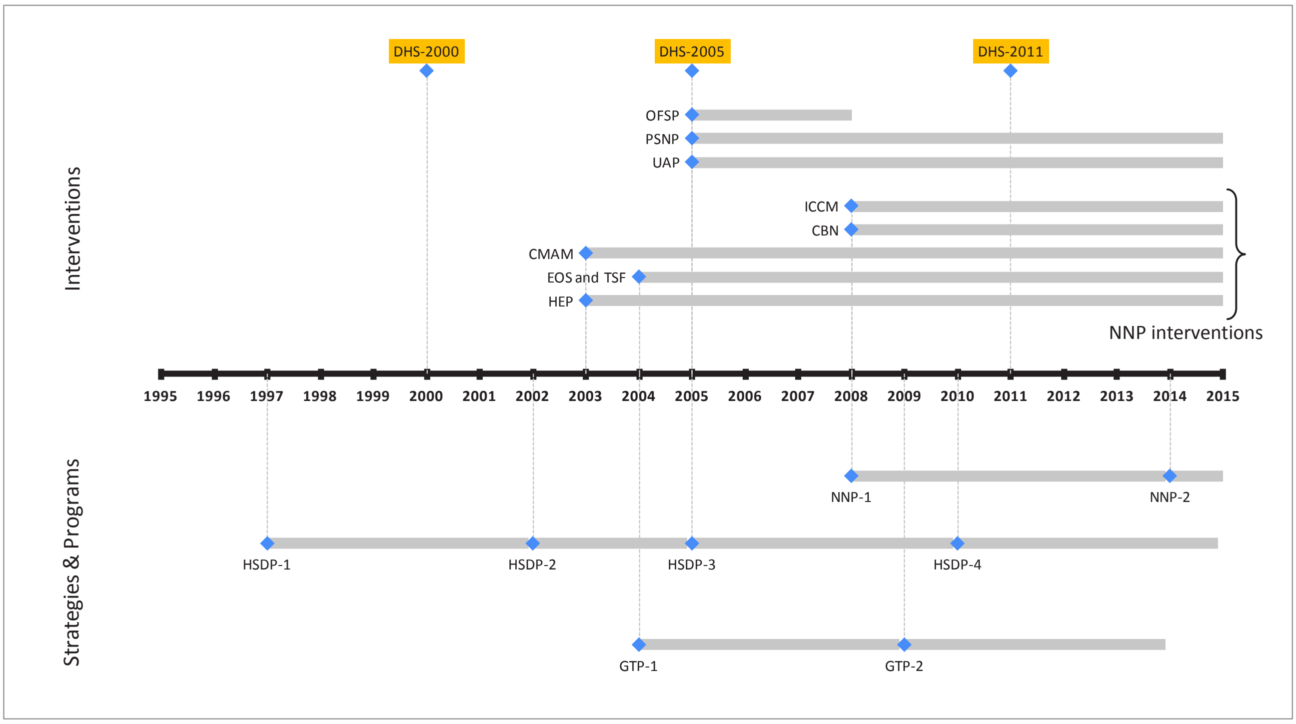

Figure 3. Ethiopia's nutrition strategies, programs, and interventions – 1995-2015

CBN: Community Based Nutrition Program; CMAM: Community Management of Acute Malnutrition; DHS: Demographic and Health Survey; EOS: Enhanced Outreach Strategy; GTP: Growth and Transformation Plan; HEP: Health Extension Program; HSDP: Health Sector Development Plans; ICCM: Integrated Community Case Management; NNP; National Nutrition Program; OFSP: Other Food Security Program; PSNP: Productive Safety Net Program; UAP: Universal Access Program; TSF: Targeted Supplementary Food.

Two national policy plans, a) Ethiopia's Growth and Transformation Plans (GTPs) and b) Health Sector Development Plans (HSDPs), have been used to launch and coordinate health-related programs and interventions in Ethiopia. The GTPs are five-year development plans which cover multiple sectors, including health, and aim at improving general economic growth and achieving various millennium development goals (MDGs). The GTP 1 (2004/05 - 2009/10) and GTP 2 (2010/11 - 2014/15) called for improvements in health care infrastructure through the establishment of health posts and increased capacity of the health care system through training of more extension workers. The HSDP, on the other hand, is an umbrella strategy and planning document for health-related programs, including nutrition. In the first four HSDP, nutrition has been considered a "cross-cutting issue", first linked to the integrated management of childhood illnesses in the HSPD I (1997-2001) and then, as a separate package of Health Extension Program (HEP) in the HSDP II (2002- 2004). The HSDP III (2005-2009) called for the development of a National Nutrition Strategy and Program (Federal Ministry of Health [Ethiopia], 2005) with centralized coordination, and HSDP IV (2010-2015) (Federal Ministry of Health [Ethiopia], 2010) has emphasized improving the coordination of nutrition programs. Stunting has been included as a key performance indicator in the HSDP III and IV. Stunting reduction targets were established in each plan; the stunting reduction targets for HSDP IV were to reduce the national stunting prevalence from 46% to 37%.

While numerous health and nutrition projects existed in Ethiopia in the 1990s and early 2000s, these programs were primarily classified as emergency responses and managed independently or in small partnerships by government ministries, UN agencies, and non-governmental organizations. Large-scale health and nutrition programs only began in 2003 and 2004 with the commencement of the HEP, the Enhanced Outreach Strategy (EOS), Targeted Supplementary Food (TSF),and the Community Management of Acute Malnutrition (CMAM) programs.

Established in 2003 and operationalized in 2004 (Amare, 2013), Ethiopia's HEP has been designed to increase access to a universal set of health services, focusing predominantly on the prevention of illness and disease (Lemma and Matji, 2013). The HEP consists of sixteen component activities spread across four thematic areas: disease prevention and control, family health, hygiene and environmental sanitation, and health education and communication. Nutrition is considered a component of the family health theme. The HEP delivers this set of health services in a decentralized manner; posting two female health extension workers to each of Ethiopia's approximately 15,000 kebeles (i.e. Ethiopia's smallest administrative unit, similar to ward). A year-long training is given to health extension workers prior to being posted, with refresher trainings on specific topics given on an on-going basis (Workie and Ramana, 2013).

The EOS program began in 2004. As part of child health days it provides semi-annual vitamin A supplementation to children 6-59 months and deworming to children 12-59 months throughout in the vast majority of Ethiopia's woredas (i.e. districts). The EOS program was initially implemented in 325 drought-prone districts, and 305 non-drought-prone districts were included (under the moniker "Extended EOS") in 2005. Children in drought-prone areas are screened using mid-upper arm circumference on a semi-annual basis, and those identified with severe acute malnutrition were referred to a CMAM outpatient therapeutic program and those with moderate acute malnutrition were referred to the TSF program. Children in non-drought-prone districts were not screened by the EOS program (Fiedler and Chuko, 2008). The EOS program also provides support to pregnant and lactating women through nutrition screening and referral to for supplementary food distribution. In 2012, the EOS program transitioned to routine implementation via the HEP.

Large-scale nutrition programs (e.g. EOS, CMAM) were integrated into the HEP in 2008. In addition, the first ever National Nutrition Strategy was launched in February 2008, and aimed to ensure that all Ethiopians secure an adequate nutritional status. The National Nutrition Program (NNP) has been implemented in two phases, from 2008-2013 (NNP-1) and from 2013-2014 (NNP-2), and will continue in a third phase from 2015-2020. An extension of National Nutrition Strategy, the NNP aims to improve the coordination of nutrition approaches and programs (Lemma et al., 2012, Federal Ministry of Health [Ethiopia], 2008). Improvements in service delivery have focused on four interventions: a) sustaining EOS with TSF and transitioning of EOS into the HEP, b) health facility nutrition services, c) Community-based Nutrition program (CBN) and d) micronutrient interventions. (Lemma et al., 2012).

Water, sanitation, and hygiene activities are implemented both by the HEP, which focuses on promotion of sanitation and hygiene facilities, and the Universal Access Program, which focuses on infrastructure-related activities. Implemented by Ministry of Water Resources but in collaboration with the Ministry of Health, the Universal Access Program began in 2005 as part of the GTP 1, and initially aimed to achieve near universal access to water and sanitation by 2012.

Ethiopia's Productive Safety Net Program (PSNP) began in 2005 and is the largest food security and social protection program in Africa. Implemented in food-insecure woredas, the PSNP provides support to food-insecure households during the hunger gap seasons to prevent the sale of household assets and to stabilize consumption patterns (Berhane et al., 2011). Specifically, support is provided in the form of a) the provision of food for work via labor-intensive public works projects, and b) direct support to households who cannot participate in public works projects. Since its creation, three separate rounds of the PSNP (2005–2006; 2007–2009; 2010–2014) have been implemented, and a new phase of PSNP is now planned for 2014 onwards.

Figure 4 illustrates the linkages between all large-scale nutrition, health, and food security programs. Multiple nutrition interventions are coordinated by the National Nutrition Program and implemented by the HEP. Notably, water, sanitation, and hygiene promotion and infrastructure activities are implemented separately. Food security programs are implemented separately from health and nutrition programs, and there are few direct linkages to the health extension program.

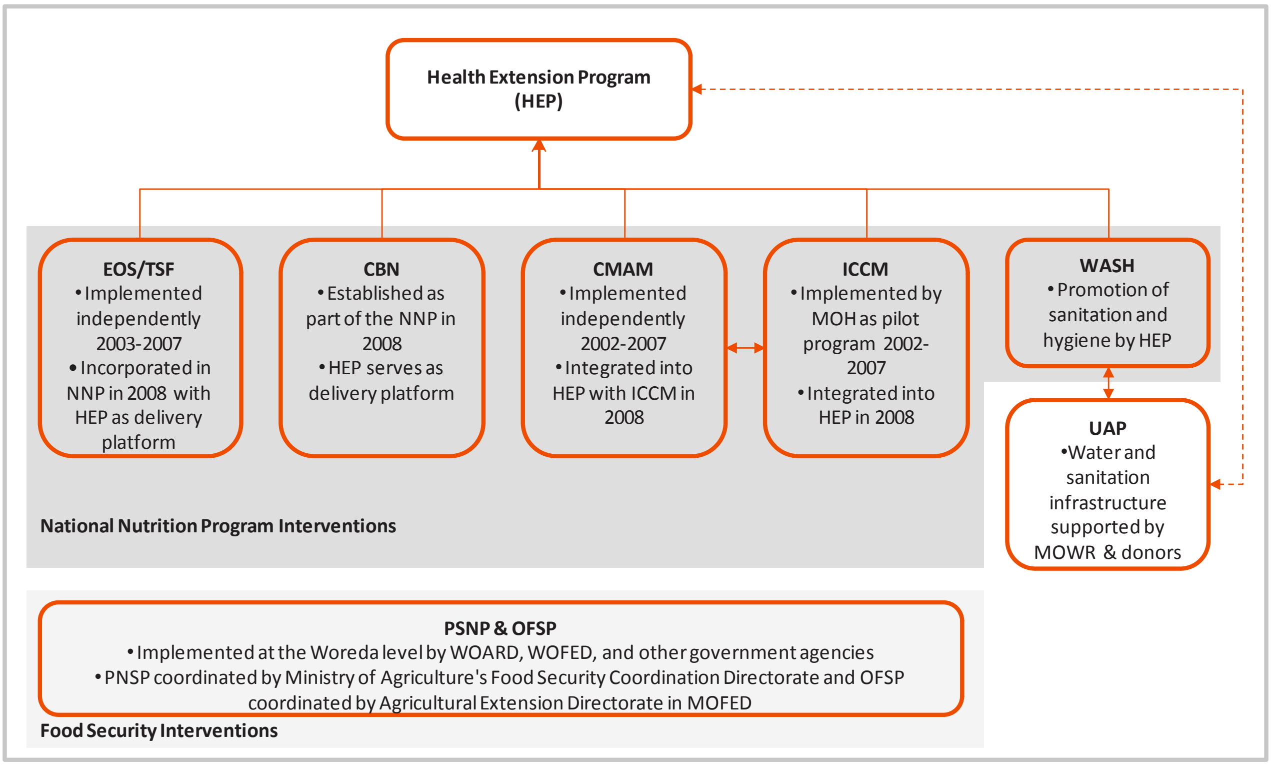

Figure 4. The Health Extension Program as the main delivery platform for nutrition programs

CBN: Community Based Nutrition Program; CMAM: Community Management of Acute Malnutrition; DHS: Demographic and Health Survey; EOS: Enhanced Outreach Strategy; GTP: Growth and Transformation Plan; HEP: Health Extension Program; HSDP: Health Sector Development Plans; ICCM: Integrated Community Case Management; NNP; National Nutrition Program; OFSP: Other Food Security Program; PSNP: Productive Safety Net Program; UAP: Universal Access Program; TSF: Targeted Supplementary Food.

Coverage of health and nutrition programs

Health Extension Program

There has been a steady increase in the coverage of local health services since 2000. As detailed by UNICEF (2012a), the number of health posts constructed steadily increased from 1,311 in 2001, 6,191 in 2005, to 14,192 in 2011. This increase shows that Ethiopia's health sector steadily increased coverage of primary health care infrastructure and nearly met the HEP goal of 15,000 health posts operational and staffed by health extension workers by 2011. Citing data from the Federal Ministry of Health, Banteyerga (2011) states that primary health care coverage increased from 77% in 2005 to 90% in 2010.

An assessment of the HEP in Tigray found that increases in program coverage were associated with increased immunization rates in children (Amare, 2013). In addition, cross sectional studies of the HEP program conducted in 2008 and 2010 in Tigray, Amhara, Oromiya, and SNNP showed that the coverage and utilization of HEP program, which was based on four measures of household health delivery, increased significantly (Karim et al., 2013).

Community Management of Acute Malnutrition

Ethiopia's CMAM program was established in response to a severe drought in Ethiopia in 2003, and was implemented as a stand-alone program from 2003 to 2007. The CMAM program was incorporated into the HEP in 2008, and scaled-up from 2008 to 2011 in Amhara, Oromiya, Tigray, Somali, SNNP, Afar, and Gambela (Lemma et al., 2012, Federal Ministry of Health [Ethiopia], 2013). The number of CMAM sites increased dramatically from 2008 and 2011, from 1,240 to about 9,000 sites (Lemma et al., 2012). The number of sites increased further to approximately 14,000 sites in 2015; the number of sites corresponded with increased numbers of admissions, however, regional admission estimates are were not available(Salama and Matji, 2013). The CMAM program also focused heavily on community mobilization activities and *outpatient* therapeutic treatment, which enabled on-going identification and monitoring of children with severe acute malnutrition and treatment via ready-to-use therapeutic food (Mates, 2011).

The number of therapeutic feeding sites increased notably in 2008-2009, corresponding with the CMAM program's incorporation into the HEP's regular health services. At the same time, the CMAM and the Integrated Community Case Management[2] (ICCM) programs were linked to consolidate service delivery as part of the HEP's routine health services. Despite this increased coverage, an evaluation of the CMAM program (Federal Ministry of Health [Ethiopia], 2013) noted regional variations in the coverage of the Outpatient Therapeutic Programme and Stabilisation Centres, with Afar and Somali demonstrating weaker coverage compared to the other regions.

Enhanced Outreach Strategy and Targeted Supplementary Feeding

[2] The ICCM program was initially referred to as Integrated Management of Childhood Illnesses

The EOS was established in 2004 in 325 drought-prone woredas in all regions but Addis Ababa (Federal Ministry of Health [Ethiopia] and UNICEF [Ethiopia], 2004). The program was expanded in 2005 to 305 non-drought-prone woredas (630 in total)[3], but the EOS in these locations does not include the nutrition screening component and referral to WFP-supported TSF (Negash, 2011).

Fiedler and Chuko (2008) present estimates of the coverage of the EOS program[4] from 2004 - 2006. During rounds 1 and 2 of the EOS screening in 2004, approximately 1.3 to 2.5 million children 6-59 months received vitamin A supplements and 0.8 to 2.2 million children 12-59 months received anthelmintics. Three rounds of the EOS program were implemented prior to the 2005 DHS, and the program reached full scale by 2006, with approximately 9 and 10 million children receiving deworming medication and vitamin A supplements, respectively. Negash (2011) presents similar trends in the number of children covered from 2004 to 2009, yet Negash reported that the number of woredas providing nutrition screening and TSF was reduced in 2008 "from 325 to 167 due to resource constraints". In 2008, EOS was transferred to the HEP into all regions except Afar, Somali, Gambella and Benishangul-Gumuz, where it continues (as of 2015) to be implemented independently of the HEP due to capacity constraints (UNICEF, 2012b). Following development of a transition strategy by Federal Ministry of Health, starting from June 2012, all woredas in agrarian regions had transited fully from EOS to Community health days (CHDs). Selected woredas are also transiting from CHD to routine Health Extension Program (HEP) integrating all intervention components into the routinely delivered HEP. In 2015, selected woredas in pastoralist regions of Somali, Afar, Gambella and Benshangul will transit from EOS to CHD.

Cross-sectional coverage data from the 2011 DHS reported that nationally, 53.1% of children received vitamin A supplements in the six months prior to data collection, ranging from 82.8% in Tigray to 26.3% in Somali. Among children aged 6-59 months, the national coverage of deworming medication was 21.0%, ranging from 6.0% in Somali to 26.6% in Benishangul-Gumuz (CSA and ICF International, 2012). Deworming in the EOS program is, however, only targeted at children 12-59 months old (Federal Ministry of Health [Ethiopia] and UNICEF [Ethiopia], 2004), thus coverage estimates in the DHS for deworming are likely underestimates as they included children 6-11 months of age who are not eligible to receive deworming medicine.

[3] Due to the geographic variety in Ethiopia, many regions contain both "drought-prone" and "non-drought-prone" woredas. For example, while the majority of the Oromiya region is classified as non-drought-prone, several woredas in southern Oromiya are considered drought-prone.

[4] Estimates presented by Fiedler and Chuko include both the EOS and Extended-EOS (EEOS) programs which were implemented in 325 and 305 districts, respectively, between 2004 and 2006. While both the EOS and EEOS provided deworming and vitamin A supplementation, only the EOS included nutrition screening.

Community-Based Nutrition Program

Targeted to children <2 years of age and pregnant and lactating women, the CBN program is comprised of six interventions: 1) growth monitoring and promotion of essential nutrition actions (ENA) by behavior change communication (BCC), 2) pregnancy weight gain using ENA by BCC, 3) targeted food supplementation, 4) micronutrient supplementation, 5) parasite control, and 6) hygiene and sanitation (Federal Ministry of Health [Ethiopia], 2008).

The development of the CBN was a central component of the 2008 NNP. While implemented through the HEP, the CBN is delivered by Volunteer Community Health Workers who are supervised by health extension workers of the HEP. The CBN is implemented in Amhara, Oromiya, SNNP and Tigray regions. Starting in 2008, the CBN roll out was gradual in each region. Between 2008 and 2009, the CBN was implemented in 39 woredas, 94 woredas in 2010, and 170 woredas in 2011. By 2011, the CBN program was implemented in 47%, 27%, 48%, and 94% of woredas in Amhara, Oromiya, SNNP, and Tigray, respectively (UNICEF data, unpublished).

Integrated Community Case Management

The ICCM program focuses on the treatment and management of pneumonia, diarrhea, malaria, and severe acute malnutrition (Miller et al., 2014). Health extension workers, working at the community level, are trained how to diagnose and treat children for these diseases.

The implementation of the ICCM program has changed over the years. Between 2002-2007, the Federal Ministry of Health implemented the "integrated management of childhood illness" program on a pilot basis, focusing on child illness with little attention toward nutrition (Benson et al., 2005). In 2008, nutrition components (e.g. screening and treatment of severe acute malnutrition) were added to the pilot program, and rebranded as the ICCM program, which was included into the HEP and was scaled up through the HEP in 2010 (Miller et al., 2014). While the scale-up was successfully accomplished in most regions, implemented by all the health posts of the HEP, Gambella, Afar, and Somali are notable exceptions, where by 2013, only 69%, 47%, and 9% of health posts had “regular ICCM capacity”, respectively (Alexander et al., 2014).

In a process evaluation of the ICCM services in Oromiya in 2010, Miller et al (2014) report that nearly all health extension workers were trained in ICCM, and

87% had received supervision in ICCM in the previous 3 months. Nearly 70% of health posts had all essential commodities for ICCM.

Productive Safety Net Program

Launched in 2004, the PSNP is implemented in food insecure woredas in six regions: Afar, Amhara, Oromiya, SNNP, Somali, and Tigray. The PSNP accelerated quickly, with nearly 5 million beneficiaries receiving either food or cash transfers in 2005, and the number of beneficiaries rose steadily to more than 7 million in 2009 and 2010 (UNICEF data, unpublished). The proportion of eligible beneficiaries covered cannot be easily calculated as the PSNP as the beneficiary targeting and selection processes vary by woreda. Using regional populations to estimate coverage, 4-14% of the population in Oromiya, SNNP, and Amhara were beneficiaries of the PSNP (authors' calculations). In Tigray and Somali, the proportion of households receiving PSNP services from 2005-2011 fluctuated between 8% and 33% in Tigray and 4 and 23% in Somali. The PSNP in Afar – where all woredas were covered by the PSNP – consistently covered an average of 34% of the population from 2005-2011.

Universal Access Program

The government of Ethiopia launched the UAP in 2005, which defined coverage targets for access to a clean water source and adequate sanitation. Prior to the UAP, Ethiopia's government established two main policies related to water in 1999 and 2001 (Calow et al., 2013) conceptualizing how the water-infrastructure projects should be managed and operated. Serial DHS showed a steady improvement in water and sanitation coverage: the percentage of rural households with an improved source of drinking water increased from 14% in 2000 to 26% in 2005 and then to 42% in 2011 (Zachary et al., 2013). On the other hand, the proportion of households with an improved sanitation source has stayed relatively low; in 2011, only 8% of households had an improved sanitation facility. Despite low coverage in improved sanitation, there has been notable increase in the use of unimproved facilities, such as pit latrines without slabs. As a result, the proportion of households with no access to a latrine facility decreased steadily from 82% in 2000 to 62% in 2005, and 38% in 2011. Improvement was most pronounced in rural areas, where the proportion of households without any facility dropped from 92% to 45% from 2000 to 2011 (Zachary et al., 2013).

Program impact on stunting and other indicators

There are only a few impact evaluations that examine the influence of Ethiopia's large-scale health and nutrition interventions on stunting, and these studies show mixed results. An evaluation of the EOS and TSF undertaken in Tigray, Amhara, Afar, and Somali found a significantly greater increase in weight-for-height z-score in treatment children compared to control children, but there was a significantly decrease in the HAZ in the treatment children (Skau et al., 2009). Despite the improvements in wasting, the effect size was small. The authors attributed the small effect size on wasting to the impact of poor enrollment processes (about 50% of those screened and enrolled in TSF were not malnourished) and consumption of TSF food by household members other than the targeted child.

An evaluation of the CBN and TSF included multiple cross-sectional baseline, midline, and endline surveys. Baseline surveys were implemented prior to commencement of the CBN, and intervention and control groups were established *de facto* based on the actual implementation of the program; due to delayed implementation of the CBN program, areas that did not implement the CBN program during part of the evaluation were classified as the "control" group. Between 2008 and 2010, intervention groups had increased contact with health workers, improved infant and young child feeding (e.g. dietary diversity, minimum acceptable diet), and a greater reduction in the prevalence of stunting compared to the control group (White and Mason, 2012). Reductions in stunting were found in intervention areas both with and without distribution of TSF regardless of the intensity of the CBN program at the community level. While this evaluation showed that the CBN program (implemented with and without TSF) was associated with stunting reduction, these results may be confounded by the fact that the initial woredas where CBN was launched in 2008 were classified as "drought prone"; thus the EOS/TSF was implemented in the same locations.

A recent evaluation examined the nutritional impact of the PSNP and CBN. This report found "no robust, statistically significant associations between PSNP participation or the duration of presence of CBN and height-for-age z scores, stunting, weight-for- height z scores and wasting after controlling for child, maternal, household and location characteristics. This remains true if we use a different measure of PSNP participation or a different survey year (Berhane et al., 2014)." These recent results support earlier research related to the PSNP which showed that while some beneficiaries of the PSNP showed improvements in household food security, these improvements did not translate to improved health and nutrition status in children (Gilligan et al., 2008).

Regarding overall delivery and intensity of the HEP, Karim e*t al*. found a dose-response relationship between program intensity in the community – calculated using multiple measures of program outreach and coverage – and the odds of receiving antenatal care and postnatal care practices (Karim et al., 2013). Child growth, however, was not included as an outcome measure.

Secular trends

In addition to large-scale programs, secular trends may have contributed to improvements in nutritional status in children. Table 3 presents information related to Ethiopia's political, economic, demographic, and programmatic contexts over time. Over the past 20 years, Ethiopia has experienced strong GDP growth and marked reductions in the proportion of the population living in poverty (i.e. living on < $1.25 per day). Particularly between 2000 and 2005, the proportion of individuals living in poverty decreased by 16% percentage points, from 54.6% to 38.9%, respectively (World Bank, 2014).

Economic growth has not, however, led to increased household wealth at the national level in Ethiopia (Woodruff et al., 2016, Zachary et al., 2013). While GDP could potentially have some positive spill-over effects, continued food crises suggest that economic growth has not increased food security in vulnerable populations. The 2002 and 2011 food crises were also not consistently associated with increased prevalence and caseloads of stunting in the three regions most affected: Afar, Oromiya, and Somali. From 2000 and 2005, the prevalence of stunting decreased in these three regions, but caseloads increased in Somali. Between 2005 and 2011, the stunting prevalence only increased in Afar, yet caseloads increased in Afar and Oromiya. Notably, despite a 17.7 percentage point reduction in stunting in Somali between 2005 and 2011, the caseloads only decreased slightly.

The dramatic increase in Ethiopia's population with relatively slow urbanization may have "diluted" any economic improvements experienced and may leave similar numbers of children vulnerable to malnutrition during food crises. Population growth also leads to additional demands on the health care system, which was only fully staffed in 2009. Changes in the fertility rate, however, may also reduce the number of young children in certain regions, such as Amhara. Internal migration within Ethiopia has also been noted, with predominant out-migration observed in Amhara, and in-migration in Addis Ababa, Dire Dawa, and Gambela (CSA, 2013).

Table 3. Ethiopia's political, economic, and health background, 1995-2014

	1995-1999	2000-2004	2005-2009	2010-2014
Political background	Early years of democracy following transitional government from 1991-1994. Constitution established in 1994, with first multiparty elections in 1995.(Dercon, 2004) Intermittent fighting with Eritrea	Second multiparty elections held in 2000.	Widespread protests following general elections in 2005.	Following the death of Ethiopia's Prime Minister in 2012, succession of power implemented according to constitution. Multiparty elections subsequently conducted in 2013.
Economic background	Average annual GDP growth of about 5% (IMF) (Federal Democratic Republic of Ethiopia and Developement, 2002). 63% of population living on less than $1.25 per day in 2000 (World Bank, 2014)	Average annual GDP growth of about 4.5% (IMF) with growth between 2003 and 2004 of 12.3%. 55% of population living on less than $1.25 per day in 2000 (World Bank, 2014)	Average annual GDP growth of 11% (World Bank, 2014). 39% of population living on less than $1.25 per day in 2005 (World Bank, 2014)	High inflation in 2011; consistent growth in GDP 37% of population living on less than $1.25 per day in 2011 (World Bank, 2014)
Demographic factors	Population in 1998 =59.8 million (CSA, 2005). 86% rural population with density of 49 people per square km (1994 census cited by (CSA and ORC Macro, 2001))	Population in 2000= 63.5 million (CSA, 2005)	Population in 2005= 73.0 million (CSA, 2005). 84% rural population with density of 67 people per square km National census conducted in 2007.	Population in 2011= 81.9 million (CSA, 2010) 80% rural population with density of 110 people per square km (CSA, 2010)

Food crises and displacement	Food crisis from 1999-2000 in Somali, Tigray, Amhara, and Oromiya (Hammond and Maxwell, 2002)	Food crisis in 2002 in displaced households in Somali, Afar, and Oromiya	Global food price crisis and drought in 2008 affected prices of staple foods throughout Ethiopia (Heady and Shenggen, 2008)	Food crisis in 2011 displaced households in Somali, Afar, and Oromiya
Health systems	Integrated management of childhood illnesses noted as key strategy in HSDP-I.	Construction of health posts prioritized by HSDP- II. Establishment of the Health Extension Program in 2004	Expansion of HEP nationwide. Large-scale independent nutrition programs (e.g. EOS/TSF, CBN) integrated into HEP. Trained health extension workers placed in all kebeles by 2009.	Continuation of HEP
Large-scale nutrition programs	No large-scale nutrition programs established at this time	CMAM begins in 2003 with limited coverage for first three years. EOS/TSF begins in 2004 with limited coverage in first year of operation.	NNP established in 2008, and nutrition programs incorporated into HEP. Increased coverage of CMAM, EOS, and ICCM programs, and start of CBN program.	Consolidation of most nutrition programs under the Health Extension Program Second NNP established in 2013
Food security programs	No large-scale food security or safety net programs established at this time	No large-scale food security or safety net programs established at this time	PSNP commenced in food insecure woredas in 2005	Continuation of PSNP program

DISCUSSION

Prevalence versus Caseloads

Ethiopia’s stunting prevalence at the national and region levels decreased consistently from 2000-2011. This large prevalence reduction only translated to relatively small reductions in the number of stunted children in Ethiopia as the country’s population size increased by more than 18 million between 2000 and 2011 (CSA, 2005, CSA, 2010). The number of children <5 years old increased by approximately 2.3 million from 2000 to 2011, yet the number of stunted children decreased by only 360,000 in the same time period. Thus, substantially improvements to child health and nutrition have not likely reduced the caseloads of existing programs designed to reduce malnutrition in children. Additional resources and long-term efforts are required to further decrease the prevalence of stunting and number of stunted children.

Overlap of programs and stunting reduction: 2000-2005

Between 2000 and 2005, the majority of stunting reduction observed nationally occurred in two regions: Tigray and Oromiya. During this period, large-scale health and nutrition interventions were limited to the CMAM, HEP, and EOS/TSF, however the low coverage of CMAM and HEP during this period reduces the likelihood that a measurable impact on stunting from these programs would occur at the population level. While the coverage of the EOS/TSF program was increasing between 2004 and 2005, the authors could not, unfortunately, identify figures detailing the *regional* coverage of the EOS program during its initial years of implementation. Notably, the program was only operating for approximately 1½ years and was not operating at full scale when the 2005 DHS was conducted (Fiedler and Chuko, 2008);only three rounds of EOS were conducted prior to the 2005 DHS. As the coverage increased each round, only a small proportion of children would have received three rounds of vitamin A supplementation, deworming, and TSF if warranted. Due to this relatively short period of partial implementation prior to the 2005 DHS, it is unlikely that the EOS program could have led to the stunting reduction observed between 2000 and 2005.

However, the EOS program may have contributed to improvements in diarrhea, a short-term indicator of health status and a risk factor of stunting in Ethiopia (Teshome et al., 2009, Woodruff et al., 2016),. The prevalence of diarrhea in children <5 years has declined from 23.6% 2000 to 18.0% 2005 (CSA and ORC Macro, 2001, CSA and ORC Macro, 2006). This reduction in diarrhea may be attributable to the short implementation of the EOS program prior to the 2005 DHS. The use of anthelmintics has also been associated with reductions in the number of diarrheal episodes in India (Sur et al., 2005), and vitamin A supplementation has been associated with reductions in the incidence of diarrhea (Mayo-Wilson et al., 2011). Moreover, the evaluation of the EOS/TSF program (Skau et al., 2009) identified that supplementary food improved wasting but not stunting. Thus, though the EOS with TSF can lead to biological improvements, it likely did not contribute to reductions in the prevalence of stunting between 2000-2005.

Contrarily, reductions in poverty and subsequent improvements in household wealth in some regions may have contributed to a reduction in stunting. Household wealth is significantly associated with child growth in Ethiopia (Gibson et al., 2009, Woodruff et al., 2016), and household wealth significantly increased in Tigray and Oromiya from 2000 to 2005. Increased household wealth may have also lead to improvements in the quality of households' water source and the use of latrines in these regions. Open defecation at the community level is significantly associated with growth in children 24-59 months and stunting reduction at the national level (Woodruff et al., 2016).

Overlap of programs and stunting reduction: 2005-2011

Between 2005 and 2011, reductions in stunting prevalence in Amhara, SNNP, and Somali contributed to the majority of the decline in the national stunting prevalence. There were numerous large-scale programs implemented in the 2005-2011 period, including the EOS, ICCM, CBN, CMAM, UAP and PSNP. With the exception of the UAP and PSNP, all other large-scale programs were merged into the HEP service delivery package around 2008 when coverage increased further, albeit not uniformly.

Increased coverage the HEP and its various nutrition interventions in Amhara, Oromiya, and SNNP correlate with regional reductions in stunting. In the Somali region, the CBN program was not implemented, and thus reductions in stunting from 2005-2011 may be attributable to the coverage of the EOS and ICCM programs, and/or the general implementation of the HEP service package. As the sixteen component activities of HEP were rolled out simultaneously, it is difficult to speculate which components could have resulted in reductions in stunting. Associations between increased coverage of HEP and improved antenatal and postnatal care practices (Karim et al., 2013) may suggest that improvements to *in utero* growth and maternal nutrition status may have contributed to reductions in stunting. This contribution would likely be small, as optimal antenatal care practices increase from 12% to only 19% between 2005 and 2011 (Zachary et al., 2013).

Sustained coverage of the EOS and ICCM potentially affected stunting by reducing the incidence of diarrhea in children <5 years old, which decreased from 19.0% to 13.7% from 2005-2011 (CSA and ICF International, 2012, CSA and ORC Macro, 2006). The CMAM program, which provided outpatient and inpatient therapeutic feeding (among other services) to children with severe acute malnutrition, may have helped to reduce stunting. Though the last of the large-scale nutrition programs to start, the CBN scaled up rapidly and documented a reduction in stunting and improved feeding practices in Amhara, Oromiya, and SNNP (White and Mason, 2012).

Unlike Amhara, Oromiya, and SNNP, no improvement in stunting from 2005-2011 in Tigray was observed by the DHS or the evaluation of the CBN (White and Mason, 2012). Low participation in the CBN and low coverage of CMAM may explain the lack of a reduction in the prevalence of stunting in Tigray. However, the EOS and ICCM programs and HEP service package were implemented in Tigray, suggesting that stunting prevalence increased despite improvements in the health care system and greater access to supplementation, deworming, and TSF. It is unclear why reductions in stunting were not observed in Tigray but were observed in Somali.

The sanitary situation also improved substantially from 2005-2011 and is associated with stunting reduction (Woodruff et al., 2016); the proportion of households *without* a latrine decreased from 62% to 38% nationally and from 70% to 40% in rural areas (Zachary et al., 2013). The increased use of latrines is characterized primarily by increased use of pit latrines without slabs which are considered an *unimproved sanitation facility* (WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation., 2012). This increased coverage in sanitation facilities, although *unimproved*, is likely attributable, to expanded coverage of the UAP, CBN, and HEP which all promoted improved sanitation practices.

Need of evidence documenting program impact on stunting

Despite the numerous large-scale nutrition programs, there is limited evidence documenting the extent to which health and nutrition programs reduce stunting in Ethiopia. Ecologic relationships suggest that large-scale programs are contributing to stunting reduction, however, further evaluations and studies can help to identify the most-effective programs. Due to the multiple programs currently implemented, studies comparing the effectiveness and cost of individual programs can provide useful information to policy makers and program planners. Because of Ethiopia’s geographic diversity, however, studies comparing program interventions should be conducted in multiple settings as the determinants of stunting may vary by agro-ecologic zone. As the HEP is currently used as a delivery platform for multiple programs, “implementation science” studies could also provide invaluable information about how to increase program delivery and coverage.

Limitations

This study has notable limitations. First, such an ecologic analysis cannot provide strong evidence of causal relationships between stunting reduction and program implementation. To address this limitation, we have explored reports and studies examining the nutritional impact of large-scale studies. Secondly, our analysis focuses on *large-scale* health and nutrition programs only. There is a myriad of smaller-scale health and nutrition projects operating at the kebele and woredas levels, and regional reductions in stunting prevalence may have resulted from these projects. Including all small and medium-scale projects in such an analysis would not be feasible. Lastly, this review relies on available data of program coverage and impact which in many cases was not available or lacking. We also recognize that estimates of program coverage often do not reflect program "intensity" or "quality".

CONCLUSION

The national stunting prevalence decreased consistently between 2000-2005 and 2005-2011, but these reductions occurred in two different programmatic environments. Whereas reductions in the 2000-2005 period correlate both with regional improvements in household wealth, , reductions in 2005-2011 correlate with increased coverage the HEP program suite. From 2005-2011, the CBN and CMAM programs show the strongest ecologic associations and have supporting evidence from independent evaluations. The EOS interventions and the component activities of the HEP may also have contributed to reductions, but there is no clear evidence to support any impact on stunting reduction.

The large reduction in the national and regional stunting prevalence has only translated to relatively small reductions in the number of stunted children in Ethiopia, substantially improvements to child health and nutrition have not likely reduced the caseloads of existing programs designed to reduce malnutrition in children. Ecologic relationships suggest that large-scale programs are making an impact, however, and further impact evaluations can help to identify the most effective programs to help policy makers accelerate the reduction in the prevalence and number of stunted children in Ethiopia.

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CHAPTER 4

Growth status, inflammation, and enteropathy in young children in Northern Tanzania

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ABSTRACT

Reducing stunting is a key goal of the United Nations Sustainable Development Goals. Recent evidence suggests that enteropathy of the gut due to environmental conditions (i.e. environmental enteropathy; EE) in young children is negatively associated with linear growth. Using a case-control study design, we examined the potential determinants of stunting in stunted and non-stunted children 22-28 months of age. Potential determinants included inflammation biomarkers C-reactive protein, alpha-1-acid glycoprotein (AGP), and endotoxin core antibody (EndoCAb) measured in serum samples; enteropathy markers alpha-1-antitrypsin, neopterin, myeloperoxidase (MPO) measured in stools samples; and demographic, health, feeding, and household characteristics. We also explored the determinants of EE by testing associations of composite EE scores and individual biomarkers with potential risk factors.

Fifty-two percent of children (n=310) were found to be stunted, and mean HAZ was -1.22 (SD ±0.56) among non-stunted (control) children and -2.82 (SD ±0.61) among stunted (case) children. Child HAZ was significantly ($p<0.05$) and inversely associated with AGP, and child stunting was significantly associated ($p<0.05$) with low dietary diversity, severe household hunger, and absence of soap in the household. AGP and EndoCAb concentrations were also significantly higher ($p<0.05$) among children in households with no soap. Our study documented a seemingly localized cultural practice of young children (25%) being fed their dirty bathwater, which was associated with significantly higher concentrations of myeloperoxidase ($p<0.05$).

AGP showed the most consistent associations with child growth and hygiene practices, but fecal EE biomarkers were not associated with child growth. The lack of retrospective data in our study may explain the null findings related to fecal EE biomarkers and child growth.

INTRODUCTION

Stunted growth remains a public health challenge globally, and reducing childhood stunting has been identified as one of the six Global Nutrition Goals adopted by the World Health Assembly [1,2]. Many factors can affect child growth and result in stunting, including sub-optimal maternal health and nutrition status, inadequate home environment, inadequate complementary feeding, and clinical and subclinical infection [3].

The linkages between child growth and household-level water, sanitation and hygiene (WASH) facilities and practices are well established [4,5]. As an underlying mechanism, nascent research suggests that due to poor sanitation and hygiene practices, children are repeatedly exposed to toxins, compromising their gut function and nutrient absorption [6]. Caregiver hygiene and animal exposure [7] have been associated with intestinal enteropathy in children, and it has been observed that young children were repeatedly exposed to E. coli via consumption of contaminated water and the ingestion of soil and chicken feces [8].

Repeated exposure to toxins that results in inflammation and reduced surface area of intestinal villi is referred to as environmental enteropathy (EE). EE is considered a potential independent predictor of stunting that is not correlated with recent diarrhea [6], a health outcome commonly seen as a sequelae to poor sanitation and hygiene conditions. Moreover, research from multiple countries [9–11] has found associations between gut function and linear growth in children.

Examining the association between EE and linear growth is particularly relevant to Tanzania, as child growth has been previously associated with inadequate household sanitation there [12]. The prevalence of child stunting in children <5 years of age in Tanzania has consistently decreased in the past decade, from 44.3% in 2004, 42.0% in 2010, to 34.4% in 2015 [13–15]. Despite this reduction, the prevalence of stunting remains high according to World Health Organization (WHO) classifications [16]. According to the 2015-2016 Demographic and Health Survey (DHS), the national prevalence of stunting was highest (44.4%) among children 24-35 months of age [15].

The objectives of this study are threefold: 1) to assess the associations between stunting and indicators of inflammation, EE, and hygiene practices in young children; 2) to examine the associations between various inflammation and enteropathy biomarkers; and 3) to identify risk factors of EE.

METHODS

Study design

We designed a case-control study to compare inflammation and EE biomarkers against socio-demographic, health and hygiene characteristics between stunted children (cases) and non-stunted children (controls) living in the same communities. The case-control study was nested into the endpoint assessment of the Creating Homestead Agriculture for Nutrition and Gender Equity (CHANGE) impact evaluation – a trial examining the impact of an integrated nutrition intervention (including micronutrient powders (MNPs), homestead food production, and WASH and nutrition education) on child anemia and growth [17]. The CHANGE project aimed to improve child growth by supporting caregivers to adopt optimal child feeding practices and improved WASH practices through a behavior change approach and to adopt improved homestead food production (e.g. vegetable gardens and chicken rearing) through training and service provision. As part of the research design, MNPs were given to all children participating in the program as well as to a control group, with the original goal of reducing anemia levels in order to understand the ability of the integrated CHANGE package to maintain these, reduced anemia levels.

For the case-control study, participants were enrolled in January-February 2016 in the control areas of the CHANGE evaluation in which only a limited set of activities were implemented. Specifically, children in the control arm received anemia and malaria diagnosis and treatment during baseline and follow-up surveys of the CHANGE evaluation, which happened 18 months, 15 months and 6 months before recruitment into the case-control study. In addition, they received a two-month supply of micronutrient powders at the CHANGE baseline and 12-month follow-up surveys (i.e. when children were 6-12 months of age and then 18-24 months of age). No other activities (e.g., support for agriculture and livestock production or behavior change communication on WASH, nutrition, or malaria prevention) were organized as part of the CHANGE program in the control communities.

Data collection procedures

The case-control study recruited all children living in the 10 control wards (i.e. smallest administrative units) of the Sengerema District in Tanzania's Lake Zone who provided blood samples during the CHANGE endline assessment (i.e. those children who stayed in the CHANGE study throughout and gave blood samples during previous survey rounds); they had an age range of 22-28 months during the endline assessment. This design was expected to identify 128 cases and 192 controls (320 children in total), considering an expected stunting rate of 40% and an 80% response rate for stool samples, with a statistical significance level of 0.05 and power of 0.8. Based on the above assumptions, the target sample size would presumably allow the study to detect an odds ratio of 2 between stunted and non-stunted children with differing endotoxin exposures and other stool biomarkers that were considered clinically relevant a priori.

A comprehensive questionnaire was administered as part of the larger study to caregivers of enrolled children. Child's age was collected as part of the household questionnaire and further validated by confirming the birthdate listed on the child's health card and records from previous rounds of the CHANGE evaluation. The questionnaire also included information on household and individual demographic variables (e.g. age, sex), household food security, household WASH facilities and practices, maternal health and education characteristics, and infant and young child feeding (IYCF) practices.

Following the completion of the questionnaire, height and weight were measured from all children using portable wooden stadiometers (Infant/Child ShorrBoard®, Maryland, USA) and standing scales (Seca, 874 U, Hamburg, Germany). In preparation for the fieldwork, a height measurement standardization exercise was conducted, and only the best-performing nurses were hired.

Capillary blood samples were collected from each child's middle or ring finger by trained nurses. After the lancet puncture, the first two drops of blood were swiped with dry gauze, and the third and fourth blood droplets were used to measure hemoglobin concentration and malaria status. Following this, approximately 300-400µl of blood was collected into dry capillary blood collection tubes (Microvette® 300 Z, 20.1308; Sarstedt, Germany). Blood samples were kept cold (+1 to +4°C) and were centrifuged on the day of blood collection. After centrifugation and separation, the serum was frozen at -20°C.

Following blood collection, nurses provided pre-labeled stool sample containers, a clean plastic spoon, and paper to place below a child when defecating should the child not be wearing a diaper. Each child's caretaker was instructed to scoop approximately 100ml of stool directly from the child's diaper or from clean paper into the pre-labeled stool container directly after a child defecated, securely close the lid, and place the sample in a cool dark spot until it was collected. Three research assistants on motorbikes accompanied the nurses to the field and collected the stool samples the same day, such that the cold chain began 1 to 4 hours after the stool was passed. After collection, the stool samples were kept in cold boxes kept at (+4 to +8°C) until the samples were delivered to the NIMR's field laboratory in Sengerema where a slide for microscopy was prepared within 12-24 hours after the stool was passed and a 10-15ml aliquot of stool was frozen at -20°C.

Laboratory analyses - Blood

Hemoglobin concentration was measured onsite using a portable hemoglobinometer (Hb201+, HemoCue AB, Ängelholm, Sweden). Current and recent malaria status was assessed using a rapid diagnostic test (Standard Diagnostics, Malaria Ag P.f/Pan, Gyeonggi-do, Republic of Korea) with the ability to detect antigens from *P. faliciparum, P. vivax, P. ovale,* and *P. malariae.*

Three markers of systemic inflammation were measured in serum. C-reactive protein (CRP) and alpha-1-acid glycoprotein (AGP) were measured in duplicate at VitMin Lab laboratory (Willstaett, Germany) using the sandwich ELISA technique described by Erhardt *et al*. [18]. Single IgG endotoxin-core antibody (EndoCAb) concentrations were assessed using commercially available kits (Hycult Biotech Inc., Uden, The Netherlands) using a 1:400 dilution factor at the Laboratory of Human Nutrition of the ETH (Zurich, Switzerland). Approximately 15% of samples were measured in duplicate, and results showed high correlation (R^2=0.91).

Laboratory analyses - Stool

Analysis of stool biomarkers was conducted at NIMR Mwanza Laboratory (Mwanza, Tanzania). Commercial ELISA kits were used to measure concentrations of three biomarkers in stool samples: neopterin (NEO; GenWay Biotech, San Diego, USA), alpha-1-antitrypsin (AAT; BioVendor, Karasek, Czech Republic), and myeloperoxidase (MPO; Immundiagnostik, Bensheim, Germany). During the extraction process, NEO was diluted with 0.9% saline solution at a dilution factor of 50, and AAT and MPO were diluted with the manufacturer's dilution buffer at a dilution factor of 63.5. All aliquots were vigorously vortexed for 1 minute, centrifuged according to the manufacture's specifications, and 1ml of the resulting supernatant was then removed and frozen at -20°C. Following an initial screening for each biomarker, a second dilution step was conducted to yield concentrations within the standard curves. The final dilutions for NEO, AAT, and MPO were 1:500, 1:12,500, and 1:200, respectively. Of note, the NEO ELISA manufactured by Genway Biotech is only marketed for analysis of serum, plasma, and urine but has been repeatedly used by other researchers to measure NEO in stool [11,19].

For NEO, the interassay coefficient of variation (CV) was 21.2% and 14.3% for the low (target concentration: 5.7 ηmol/L) and high (target concentration: 18.8 ηmol/L) controls, respectively. The interassay CV for AAT was 4.1% for the low (target concentration: 8.3 ng/ml) and 6.4% high (target concentration: 26.2 ng/ml) controls. For MPO, the interassay CV was 14.9% for the low (target concentration: 6.9 ng/ml) and 5.9% high (target concentration: 26.4 ng/ml) controls.

Indicator definitions and cut-offs

CRP and AGP were used in tandem to capture the various stages of inflammatory response as defined by Thurnham *et al*. [20]. Incubation was defined as elevated CRP (>5mg/L) alone, early convalescence as elevated CRP and AGP (>1.0 g/L), and late convalescence defined as elevated AGP alone. Incubation, early convalescence, or late convalescence were defined as *any* inflammation, and no inflammation was defined as CRP ≤5 mg/L and AGP ≤1.0 g/L.

Weight and height measurements were used to calculate sex-specific height-for-age Z scores (HAZ) and weight-for-height Z scores (WHZ) according to the World Health Organization (WHO) Child Growth Standards [21]. Children with HAZ and WHZ scores < -2.0 were classified as stunted and wasted, respectively [22]. Hemoglobin concentration <110 g/L was used to define anemia [23] following a subtraction of 2 g/L hemoglobin to adjust concentrations for altitudes 1000-2000 meters above sea level [23].

Using questionnaire data collected within the CHANGE study, minimum dietary diversity for each child was calculated using WHO guidelines [24], though most of the children in our study are outside the age range (i.e. >24 months of age) recommended by WHO. Despite the age of most children in our study, dietary diversity is still likely a relevant indicator of dietary adequacy as it is often used in other population groups, such as women of reproductive age [25]. In addition, caretakers reported recent illnesses of the children in the past 2 weeks according to their own understanding of descriptions used by interviewers. Illnesses examined were watery diarrhea (i.e. "stool like water") and fever ("hot body"). Caretakers also reported when their child's hands were typically washed, and response options a) "after defecation", b) "before eating", and c) "frequently throughout the day" were used to determine if at least one of these key practices was employed. Caretakers also reported if the child was fed his/her own bath water a) anytime when the child was < 1 year of age, and b) anytime in the past month. The practice of feeding children their own bath water had been observed in the region during previous rounds of the CHANGE evaluation.

Interviewers observed the presence and type of sanitation facility at the household, using WHO/UNICEF criteria [26], and determined if the sanitation facilities were considered "improved" (i.e. flush to piped sewer system/septic tank/pit, ventilated improved pit latrine, pit latrine with a slab, composting toilet) or "un-improved" (i.e. pit latrine without slab, bucket toilet, hanging toilet, no facilities). Household food security in the past month was measured using the standard Household Food Insecurity Access Scale (HFIAS) classification into food secure, or mildly, moderately, or severely food insecure [27]. In addition to the HFIAS, the standard Household Hunger Scale (HHS), which captures more severe hunger-related behaviors [28], was calculated and separated in three categories (little to no hunger, moderate hunger, severe hunger) [29].

We constructed a composite "EE score" using the approach developed by Kosek *et al*. [11]. Using this approach, each child was assigned to a one of three categories based on their percentile for NEO, AAT, and MPO concentrations, "where AAT, MPO, and NEO categories were defined as 0 (< = 25th percentile), 1 (25–75th percentile), or 2 (> = 75th percentile)." [11] In addition, we developed and *expanded* EE score by incorporating the systemic inflammation markers EndoCAb and AGP into the equation developed by Kosek *et al*. (see equation below).

$$2 \times (AAT\ category) +\ 2\ \times (MPO\ category) + 2 \times (AGP\ category) + \\ 1 \times (MPO\ category) +\ 1 \times (EndoCab\ category) =\ Expanded\ EE\ score$$

Statistical analysis

For all indicators examined, measures of central tendency and variance were calculated for stunted and non-stunted children separately and compared. For normally-distributed variables, means and standard deviations were calculated, and the p-values expressing the difference between non-stunted and stunted children were calculated using ANOVA. P-values less than 0.05 were considered statistically significant. For non-normally distributed variables, the medians of each subgroup were compared using the Wilcoxon rank-sum test. For dichotomous and categorical variables, odds ratios and their respective confidence intervals (95%) were calculated [30]. Data analysis was conducted using Stata 14 (StataCorp, College Station, TX).

Ethics and consent

Ethical approval for the case-control study was received from the Lake Zone Ethics Committee (REF: MR/53/100/3) housed at the NIMR

Mwanza Center and IFPRI's Institutional Review Board (REF: 2016-7-PHND-M). Ethical clearance for the CHANGE study was obtained from Medical Research Coordinating Committee housed at NIMR headquarters in Dar es Salaam (REF: NIMR/HQ/R.8a/Vol.IX/1721) and IFPRI's Institutional Review Board (REF: 2014-PHND-12-M). A separate written informed consent statement was used to request consent to collect stool samples for the measurement of EE markers and to measure EndoCAb from serum samples collected for micronutrient biomarkers. This consent statement was read aloud in the local language to the child's caretaker, who gave consent on the child's behalf and agreed to collect the stool sample according to the procedures described by the nurse. To meet the requirements of NIMR's National Ethics Committee, a single dose of albendazole was given to all children who provided stool samples according to procedures described in Tanzania's public health policy [31].

Consent forms were stored in a locked cabinet categorized per NIMR's standardized filing and storage procedure. Stool sample data contained no identifying information.

RESULTS

Inflammation, enteropathy, and other potential risk factors of stunting

Complete questionnaire, anthropometry, blood biomarker, and stool biomarker data was available for 310 children. Fifty-two percent of children were found to be stunted, and mean HAZ was -1.22 (SD ±0.56) among non-stunted (control) children and -2.82 (SD ±0.61) among stunted (case) children. Mean WHZ was significantly lower (p=0.016) in stunted children compared to non-stunted children.

As shown in Table 1, no significant differences were found between median concentrations of CRP and AGP in non-stunted and stunted children. Similarly, there was no significant difference in the median EndoCab, NEO, AAT, and MPO concentrations between non-stunted and stunted children. While there were no significant differences in hemoglobin concentration, the prevalence of anemia was significantly (p=0.016) higher in stunted children. We found no difference in malaria prevalence or recent diarrhea and fever between non-stunted and stunted children.

Nearly all children (96.7%) received MNPs in the six months preceding the survey. Nearly half of all children had a minimum diverse diet in the 24 hours before the survey, but the proportion of non-stunted children (54.4%) receiving a minimum diverse diet was significantly higher than that of stunted children (42.5%; p=0.037). Regarding handwashing, nearly all caretakers reported washing their children's hands at least once throughout the day, with no significant difference between stunted and non-stunted children. Washing a child's hands before eating (78.5% non-stunted; 83.9% stunted, NS) and after defecation (47.1% non-stunted; 53.5% stunted, NS) were the most frequently reported handwashing practices; only 5.0% and 7.1% of caretakers of non-stunted and stunted children reported washing a child's hands frequently throughout the day. No individual handwashing practice was significantly associated with stunting status (data not shown). Approximately 25% and 40% of children were fed their own bathwater in the past month and when less than 1 year old, respectively. There was no statistically significant difference in the proportion of non-stunted and stunted children fed their own bathwater.

The number of household members and a household's classification as experiencing severe food insecurity in the past month were not associated with stunting. Severe household hunger, although only affecting a small proportion of households, and was statistically significantly higher (p=0.045) in the households of stunted children. Only 7% of households had an "improved" sanitation facility, and no statistically significant difference in the proportions of any sanitation facility or improved sanitation facility was observed for non-stunted and stunted children. More than half of the households possessed soap, and soap ownership was significantly more frequent in the homes of non-stunted children. Possession of soap was also significantly associated with lower odds of stunting (OR = 0.61; 95% CI: 0.38, 0.96; data not shown). Of note though, only 2.3% of households had a fixed station for handwashing (data not shown), with no statistical difference between cases and controls. Ascaris helminthes were very rare: they were found in only four children, all of whom were stunted (data not shown).

Table 1. Inflammation, enteropathy, and other risk factors for stunting among non-stunted and stunted children 22-28 months of age

Indicator	Non-stunted children (n=149)	Stunted children (n=161)	P-value§
Inflammation and enteropathy biomarkers			
CRP (mg/L); median, (IQR)	1.3 (0.5, 5.8)	1.4 (0.6, 3.5)	0.932
AGP (g/L); median, (IQR)	1.1 (0.8, 1.7)	1.3 (0.8, 2.1)	0.119
EndoCab (GMU/mL); median, (IQR)	100.2 (57.0, 150.0)	89.2 (60.8, 152.8)	0.799
NEO (nmol/L); median, (IQR)	609.0 (338.5, 1015.5)	585.0 (334.5, 1048.0)	0.701
AAT (mg/g); median, (IQR)	0.15 (0.03, 0.33)	0.18 (0.7, 0.39)	0.147
MPO (ng/mL); median, (IQR)	1340.8 (346.0, 4756.8)	1614.0 (368.0, 4483.8)	0.656
Child demographic characteristics			
Female child; %	49.7	46.6	0.588
Age in months; mean, (SD)	25.2 (±1.4)	25.4 (±1.4)	0.263
Caregiver age in years; mean, (SD)	30.9 (±8.6)	29.6 (±9.7)	0.189
Child health characteristics			
Hemoglobin (g/L); mean, (SD)	107 (±13)	105 (±15)	0.131
Anemia; %	53.0	66.5	**0.016**
Malaria parasitemia; %	17.3	21.6	0.356
Watery diarrhea in past 2 weeks; %	2.0	4.9	0.161
Fever in past 2 weeks, %	47.8	44.9	0.639
WHZ; mean, (SD)	0.37 (±1.00)	0.10 (±0.95)	**0.017**
Child feeding characteristics			
MNPs in past 6 months; %	95.9	97.5	0.443
Minimum dietary diversity; % *	54.4	42.5	**0.037**
At least 1 handwashing practice, %	90.0	94.8	0.115
Child fed own bathwater in past month; %	27.5	23.6	0.431
Child fed own bathwater when child was <1 year old; %	39.6	40.4	0.889
Household characteristics			
Number of members; mean, (SD)	7.0 (±2.6)	6.8 (±2.07)	0.459
HFIAS - Severely food insecure; %	42.9	45.0	0.706
HHS - Severe hunger; %	1.4	5.6	**0.045**
Improved sanitation facility; %	8.1	6.8	0.682
Any sanitation facility; %	72.1	71.9	0.964
Soap present; %	67.1	55.3	**0.033**

§ P-value represents Mann-Whitney test for comparisons of medians, Pearson's chi square for dichotomous variables, and ANOVA for continuous variables.

* Measured in children outside the age range recommended by WHO [24].

AGP = alpha-1-acid glycoprotein, AAT = Alpha-1-antitrypsin, CRP = C-Reactive Protein, EndoCAb = IgG endotoxin-core antibody; NEO = Neopterin, MPO = myeloperoxidase; HFIAS = household food insecurity and access scale; HHS = household hunger scale; WHZ= weight-for-height Z score.

Table 2 presents the pairwise correlations between HAZ and all inflammation and enteropathy biomarkers. Only AGP was statistically significantly and negatively associated with HAZ (i.e. lower AGP concentrations are associated with higher HAZ). Amongst inflammation markers, positive and statistically significant associations were found between CRP and AGP, AGP and EndoCAb, and MPO and AAT.

Elevated CRP and elevated AGP were common, affecting approximately 20% and 58% of children, respectively. About 60% of children had elevated CRP and/or AGP (i.e. any inflammation), and there was a nearly complete overlap of elevated CRP and AGP; only about 2% of children had elevated CRP without elevated AGP.

As shown in Table 3, the proportions of non-stunted and stunted children with elevated inflammation and EE biomarkers and higher EE scores were similar. For inflammation and enteropathy biomarkers, the confidence intervals of the odds ratio consistently crossed 1.0, illustrating no significant differences between non-stunted and stunted children.

Table 2. Spearman pairwise correlation coefficients for HAZ and inflammation and enteropathy markers in children 22-28 months of age

	HAZ	CRP	AGP	EndoCAb	NEO	AAT	MPO
HAZ	1.00						
CRP	0.04	1.00					
AGP	-0.14 *	0.50 *	1.00				
EndoCAb	-0.04	0.06	0.23 *	1.00			
NEO	0.07	-0.07	-0.08	0.02	1.00		
AAT	0.05	-0.05	0.02	-0.03	0.00	1.00	
MPO	0.03	-0.03	-0.01	0.05	0.11	0.26 *	1.00

* Indicates significance at p<0.05
HAZ = Height-for-age Z score, CRP = C-Reactive Protein, AGP = alpha-1-acid glycoprotein, EndoCAb = IgG endotoxin-core antibody; lnEndoCAb = natural log of IgG endotoxin-core antibody, NEO = Neopterin, AAT = Alpha-1-antitrypsin, MPO, myeloperoxidase.

Table 3. Inflammation and enteropathy biomarkers for non-stunted and stunted children 22-28 months of age

Characteristic	**Non-stunted n (%)**[§]	**Stunted n (%)**[§]	**OR (95% CI)**
Systemic inflammation			
Elevated CRP	38 (25.7)	33 (20.5)	0.75 (0.44, 1.27)
Elevated AGP	83 (56.1)	96 (59.6)	1.15 (0.74, 1.82)
Any inflammation (elevated CRP and/or AGP)	89 (59.7)	98 (60.9)	1.05 (0.66, 1.65)
Thurnham inflammation categories			
No inflammation	60 (40.3)	63 (39.1)	Reference
Incubation (Elevated CRP only)	5 (3.3)	2 (1.2)	0.38 (0.07, 2.07)
Early convalescence (Elevated CRP & AGP)	34 (22.8)	31 (19.3)	0.87 (0.47, 1.59)
Late convalescence (Elevated AGP only)	50 (33.6)	65 (40.4)	1.24 (0.74, 2.07)
Elevated EndoCab; >median 92.4 GMU/mL	77 (53.5)	72 (45.5)	0.73 (0.46, 1.15)
Enteropathy			
Elevated NEO; >median of 587.5 nmol/L	69 (51.5)	64 (48.1)	0.87 (0.54, 1.41)
Elevated AAT; >median of 0.15 mg/g	64 (48.5)	74 (52.2)	1.16 (0.72, 1.87)
Elevated MPO; >median of 1591.7 ng/mL	50 (46.3)	63 (51.6)	1.24 (0.73, 2.08)
Kosek EE Score; >median of 5	33 (33.0)	38 (35.8)	1.13 (0.64, 2.02)
Expanded EE Score; >median of 7	33 (34.0)	38 (36.9)	1.13 (0.63, 2.02)

[§] Note: The n's are numbers of those exposed to the characteristic in each subgroup

Risk factors of inflammation and enteropathy

Table 4 presents associations between the potential risk factors of inflammation or enteropathy and the *EE score* and *Expanded EE Score*, showing that no statistically significant differences were found for any health, feeding, or hygiene characteristics. We also measured the associations between the same risk factors and individual inflammation and enteropathy indicators (i.e. CRP, AGP, AAT, NEO, MPO) and found significantly higher concentrations of a) AGP (p=0.015) and EndoCAb (p=0.018) in children from households without soap; b) AGP (p=0.028) in children with fever in the past two weeks; c) NEO (p=0.031) in children without minimum dietary diversity; and d) MPO (p=0.039) in children who were fed their bathwater in the past month (data not shown).

Table 4. Mean enteropathy scores by various risk factors of inflammation and enteropathy in children 22-28 months of age

Indicator	**Mean Kosek EE score**		**P Value[§]**	**Mean Expanded EE score**		**P Value[§]**
Characteristic (No / Yes)	**No**	**Yes**		**No**	**Yes**	
Child health characteristics						
Fever in past 2 weeks	4.8	4.6	0.601	7.8	7.6	0.642
Watery diarrhea in past 2 weeks	4.8	4.8	0.945	7.8	7.6	0.944
Child feeding characteristics						
Minimum dietary diversity*	4.7	4.8	0.837	7.9	7.7	0.633
Child fed own bathwater in past month	4.8	4.6	0.624	7.7	7.8	0.927
Child fed own bathwater when child was <1 year old	4.9	4.6	0.3631	7.8	7.7	0.794
Hygiene characteristics						
Improved sanitation facility	4.8	5.5	0.145	7.7	8.6	0.157
At least one handwashing practice	4.8	4.8	0.936	7.7	7.8	0.939
Soap present	4.6	4.9	0.497	8.0	7.6	0.298

[§] P-value represents ANOVA test for continuous variables

* Measured in children outside the age range recommended by WHO [24].

DISCUSSION

Child growth and inflammation and enteropathy

Our study found a significant negative association between AGP and HAZ, indicating that chronic inflammation is negatively associated with child growth. Other studies have observed similar associations; a recent publication Merrill *et al*. [32] found consistent associations between elevated AGP and the odds of stunting in children 6-59 months of age residing in Sub-Saharan African countries. Similarly, a publication of the MAL-ED project [33], which investigates the associations between child growth and EE among children 3-20 months of age in multiple countries, found significant associations between AGP and growth in early childhood. Moreover, the authors concluded that "evidence for the association with reduced linear growth was stronger for systemic inflammation than for gut inflammation" [33].

Unlike AGP, elevated CRP concentrations were not associated with child growth or stunting in our study. This lack of association is likely explained by the fact that elevated CRP concentrations capture acute inflammation, which relates principally to recent illnesses and likely serves as a poor proxy for repeated illnesses at early ages. Prendergast *et al*. [34] observed that CRP and AGP concentrations were significantly higher in Zimbabwean stunted children from 6 weeks to 12 months of age, however by 18 months of age there was no difference in CRP and AGP concentrations between non-stunted and stunted children. This finding suggests that acute and chronic inflammation may have a larger impact on child growth during infancy and young childhood compared to when children are older (e.g. > 2 years). This is supported by Merrill *et al.* [32], who observed that the odds of having elevated AGP were significantly lower in children 36-59 months compared to children 12-23 months. Although Merrill *et al.* found few associations between child age and stunting when age was measured as a continuous variable, this categorical analysis suggests that age likely has a modifying effect on the association between AGP and stunting.

Our study found no significant association between child growth and EndoCab. EndoCab is an antibody produced in response to exposure to lipopolysaccharide – a component of the cell wall of gram negative bacteria – following its translocation of the musocal lining of the intestinal wall [35]. As such, EndoCab has been suggested as a potential indicator of EE [36]. However, the current evidence examining the association between EndoCab and stunting or child growth is mixed: Campbell *et al*. observed significant associations between EndoCab concentrations and child growth and intestinal permeability (measured using lactulose:mannitol ratio) in Gambian children 1-16 months of age [9]. Other researchers [10,37] found an association of EndoCab and growth in Gambian children below 2 years of age, whereas no associations between EndoCab concentrations and child growth were found in Malawian children aged 24-59 months [37] or Bangladeshi children 10-48 months of age [10]. Significant associations in studies including only children less than 2 years, compared to the older age of children in this study, may suggest that EndoCab, similar to AGP, is more closely associated with growth in young children. The mediating affect of age on the association between inflammation and growth may be due to the fact that the period of rapid growth from 6-23 months of age is accompanied by repeated and increased exposure to environmental pathogens, as children consume complementary foods that are potentially prepared in un-hygienic conditions and become more mobile and come into greater contact with their environment [32,38]. During this period of increased exposure to environmental pathogens, a child's adaptive immune system gradually matures, which influences a child's inflammatory response to infections [39,40].

Contrary to other evidence, our study found no significant association between stunting or child growth status and fecal EE biomarkers or composite EE scores. To illustrate, Kosek *et al*. measured NEO, AAT, and MPO in children at either 3, 6, or 9 months of age in eight countries and found that children with the highest EE scores grew about 1 centimetre less than children with the lowest EE scores in the 6 months following the last measurement (i.e. at either 9, 12, or 15 months of age) [11]. The ability of Kosek *et al*. to clearly detect a relationship may be partly due to the longitudinal study design, the ability to control for incidence of diarrhea, and the fact that all subjects were within the typical window of growth faltering (i.e. <24 months of age) [41].

In addition to differences in study design and subject age, our study observed relatively low concentrations of EE biomarkers compared to other studies. Kosek *et al*. observed median NEO, AAT, and MPO concentrations of 1,847 nmol/L, 0.44 mg/g, and 11,118 ng/mL, respectively [11], across eight countries. In Bangladesh, George *et al* observed median NEO, AAT, and MPO concentrations of 1,506 nmol/L, 0.26 mg/g, and 3,577 ng/mL, respectively [19]. It is not clear why our study observed lower fecal EE concentrations than these other studies. The implementation of a stringent cold chain during field collection undoubtedly prevented degradation. However, our study provided caretakers with simple plastic stool containers and not containers with a catalyst (e.g. Anaerocult®, AnaeroGen™) to produce an anaerobic environment for the sample. Thus, some degradation of proteins between defecation and collection by field staff could have occurred. That said, Kosek *et al*. [11] and George *et al*. [19] did not report using anaerobic catalysts as part of their stool collection, so our collection methods appear to closely match theirs.

Low concentrations of fecal EE biomarkers are surprising considering the sub-optimal household sanitation conditions and the fact that nearly all children consumed MNPs containing iron in the 6 months prior to data collection. Jaeggi *et al*. [42] found that consumption of MNPs with iron increased levels of enterobacteria and fecal calprotectin concentrations in children 6-10 months of age. Further research in northern Tanzania is required to identify why fecal EE biomarkers are lower than in other locations, as is it clear that the suboptimal sanitation and feeding practices would suggest that fecal EE markers should be high.

Household possession of soap

Presence of soap at the household level was the sole indicator related to hygiene and sanitation that was significantly associated with stunting and inflammation and EE indicators (i.e. AGP and EndoCAb). These findings are likely explained as regular handwashing with soap can prevent contamination of food stuffs and transmission of pathogens [43]. While there is little data examining the linkages between handwashing and EE, a recent study in Bangladesh found that children 0-30 months of age were more likely to have elevated levels of fecal calprotectin – a marker of gut inflammation – when their caretaker had visibly soiled hands [7]. A recent study from India also found the risk of stunting in children 0-23 months of age was significantly lower for caregiver's self-reporting washing hands with soap before meals or after defecation [44].

Notably, these studies observed linkages with caretaker hand hygiene rather than the child's hand hygiene; our study only collected information related to caretaker hand-washing practices. Notably, our study found a higher proportion of caretakers reporting washing their child's hands before eating and after defecation than those possessing soap. This suggests that, in some instances, caretakers wash their child's hands without soap. Furthermore, the CHANGE study's 2014 WASH formative research report [45], in which data was collected through systematized caretaker and child observation of sanitation and hygiene practices in Tanzania's Sengerema and Ukerewe districts prior to the project being implemented, reported that soap was primarily used for washing dishes, washing clothes, and bathing of adults and children. The report also noted that hand washing is not often practiced before eating but only after eating to clean food and oil from one's hands.

While household ownership of soap may serve as an accurate proxy for washing dishes and clothes – activities that are routinely practiced on a daily and weekly basis – it may not be a suitable proxy for caretaker or child bathing. Daily bathing of Nepali children 0-59 months of age has been shown to reduce the odds of underweight [46], but no other studies could be found. As bathing frequency of child and caretaker can be considered a strong proxy of general hygiene practices, future studies examining the determinants of stunting should consider collecting this information and examining associations with child growth.

Dietary diversity and household hunger

Our study found significant associations between dietary diversity and stunting. Of note, the proportion of children in our study with minimum dietary diversity (54% in non-stunted children; 42% in stunted children) was notably higher than that reported in the 2015-16 DHS for children 6-23 months of age (i.e. 26%) [15]. This difference was likely explained by the higher age of our study population. Previous findings from multi-country analyses suggest that dietary diversity is associated with linear growth. A pooled analysis of DHS data from 14 countries (including Tanzania) conducted by Marriot *et al.* [47] found that children 6-23 months of age with minimum dietary diversity were less likely to be stunted but only among children whose caretakers had completed higher levels of education (i.e. secondary school or greater). In another pooled analysis of 21 countries (not including Tanzania), Onyango *et al*. found that 12 countries had significant associations between dietary diversity and linear growth in children 6-23 months of age [48].

Regarding households hunger and food security, we found that of the two household-level scores, HFIAS and HHS, the stunting prevalence was significantly higher only for children in households reporting a HSS in the 'severe' category. Due to the low proportion of children residing in households with severe household hunger, its contribution to the high stunting prevalence observed is minimal. Differing associations between HFIAS and HHS can be explained by the fact that they capture different dimensions of food insecurity. According to Maxwell *et al*. [28] " ... the HHS measures the most extreme consequences of food insecurity, while the HFIAS captures a greater range of the food security spectrum." Conversely, Psaki *et al.* [49] observed a significant relationship between HFIAS and HAZ but not HHS and HAZ. Thus, future studies examining the determinants of child growth should consider using both measures of household food insecurity as the influence of each indicator on child growth may vary depending on the local context.

Drinking bathwater and geophagy practices

Our study documents, for the first time, a seemingly infrequent cultural practice whereby children were fed their bathwater after being bathed. Little is known about the rationale for this practice, the authors could not find any documentation of this practice in scientific literature, and this practice was not considered in the CHANGE study's 2014 formative research [45]. It is possible that feeding bathwater is practiced to protect children against pathogenic bacteria and other toxins and could thus relate to geophagy, a practice of soil eating. A 2011 review of geophagy practices [50] postulates that the practice of eating soil is most commonly a preventive approach to "inhibit parasites" and other toxins and notes that geophagy is most common among pregnant women [50]. In Tanzania, a study of pregnant women in Dar es Salaam found that 29% of subjects regularly consumed soil [51], and a study on Pemba Island found that 6% of women consumed soil and that consumption of soil was not associated with increased helminth infection (i.e. Ascaris, Trichuris or hookworm) [52]. The practice of eating earthy substances in humans can also be performed to augment a scanty or mineral-deficient diet or as part of a cultural tradition, but this cannot be said of drinking bathwater.

In contrast to research related to pregnant women, there are few studies that examine this practice in children. Though unclear, the practice of feeding a child his/her dirty bathwater appears to be a practice localized to Tanzania's Lake Zone. While feeding a child bathwater in the past month or at any time when the child was <1 year of age was not associated with stunting or growth status in the population, a bathwater feeding in the previous month was linked to higher MPO concentrations and thus likely contributes to EE in children. Additional research is needed to understand the rationale behind this practice, which could likely pose health risks to infants and young children as dirty bathwater likely contains soil, feces, and potentially toxins. In addition, understanding this practice is important for government and local organizations as feeding children bathwater may undermine interventions in stunting reduction programs.

Limitations

We acknowledge that our study has a few notable limitations. First, our case-control study did not contain retrospective information on EE status, and thus we used current EE status as a proxy indicator of previous exposure. As such, we were unable to measure EE during periods of typical growth faltering when children are between 6 and 24 months of age. Second, the age of our subjects was mostly outside the window of growth faltering. Thus, our study assumed that enteropathy at 22-28 months of age served as an adequate proxy for enteropathy during periods of more intense growth faltering. To address this, future case-control studies should be conducted in younger children (e.g. 6-18 months of age) to determine if enteropathy (measured cross-sectionally) is associated with child growth during the beginning and middle stages of growth faltering. Thirdly, though we measured the presence of ascaris helminths, we were unable to measure hookworm, which may be more common in Tanzania's Lake Zone [53]. Examining hookworm infection requires that stool sample smears are prepared within 1 hour following the stool's passing since hookworm eggs deteriorate quickly [54].

CONCLUSION

This study used a case-control design to examine the potential determinants of stunting in stunted and non-stunted children 22-28 months of age in Tanzania’s Lake Zone, with a focus on inflammation and EE markers. The results showed that chronic inflammation, measured by elevated AGP, was significantly associated with child growth. Household possession of soap was associated with higher HAZ and lower concentrations of inflammatory biomarkers. Ownership of soap likely had protective effects on child growth by reducing exposure to bacteria and pathogens that may have resulted in inflammation and EE. While no significant association was observed between EE and growth, this may be due to the non-retrospective nature of the study and the fact that most children were outside the age of typical growth faltering.

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CHAPTER 5

Conclusion

This thesis identified a myriad of factors associated with stunting and stunting reduction. Notably, this thesis highlights that the risk factors of stunting vary by age, and suggests that risk factors related to sanitation and sub-clinical inflammation are more strongly associated with stunting than dietary factors.

Stunting and child age

The manuscript examining stunting and stunting reduction in Ethiopia added to the relatively sparse data examining factors related to stunting in children 0-5 months for age. Strikingly, relatively few factors are associated with HAZ in this age group, and HAZ was not statistically significantly related to variables measuring child feeding, child morbidity, perinatal care, mother's health (except height), parent characteristics, household characteristics (except wealth index), or environmental sanitation and hygiene.

In general, our analysis from Ethiopia revealed few direct points for potential interventions to prevent future stunting in children 0-5 months of age. Nonetheless, the strong association between HAZ and birth size and maternal height – slowly-changing indicators of women's nutritional status at the population level – may indicate that maternal and ante-natal interventions could increase fetal growth and thus lead to higher birth weight and greater linear growth in the first half of infancy and perhaps later in a child's life.

Some of the risk factors of stunting are readily "modifiable", and could likely be addressed in the near term, whereas other factors, such as maternal education, may be "modifiable" but would take much longer to improve substantially. Still other risk factors, such as child sex, child age, and the age and sex of household head, are not modifiable at all and cannot be addressed by interventions.

Compared to children 0-5 months of age, more household factors are associated with HAZ in children 6-23 months of age. The factors that are modifiable by public health interventions are consumption of non-human milk, mother's use of modern contraception, and mother's height and BMI. Many other direct measures of child feeding behaviors, however, did not exhibit a statistically significant association with HAZ, including ever breastfeeding, early initiation of breastfeeding, drinking from a bottle with a nipple, dietary frequency, dietary adequacy, eating vitamin A rich foods, and consumption of iodized salt.

In children 24–59 months of age, the list of variables significantly associated with HAZ is even longer than in younger children. Like younger children, estimated size at birth, child's WHZ, and mother's height and BMI remain significantly associated with HAZ. On the other hand, unlike in younger children, various measures of child morbidity and household composition are associated with HAZ, such as diarrhea, respiratory infections, the prevalence of open defecation.

Overall, only a few variables are associated with HAZ in all age groups; these include child's WHZ, child's estimated size at birth, mother's height, and household wealth index. Most of these variables are, however, not modifiable by short-term public health interventions. Modifiable variables may be age-specific. Thus, program planners and managers should be sensitive to the fact that interventions may have effects on some age groups and not others.

Chronic inflammation, enteropathy, and child growth

The results of the case-control study conducted in Tanzania related to chronic inflammation – measured using AGP – corresponded to the those found in other studies. Nonetheless, the research exploring the linkages between in sub-clinical inflammation and child growth is nascent, and should be explored further.

However, the findings in this study related to environmental enteropathy (EE) do not corroborate the findings of other studies [1,2]. As with sub-clinical inflammation, the literature exploring the associations between EE and stunting is limited. Further studies should be conducted to build the evidence base.

Modifiable risk factors in the near term

Household and community level sanitation and hygiene was a consistent risk factor of stunting, and improvements in sanitation and hygiene were associated with lower levels of stunting. These findings are similar to those found in other countries. In the WHO Stunting Framework, WASH factors and infection occur in nearly all sections of the Framework, illustrating the multiple pathways by which poor WASH conditions impair child growth.

Although the prevalence of open defecation substantially declined in Ethiopia since 2000, the majority of latrines used in Ethiopia are pit latrines without slabs, which are classified as unimproved by WHO and UNICEF [3]. This illustrates that shifting from open defecation to unimproved sanitation facilities can reduce stunting and suggests that increased coverage of improved sanitation facilities may result in additional reductions in stunting prevalence by further preventing diarrhea and EE.

The use of soap at the household level is also a viable strategy to reduce stunting by limiting the exposure of children to pathogens. In the case-control study conducted in Tanzania, the presence of soap at the household level was the sole indicator of hygiene and sanitation that was significantly associated with stunting, inflammation and EE indicators (i.e. AGP and EndoCAb). These findings are likely explained as regular handwashing with soap can prevent contamination of food stuffs and transmission of pathogens [4]. While reductions in stunting in Ethiopia have followed WASH programs promoting handwashing with soap [5], there is little data examining the linkages between handwashing and EE. A recent study in Bangladesh found that children 0-30 months of age were more likely to have elevated levels of fecal calprotectin – a marker of gut inflammation – when their caretaker had visibly soiled hands [6]. A recent study from India also found the risk of stunting in children 0-23 months of age was significantly lower for caregiver's self-reporting washing hands with soap before meals or after defecation [7].

In addition to WASH programs, interventions that improve mother's health and nutrition could likely be used as "near-term" strategies to reduce stunting by improving fetal growth and care giving practices during infancy and early childhood.

It is notable that modifiable variables may be age-specific, and we found that risk factors of stunting change with age [8]. Thus, program planners and managers should be sensitive to the fact that interventions may have effects on some age groups and not others.

Modifiable risk factors in the long term

Maternal education and access to health care were repeatedly identified as risk factors of stunting, and improving these factors may be an effective long term strategy to reduce stunting.

Our analysis in Ethiopia found that maternal education was associated with child growth, and other studies in Ethiopia have documented the association between caregiver education and stunting [9,10]. As low maternal education likely contributes to stunting by affecting caring practices [11], expanding access of primary and then secondary education to women can likely help to reduced stunting in the long-term by modulating caring practices. Access to primary education to girls throughout Ethiopia increased following the elimination of school fees for primary education in 2002 [12], and thus this investment in education may have contributed to the reduction in stunting, particularly in younger women. However, for children 24-59 months of age, we found HAZ was highest in children of mothers more advanced (i.e. secondary school or higher) education. Thus, it can be anticipated that public policies that expand access of primary and secondary school to girls in the near term can contribute to stunting reduction in the future.

Our analysis in Ethiopia observed that use of modern contraceptives was associated with stunting reduction. In Ethiopia, because the HEP is the major provider of contraceptive services [13], the use of contraception may reflect access to and use of this program which provides other health and nutrition services which may have played a role in ameliorating stunting [14]. Moreover, increased coverage of the HEP and its various nutrition interventions in Ethiopia's Amhara, Oromiya and SNNP regions correlate with regional reductions in stunting between 2005 and 2011 [14], before the HEP was implemented at full scale. In addition, the use of modern contraceptives may lead to increased birth spacing and reduced parity. The expansion of Ethiopia's HEP occurred over a 10-15 years period, and a similar expansion of health and nutrition services in other countries should be considered as a long term approach to expanding health care access and reducing stunting.

Research gaps

This thesis identified notable gaps in the literature on stunting and child growth. First, the studies conducted as part of this manuscript employed either cross-sectional or ecologic analyses. In Ethiopia, much of the literature reviewed used similar study designs, which limits the interpretation of the results. To address the limitations of the stunting literature in general, nutrition researchers in Ethiopia and elsewhere should investigate the determinants of stunting using longitudinal cohort studies that examine children at multiple times from birth to five years of age. Future studies should examine factors often absent from DHS surveys (e.g. household food security, dietary intake, participation in nutrition and health programs, micronutrient and inflammation status) to identify factors directly associated with and preceding growth faltering. Moreover, the greater control inherent in collecting data as part of such a study would reduce random measurement error in key variables, such as feeding indicators.

Secondly, despite the numerous large-scale nutrition programs, there is limited evidence documenting the extent to which health and nutrition programs reduce stunting in Ethiopia, Tanzania, and other countries. Ecologic relationships suggest that large scale programs are contributing to stunting reduction; however, further evaluations and studies can help to identify the most-effective programs. Because of the multiple programs often implemented simultaneously in developing countries, studies comparing the effectiveness and cost of individual programs can provide useful information to policy makers and program planners. Due to geographic and demographic diversity found in developing countries, however, studies comparing program interventions should be conducted in multiple settings as the determinants of stunting in each locale will likely vary.

Thirdly, additional research examining the association between chronic inflammation and stunting is required. Although the case control study in Tanzania and other studies [15] have identified a significant association between elevated AGP and stunting, there is little research exploring interventions to reduce inflammation in children. To illustrate, there is little data examining the linkages between handwashing and chronic inflammation or EE.

Lastly, the review paper of the WHO stunting framework found sparse literature related to stunting and feeding practices implemented during and after illness. As the impact of certain dietary patterns may be modulated by child age, future research on this topic should explored on various age groups in children 0-59 months of age, to ascertain which programs are the most effective for a given target age group.

Closing statement

To achieve global stunting reduction targets, national policy makers and program planners must first identify the country-specific determinants of stunting if these have not already been elucidated. Additional analyses of existing data sources, such as DHS, can often be used to identify key determinants of stunting. And in combination with studies specifically designed to explore the association of various biomarkers on stunting, an understanding of the context-specific factors contributing to stunting can be revealed. Secondly, program planners should use a multi-pronged approach to reduce stunting, as nutrition-specific interventions alone are unlikely to sufficiently reduce stunting. Programs designed to improve WASH facilities and practices, in particular, should be pursued as improving WASH conditions can – in many contexts – contribute to reductions in stunting. Moreover, WASH interventions will likely have more near-term benefits and can help to reduce the prevalence and caseloads of stunting in the next 8 to 13 years, by when global targets set by WHA and SDGs will be measured.

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