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REVIEW

Review of the importance of nutrition during the first 1000 days: maternal nutritional status and its associations with fetal growth and birth, neonatal and infant outcomes among African women

S. V. Wrottesley[1]*, C. Lamper[1,2] and P. T. Pisa[1]

[1]*MRC/Wits Developmental Pathways for Health Research Unit, Department of Paediatrics, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa*
[2]*Radboud University` Medical Center, Nijmegen, The Netherlands*

Maternal nutritional status (MNS) is a strong predictor of growth and development in the first 1000 days of life and may influence susceptibility to non-communicable diseases in adulthood. However, the role of nutrition during this window of developmental plasticity in Africa is unclear. This paper reviews published data to address whether maternal nutrition during the first 1000 days is important for Africa, with a focus on MNS and its associations with fetal growth and birth, neonatal and infant outcomes. A systematic approach was used to search the following databases: Medline, EMBASE, Web of Science, Google Scholar, ScienceDirect, SciSearch and Cochrane Library. In all, 26 studies met the inclusion criteria for the specific objectives. MNS in Africa showed features typical of the epidemiological transition: higher prevalences of maternal overweight and obesity and lower underweight, poor diet quality 1 and high anaemia prevalence. Maternal body mass index and greater gestational weight gain (GWG) were positively associated with birth weight; however, maternal overweight and obesity were associated with increased risk of macrosomia and intrauterine growth restriction. Maternal anaemia was associated with lower birth weight. Macro- and micronutrient supplementation during pregnancy were associated with improvements in GWG, birth weight and mortality risk. Data suggest poor MNS in Africa and confirms the importance of the first 1000 days as a critical period for nutritional intervention to improve growth, birth outcomes and potential future health risk. However, there is a lack of data beyond birth and a need for longitudinal data through infancy to 2 years of age.

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Introduction

Nutrition, among other factors, seems to be one of the pivotal drivers and determinants of maternal and child health. Maternal nutritional status (MNS) has been shown to be an important predictor of maternal health,[1–5] fetal growth,[1,6,7] birth outcomes[6,8–10] and infant growth[10] in both high-income countries (HICs) and low- and middle-income countries (LMICs). However, the association between maternal nutrition and these multifaceted outcomes is complex and is influenced by many other factors, including genetic, socio-economic and demographic variables that differ greatly between populations.[3,11] Increased prevalence of non-communicable diseases (NCDs) in LMICs, including Africa, is attributed mainly to the epidemiological health transition. Poor maternal and child health has been associated with increased risk of NCDs, including obesity, type 2 diabetes mellitus (T2DM), metabolic syndrome and cardiovascular disease (CVD) in various studies.[12–15]

In addition, restricted fetal growth, adverse birth outcomes and poor growth in infancy have been associated with increased risk of developing NCDs in adulthood.[15] Malnutrition and/or other adverse exposures during critical periods of plasticity (fetal and infant development) may alter gene expression and permanently restructure the body's tissues, thereby resetting metabolism and function, with long-term consequences.[16] Maternal undernutrition has long been thought to play a role in phenotypic programming of the growing fetus, which results in intrauterine growth restriction (IUGR) and low birth weight (LBW) babies with increased risk of developing adult NCDs. Maternal obesity, adiposity and weight gain are associated with negative outcomes for women, including (i) increased risk of gestational diabetes mellitus (GDM), pre-eclampsia, preterm births, stillbirths and low breast-feeding rates, (ii) fetal growth and (iii) birth and infant outcomes. Although the importance of maternal nutrition in fetal development and birth outcomes has been clearly demonstrated in experimental animal studies, the findings of studies in humans are less consistent.

The first 1000 days of life – defined as the period from conception to 2 years of age – seems to be an optimistic window for intervention to prevent/reverse programming and improve both maternal, fetal, birth and infant outcomes; ultimately

*Address for correspondence: S. V. Wrottesley, MRC/Wits Developmental Pathways for Health Research Unit, Department of Paediatrics, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa 1864. (Email stephanie.wrottesley@gmail.com)

reducing the risk of infants developing NCDs in later life. Evidence seems to suggest that, where mother and child are concerned, chronic conditions have a transgenerational effect.[16] However, the extent to which maternal biological factors independently and interactively relate to patterns and proportionality of fetal growth, birth outcomes and infant growth, remains unclear.

To date, most of the studies and literature reviews dealing with maternal nutrition and its various outcomes have investigated single nutrients in isolation. Though important, nutrient deficiencies are generally found in low socio-economic status populations, where they present as multiple, rather than single deficiencies. Studies addressing and pulling together the broader picture of multiple nutrient intakes or deficiencies are lacking. In addition, studies reporting on associations between MNS and maternal, fetal, birth and infant outcomes in Africa are few.

In this review, our aim was to provide and report on the available data from Africa, using a systematic approach, to illustrate whether maternal nutrition during the first 1000 days of life is important to this unique continent, undergoing rapid urbanization and characterized by a triple burden of disease, including infection-related undernutrition illnesses, HIV/AIDS and the emergence of NCDs.[17] The specific objectives were as follows:

i. Report on the MNS of pregnant African women.
ii. Examine the associations between MNS (using anthropometric indicators) and fetal growth and birth, neonatal and infant outcomes.
iii. Examine the associations between MNS (using nutritional biomarkers) and fetal growth and birth, neonatal and infant outcomes.
iv. Examine the associations between MNS (using reported dietary intakes) and fetal growth and birth, neonatal and infant outcomes.
v. Explore the evidence from randomized/quasi-randomized clinical trials on the associations between maternal nutritional interventions and fetal growth and birth, neonatal and infant outcomes.
vi. Explore the evidence from randomized/quasi-randomized clinical trials on the associations between nutritional interventions in the first 2 years of life and any later adolescent or adult health outcomes.

Methods

Search strategy

Comprehensive literature searches were independently performed in May 2015 by a team of researchers. Although this is not a generic systematic review, this paper followed a systematic approach to select all available studies describing MNS and how it associates with fetal, birth, neonatal and/or infant outcomes in Africa. Database used to conduct the searches included the following: Medline, EMBASE, Web of Science, Google Scholar, ScienceDirect, SciSearch and Cochrane Library. Search terms and phrases included the following, as well as variations of the following where applicable: prenatal/anthropometry/(specific anthropometric measure of interest, e.g. body mass index)/maternal nutrition/(specific nutrient of interest, e.g. protein or iron)/(specific micronutrient deficiency of interest, e.g. anaemia)/(specific nutritional biomarker of interest, e.g. ferritin)/(specific dietary intake assessment method of interest, e.g. food frequency questionnaire) and birth outcome/pregnancy outcome/(specific adverse outcome of interest, e.g. low birth weight)/(specific growth or body composition variable of interest, e.g. head circumference or fat mass) and Africa. These terms and phrases were used in different combinations to be identified in titles and abstracts. Full-text articles were obtained and reviewed to identify those which met selection criteria below and data were extracted from relevant publications into tables appropriately.

Selection criteria

Studies which met the following criteria were considered relevant for inclusion:

- studies conducted in African countries;
- any study design;
- For observational studies
  - Studies that described MNS (defined by reported dietary intakes, anthropometric data and biochemical indicators) in pregnant women of any age.
  - Studies that associated MNS in pregnant women of any age with any fetal, birth, neonatal or infant outcome.
- For intervention studies
  - Nutritional interventions done in pregnancy with dietary values and/or where biochemical indicators and fetal, birth, neonatal and/or infant outcome data from both the intervention and control group could be extracted.
  - Nutritional interventions done in infancy with later adolescent or adult outcomes reported.
- Studies reporting data in a format that enabled daily mean or median nutrient intake for the population to be extracted.

Studies were excluded from the review according to the following criteria:

- studies conducted in animals;
- studies in subjects with health conditions that may have influenced dietary intake (i.e. gestational diabetes, coeliac disease);
- interventions (including any supplements) in which MNS and fetal, birth, neonatal and/or infancy outcomes were reported for the intervention group only.

Results

The results of the scientific papers included in this review are presented and structured according to the specific aims.

MNS of pregnant African women (Table 1)

In all, 19 studies met the inclusion criteria.[18–36] The publication year ranged from 2002 to 2014. The number of pregnant women examined in the studies ranged from 30 to 191,834 and the gestational age at MNS assessment varied between 18 and 39 weeks. Six studies used anthropometric measurements to describe MNS in pregnant women,[19,23–25,31,33] one used a biomarker of anaemia (haemoglobin (Hb)),[36] two used reported dietary intakes[20,26] and the remaining 10 used a combination of anthropometry, biomarkers and reported dietary intakes[18,21,22,27–30,32,34,35] (Table 1).

Of the studies including anthropometric measures of MNS, five provided data for the mean/median body mass index (BMI). BMI varied from being within the normal range (18.5–24.9) in Tanzania,[21] Ethiopia[18] and Zambia,[31] to being within the overweight category (25.0–29.9) in South Africa,[32] Sudan[23,24] and Zambia.[31] No studies reported mean/median BMI in either the underweight or obese categories. BMI was described according to WHO classification in two studies, with one describing a prevalence of 79.1% overweight and obesity in South African women and the other showing prevalence of 34.1 and 60.2% overweight and obesity in women who gave birth to normal weight and macrosomic babies, respectively, in Zambia.[29,31] Weight gain was 228 g/week from ~23 weeks gestational age in Malawi[25] and 1.06 kg/week during the third trimester in Liberia.[27] In Sudan, the mean mid-upper arm circumference (MUAC) of pregnant women at delivery was 26.9 cm,[23,24] whereas in Ethiopia 52.7% of women had an MUAC of <23 cm[19] (Table 1).

Hb was used as a biomarker of iron status in pregnant women in five studies.[21] All studies described mean Hb values above the threshold for diagnosis of anaemia in pregnant women (<11 g/dl), with the exception of one study in Tanzania.[21] Based on this cut-off point 66.7 of rural and 26.7% of urban women were classified as anaemic in one study in Ghana and 32% were classified as anaemic in another study in the same setting.[34,36] Kenyan pregnant women had a 32% anaemia prevalence in one study,[28] whereas 42.2 and 21.8% of women from pastoral and farming communities, respectively, were diagnosed with anaemia in another study.[30] In addition to anaemia diagnosed via Hb concentrations, Keverenge-Ettyang *et al.*[30] also assessed iron stores in pregnant women using serum ferritin concentrations. Pregnant women from pastoral communities had significantly higher serum ferritin concentrations than those from farming communities, although the difference was relatively small (25.8 *v.* 24.4 μg/l, $P < 0.05$). The prevalence of low maternal iron stores (serum ferritin < 32 μg/l) was high in both groups (77% in pastoral and 85.9% in farming communities).[30] A total of 27.9 and 24.2% of women from pastoral and farming communities, respectively, had low vitamin A status (serum retinol). Iron deficiency and iron deficiency anaemia (IDA) prevalence were 41.6 and 50%, respectively, in pregnant South African women based on a combination of biochemical markers (serum iron, ferritin, transferrin, Hb, haematocrit, mean corpuscular volume and red blood cell count).[29]

Red cell folate concentrations were between 166 and 183 nmol/l in rural and between 158 and 177 nmol/l in urban Nigerian women.[35] Mean calcium concentrations were 8.9 mg/dl in Egyptian pregnant women.[22]

Of the 10 studies reporting dietary intake in pregnant women, most used 24 h recall and/or food frequency questionnaires as the assessment method,[20,21,26,28,29,32,34] whereas two used weighed food records[18,35] and one used a food survey questionnaire for calcium intake specifically.[22] Mean energy intake ranged between 952 and 3981 kcal/day across study sites. Mean macronutrient intakes ranged as follows: carbohydrate 231–350 g/day, protein 15–104 g/day and fat 7–62 g/day; with the lowest intakes of all macronutrients found in the same Ethiopia population.[18] Mean intake of the key pregnancy micronutrients analysed ranged between 7–41 mg/day of iron, 194–424 μg/day of folate, 355–974 mg/day of calcium and 5–13 mg/day of zinc.

Associations between MNS (anthropometry) and fetal growth and birth, neonatal and infant outcomes (Table 2)

Eight studies met the inclusion criteria.[19,23–25,27,30,31,33] The publication year ranged from 2005 to 2014. Four studies followed a prospective cohort design,[19,27,30,33] two studies used retrospective data[25,31] and two were cross-sectional studies.[23,24] The number of pregnant women included in the studies ranged from 80 to 191,834. Anthropometric measurements used to describe MNS in study participants included weight and height,[30,33] BMI,[31] gestational weight gain (GWG),[25,27] MUAC[19] and lean body mass; with two studies describing all of these variables in pregnant women.[23,24] All offspring outcomes were assessed at birth or within the first 30 days of life; with the most commonly examined outcomes being birth weight and gestational age (Table 2).

In Sudan, postpartum maternal weight and BMI were positively associated with birth weight ($P < 0.001$), but neither variable predicted risk of LBW (<2500 g).[24] Although risk of LBW in Kenya was 2.4 times greater in infants born in farming than in pastoral communities, there was no difference in mean weight of the pregnant women during the third trimester of pregnancy.[30] GWG in the second and third trimesters showed a strong seasonality effect in rural Malawian women, with those delivering in the rainy season gaining significantly less weight than those delivering in temperate/dry months (100–200 g/week compared with 250–300 g/week, $P < 0.001$); however, this was not reflected as strongly in birth weight ($P < 0.05$) and GWG was therefore only weakly correlated with birth weight (Pearson's correlation coefficient 0.13; significance not reported).[25] In contrast, although birth weight was correlated with maternal weight at 6 ($r = 0.54$, $P = 0.01$) and 9 months ($r = 0.53$, $P = 0.01$) in Liberia, there was a stronger, positive correlation with net weight gain between the two time points ($\beta = 0.059$, $P < 0.001$).[27]

Table 1. *Results from observational studies describing maternal nutritional status (MNS) of pregnant African women*

					MNS measures [mean (S.D.)/median (range)]						
					Anthropometry		Biomarkers		Dietary intake		
First author, year	Country	Main objective(s)	Sample size	Gestational age	Measurement(s)	Value(s)	Type(s)	Value(s)	Energy (kcal/day)	Macronutrient(s)/fibre (g/day)	Micronutrient(s) (mg/day)
Changamire, 2014	Tanzania	To examine the effect of maternal macronutrient intake on GWG	8428	12–27 weeks	Weight (kg) BMI (kg/m^2)	59.5 (10.7) 24.6 (3.9)	Hb (g/dl)	10.2 (1.6)	2108 (804)	CHO: 344 (132) Protein: 53 (35) Fat: 59 (37)	
Kesa, 2005	South Africa	Explore anthropometry and nutritional intake of pregnant and lactating women (table includes only pregnant women)	315	First, second and third trimesters	Overweight/obese (BMI > 25 kg/m^2) (%)	79.12%	Fe deficient (%)[a] Fe deficiency anaemia (%)[a]	41.6% 50%	8425.71 (2279)[b]	CHO: 292.45 (72.2) Protein: 73.18 (23) Fat: 62.29 (23.7)	Fe: 9.74 (3.8)
Darwish, 2009	Egypt	To assess the prevalence and predictors of low calcium intake in pregnant women	503	34 (2) weeks	Weight (kg) Height (m)	67.5 (42–107) 160.6 (143–173)	Ca (mg/dl)	8.9 (1.6)			Ca: 879.1 (504.9)
Abebe, 2007	Ethiopia	To assess the prevalence of zinc inadequacy based on dietary intakes and plasma zinc concentrations	99	>28 weeks	Weight (kg) Height (m) BMI (kg/m^2)	52.1 (6.1) 154.8 (6.5) 21.7 (2.0)			3981 (3156, 5211)[b]	CHO: 231.2 (178.2, 299.7) Protein: 15.5 (10.4, 20.1) Fat: 7.7 (4.7, 11.7) Fibre: 24.4 (15.3, 32.8)	Fe: 27.1 (20.7, 33.2) Ca: 479 (220, 680) Zn: 5.0 (3.3, 7.2) Vit C: 2.2 (0.8, 4.7)
Keverenge-Ettyang, 2006	Kenya	To assess differences in maternal body composition, iron and vitamin A status during pregnancy and postpartum in pastoral (P) and farming (F) communities	122 P, 128 F	Third trimester (28–36 weeks)	Weight (kg) Height (m)	P: 51.9 (5.5); F: 51.6 (7.1) P: 160 (5.6); F: 160 (6.8)	Hb (g/l) Haematocrit Serum ferritin (SF) (μg/l) Serum retinol (SR) (μmol/l) Anaemia (Hb < 110 g/l) [*n* (%)] Low Fe stores (SF < 32 μg/l) [*n* (%)] Low vit A status (SR < 0.70 μmol/l) [*n* (%)]	P: 119 (11.3); F: 124 (15.0) P: 33 (3.95); F: 32 (5.42) P: 25.8 (4.82); F: 24.4 (4.87) P: 0.92 (0.43); F: 0.92 (0.35) P: 49 (42.2); F: 27 (21.8) P: 95 (77); F: 110 (85.9) P: 34 (27.9); F: 31 (24.2)			
Kamau-Mbuthia, 2007	Kenya	To determine diet quality and common food sources of nutrients in pregnant women	716	First antenatal visit			Hb (g/dl) Anaemia (Hb < 11 g/dl) [*n* (%)]	11.7 (1.98) 18 (32)	2055 (537)	CHO: 350 (96.8) Protein: 59.3 (22.4) Fat: 51 (24.5) PUFA: 13.8 (8.3) Fibre: 38.8 (15.1)	Fe: 16.1 (5.4) Folate (μg/day): 317 (161) Ca: 441 (386) Zn: 9.4 (3.4) Vit A (μg/day): 1187 (878) Vit C: 110 (71.9)

Table 1. *Continued*

First author, year	Country	Main objective(s)	Sample size	Gestational age	MNS measures [mean (S.D.)/median (range)]						
					Anthropometry		Biomarkers		Dietary intake		
					Measurement(s)	Value(s)	Type(s)	Value(s)	Energy (kcal/day)	Macronutrient(s)/fibre (g/day)	Micronutrient(s) (mg/day)
Belgnaoui, 2006	Morocco	To assess dietary intake and nutrient adequacy in an agricultural population of pregnant women	172	First (19.4%), second (49%), third (31.6%) trimesters					2947.0 (827.9)	Protein: 104.1 (38.7)	Fe: 17.2 (5.1) Folate (μg/day): 423.8 (140.4) Ca: 832.3 (397.4) Zn: 10.4 (4.3) Vit C: 127.6 (112.5) Vit B_1: 1.55 (0.50) Ph: 1867.0 (519.8) Mg: 528.2 (192.9) Vit E: 22.7 (24.1)
Oguntona, 2002	Nigeria	To assess the food intake and nutrition status of rural and urban pregnant adolescents in the south-western region of Nigeria	54 rural (R), 47 urban (U)	>28 weeks			Red cell folate (nmol/l)	R < 17 years: 166 (18.4); R > 17 years: 183 (41.4) U < 17 years: 158 (28.5); U > 17 years: 177 (24.7)	R < 17 years: 5571 (307)[b]; R > 17y: 5693 (481)[b] U < 17 years: 5209 (214)[b]; U > 17 years: 5864 (416)[b]	Protein: R < 17 years: 33.6 (2.4); R > 17 years: 37.0 (3.0) U < 17 years: 33.1 (2.2); U > 17 years: 42.2 (3.9) Fat: R < 17 years: 11.2 (1.1) R > 17 years: 24.4 (2.1) U < 17 years: 9.0 (1.0); U > 17 years: 26.5 (5.8)	Fe: R < 17 years: 9.7 (2.1); R > 17 years: 10.9 (1.5) U < 17 years: 9.9 (1.0); U > 17 years: 11.8 (3.3) Zn: R < 17 years: 10.6 (2.6); R > 17 years: 12.0 (2.1) U < 17 years: 10.8 (2.0); U > 17 years: 13.6 (2.1) Ca: R < 17 years: 662.6 (200.3); R > 17 years: 609.4 (210.5) U < 17 years: 623.8 (176.8); U > 17 years: 739.5 (119.0)
Nti, 2002	Ghana	To determine the food consumption, diet quality and awareness of nutritional requirements in rural and suburban pregnant women	15 rural (R), 15 suburban (S)	6 months			Anaemia (Hb < 11 g/dl) [n (%)]	R: 10 (66.7); S: 4 (26.7)	R: 2640 (2189–3205); S: 3018 (2314–3783)	Protein: R: 41.6 (35.0–57.3); S: 59.6 (46.2–83.7)	Fe: R: 7.3 (4.9–9.3); S: 10.6 (7.6–13.7) Ca: R: 860.0 (419.1–1 744.5); S: 974.4 (453.2–1700.0) Vit A (IU/day): R: 13,825 (1396–37,310); S: 21,893 (3118–71,643) Thiamin: R: 1.6 (0.7–2.4); S: 2.2 (1.3–4.6) Riboflavin: R: 1.5 (0.5–2.1); S: 1.4 (0.8–1.9) Niacin: R: 16.6 (5.7–25.6); S: 20.2 (14.9–31.7) Vit C: R: 42 (18.0–85.0); S: 36 (22.3–51.2)
Huybregts, 2009	Burkina Faso	To assess potential changes in dietary habits in during pregnancy in a sample of rural women	218	126 in 1/2nd trimester (T1/2), 92 in 3rd trimester (T3)					T1/2: 8600 (6800; 11,100)[b]; T3: 9000 (7000; 11,300)[b]	Protein: T1/2: 60.5 (44.8; 76.8); T3: 61.2 (46.5; 77.8) Fat: T1/2: 31.2 (17.1; 47.5); T3: 27.0 (15.4; 46.5)	Fe: T1/2: 40.6 (28.9; 57.7); T3: 40.1 (25.4; 54.6) Folate (μg/day): T1/2: 234.7 (152.1; 367.5); T3: 217.2 (150.3; 316.9) Ca: T1/2: 574.3 (335.3; 1081.5); T3: 468.6 (231.0; 708.5) Zn: T1/2: 13.1 (10.1; 16.2); T3: 13.3 (10.4; 16.6)

										Thiamine: T1/2: 0.85 (0.53; 1.1); T3: 0.81 (0.57; 1.1) Riboflavin: T1/2: 0.20 (0.13; 0.34); T3: 0.25 (0.14; 0.5) Niacin: T1/2: 7.3 (5.2; 10.0); T3: 7.8 (5.5; 10.3) Ph: T1/2: 839.7 (616.9; 1135.7); T3: 852.1 (670.7; 1180.7) Vit A (μg/day): T1/2: 118.9 (60.5; 249.6); T3: 117.6 (53.8; 242.3) Vit B_6: T1/2: 0.84 (0.63; 1.14); T3: 0.88 (0.68; 1.26) Vit C: T1/2: 11.0 (5.7; 21.2); T3: 10.4 (6.1; 28.4)
Mostert, 2005	South Africa	(i) To determine the dietary intake of poor rural women during pregnancy and lactation; (ii) to determine the nutritional status and dietary intake of their infants at 6 months	46	Anthropometry: first visit (4–6 months) Dietary intake: during second and third trimesters	BMI (kg/m^2)	27.2 (5.5)		7760 (2059)[b]	CHO: 306.2 (88.0) Protein: 66.8 (30.3) Fat: 55.5 (47.3) Fibre: 21.7 (5.5)	Fe: 9.6 (4.3) Folate (μg/day): 194.5 (75.3) Ca: 354.8 (245.5) Zn: 8.1 (4.3) Vit A (μg/day): 574.2 (428.4) Vit C: 34.7 (26.6) Vit E: 5.6 (3.2) Vit B_6: 0.87 (0.39) Niacin: 10.94 (4.97)
Assefa, 2012	Ethiopia	To measure the incidence and determinants of LBW in a rural population	956		MUAC < 23 cm [*n* (%)] MUAC ⩾ 23 cm [*n* (%)]	504 (52.7) 452 (47.3)				
Elshibly, 2008; Elshibly, 2009	Sudan	(i) To quantify the effect of maternal anthropometry, education and socio-economic status on gestational age and birth weight; (ii) to investigate the relationship between maternal and newborn anthropometry	1000	39.1 (1.8)	Weight (kg) Height (cm) BMI (kg/m^2) MUAC (cm) Lean body mass	65.2 (13.0) 159.6 (6.2) 25.5 (4.8) 26.9 (3.9) 44.2 (4.9)				
Liu, 2013	Zambia	To identify predictors and outcomes associated with a birth weight of 4000 g or more in Lusaka. Women were analysed according to those who gave birth to normal weight (N) compared with macrosomic (M) babies	191,834	First antenatal visit	BMI (kg/m^2) Underweight (BMI < 18.5 kg/m^2) [*n* (%)] Normal weight (BMI = 18.5–24.9 kg/m^2) [*n* (%)]	N: 23.5 (21.5–26.1)[c]; M: 26.2 (23.4–29.8)[c] N: 3289 (2.8); M: 41 (1.4) N: 75 043 (63.2); M: 1 135 (38.4)				

Table 1. *Continued*

First author, year	Country	Main objective(s)	Sample size	Gestational age	MNS measures [mean (S.D.)/median (range)]						
					Anthropometry		Biomarkers		Dietary intake		
					Measurement(s)	Value(s)	Type(s)	Value(s)	Energy (kcal/day)	Macronutrient(s)/fibre (g/day)	Micronutrient(s) (mg/day)
					Overweight (BMI = 25–29.9 kg/m^2) [n (%)]	N: 30 464 (25.7); M: 1 057 (35.7)					
					Obese (BMI ⩾ 30 kg/m^2) [n (%)]	N: 9934 (8.4); M: 724 (24.5%)					
Hartikainen, 2005	Malawi		1032	23 (25th, 75th percentiles: 20, 26)	Weight (kg)	52 (48; 55)[d]					
					Weight gain (g/week)	228 (111; 355)[d]					
Nieuwoudt, 2014	South Africa	To investigate whether differences exist in adverse pregnancy outcomes between morbidly obese (MO, BMI = 40–49.9) and super obese (SO, BMI ⩾ 50) women	66 MO, 46 SO	MO: 29 (range: 9–40); SO: 29 (range: 10–40)	Height (cm)	MO: 160 (142–175); SO: 159 (136–172)					
					Weight (kg)	MO: 114 (89–144); SO: 135 (111–193)					
Stephens, 2014	Ghana	To establish the prevalence of pregnancy-associated malaria and its associated consequences	320	18.5 (95% CI: 17.12; 19.05)			Hb (g/dl)	11.44 (95% CI 11.29; 11.80)			
							Anaemia (Hb < 11 g/dl) [n (%)]	102 (32)			
Jackson, 2010	Liberia	(i) Estimate the proportion of LBW infants; (ii) study the relationship between mothers' health complaints and pregnancy outcomes; (iii) examine the relationship between GWG and pregnancy outcome; (iv) determine the optimal weight gain associated with a favourable birth weight range	80	6 and 9 months	Third trimester GWG (kg)	3.18	Hb (g/dl)	6 months: 9.9 (1.1)			
					Third trimester GWG (kg/week)	1.06		9 months: 11.5 (1.2)[e]			

LBW, low birth weight; GWG, gestational weight gain; BMI, body mass index; MUAC, mid-upper arm circumference; Fe, iron; Ca, calcium; Zn, zinc; Vit, vitamin; Hb, haemoglobin; Ph, phosphorus; Mg, magnesium.

[a]Based on serum Fe, ferritin, transferrin, Hb, haematocrit, mean corpuscular volume and red blood cell count.

[b]Reported as kJ/day.

[c]Median (interquartile range).

[d]Median (25th, 75th percentiles).

[e]Routine Fe supplementation received between 6 and 9 months.

Table 2. *Results from observational studies of the associations between maternal nutritional status (anthropometry) and fetal growth and birth, neonatal and infant outcomes*

					Anthropometry			Outcome			
First author, year	Country	Study design	Sample size	Participant characteristics	Timing	Measurement(s)	Mean (S.D.)/median (range)	Timing	Variable	Mean (S.D.)/ median (range)	Conclusions
Assefa, 2012	Ethiopia	Prospective cohort	956	Urban and rural Ethiopian pregnant women		MUAC < 23 cm [*n* (%)] MUAC ⩾ 23 cm [*n* (%)]	504 (52.7) 452 (47.3)	Birth	LBW [*n* (%)]	271 (28.3)	MUAC < 23 cm significantly associated with LBW and increased odds of LBW by 1.6 times (95% CI: 1.19; 2.19)
Elshibly, 2008; Elshibly, 2009	Sudan	Cross-sectional study	1000	Urban non-diabetic Sudan women with singleton births	Birth, 39.1 (1.8) weeks gestational age	Weight (kg) Height (cm) BMI (kg/m^2) MUAC (cm) Lean body mass	65.2 (13.0) 159.6 (6.2) 25.5 (4.8) 26.9 (3.9) 44.2 (4.9)	Neonatal (within 24 h of birth)	Gestational age (weeks) Birth weight (g) LBW [*n* (%)] Preterm [*n* (%)] Supine length (cm) Crown-rump length (cm) Limb length (cm) Head circumference (cm) Chest circumference (cm) Abdominal circumference (cm) MUAC (cm) Mid-thigh circumference (cm) Triceps skinfold thickness (mm) Subscapular skinfold thickness (mm) Ponderal index (g/cm^3)	39.1 (1.8) 3131.7 (538.9) 83 (8.3) 57 (5.7) 49.3 (2.9) 33.6 (2.2) 15.0 (1.0) 34.4 (1.7) 31.7 (2.4) 28.2 (2.7) 10.0 (1.1) 15.0 (1.7) 0.81 (0.21) 0.83 (0.24) 2.61 (0.45)	Maternal height identified as strongest anthropometric predictor of neonatal outcomes; associated positively with gestational age ($P < 0.002$), limb length ($P < 0.001$) and birth weight ($P < 0.001$) Height < 156 cm increased RR of LBW by 52% Maternal weight, BMI and MUAC positively correlated with birth weight ($P < 0.001$), but did not predict LBW Maternal BMI significantly associated with skinfold thicknesses ($P < 0.001$) Postpartum maternal lean body mass positively associated with birth weight, body length and body circumference ($P < 0.001$)
Liu, 2013	Zambia	Retrospective cohort	191,834	Women with singleton births > 2500 g and at least one documented prenatal visit. Analysed as two groups: normal birth weight (N, 2500–3.999 g) and macrosomia (M, ⩾ 4000 g)	First antenatal visit	BMI (kg/m^2) Underweight (BMI < 18.5 kg/m^2) [*n* (%)] Normal weight (BMI = 18.5–24.9 kg/m^2) [*n* (%)] Overweight (BMI = 25–29.9 kg/m^2) [*n* (%)] Obese (BMI ⩾ 30) [*n* (%)]	N: 23.5 (21.5–26.1)[a]; M: 26.2 (23.4–29.8)[a] N: 3289 (2.8); M: 41 (1.4) N: 75,043 (63.2); M: 1135 (38.4) N: 30,464 (25.7); M: 1057 (35.7) N: 9 934 (8.4); M: 724 (24.5)	Birth	Macrosomia [*n* (%)]	4 717 (2.5)	Mean BMI higher in women who gave birth to macrosomic infants ($P < 0.01$) Overweight and obesity at baseline associated with 1.72 and 2.88 times greater odds of giving birth to a macrosomic infant, respectively

Table 2. *Continued*

					Anthropometry			Outcome			
First author, year	Country	Study design	Sample size	Participant characteristics	Timing	Measurement(s)	Mean (s.d.)/median (range)	Timing	Variable	Mean (s.d.)/ median (range)	Conclusions
Hartikainen, 2005	Malawi	Retrospective cohort	1032	Rural Malawian women with singleton births	23 weeks (25th, 75th percentiles: 20, 26)	Weight (kg) Weight gain (g/week)	52 (48; 55)[b] 228 (111; 355)[b]	Neonatal (within 30 days of birth)	Birth weight (g) Gestational age (weeks)	3400 40 (38; 41)[b]	Seasonal variation in maternal weight gain: highest in those who delivered in the third quarter of the year (250–300 g/week) and lowest in the first quarter (100–200 g/week) ($P < 0.001$) Weaker correlation for seasonality in newborn weight ($P < 0.05$) GWG showed a modest correlation with newborn weight (Pearson's correlation coefficient: 0.13)
Keverenge-Ettyang, 2006	Kenya	Prospective cohort	122 P, 128 F	Rural pregnant women in their third trimester from pastoral (P) and farming (F) communities	Third trimester (28–36 weeks gestational age)	Weight (kg) Height (cm)	P: 51.9 (5.5); F: 51.6 (7.1) P: 160 (5.6); F: 160 (6.8)	Neonatal (within 7 days of birth)	Birth weight (kg) LBW [*n* (%)]	2.856 (0.314) P: 19 (16.8); F: 35 (31.3)	Mean infant weight significantly lower in the farming communities ($P < 0.01$) and LBW prevalence significantly higher in farming villages RR of death was 2.4 times greater for neonates born in farming compared with pastoral communities
Nieuwoudt, 2014	South Africa	Prospective cohort	66 MO, 46 SO	Pregnant women attending a high-risk antenatal clinic with BMIs ≥ 40 kg/m^2	Gestational age (weeks): MO: 29 (range: 9–40); SO: 29 (range: 10–40)	Height (cm) Weight (kg)	MO: 160 (142–175); SO: 159 (136–172) MO: 114 (89–144); SO: 135 (111–193)	Neonatal	Symphysis-fundal height ≥ 90th percentile [*n* (%)] IUGR [*n* (%)] Macrosomia [*n* (%)] Weight (g)	MO: 44 (66.7); SO: 28 (60.9) MO: 1 (1.5); SO: 6 (13) MO: 5 (7.6); SO: 3 (6.5) MO: 3200 (525–4330); SO: 3430 (640–4690)	Incidence of IUGR greater in the SO than the MO group (13 *v.* 2%; $P = 0.02$) No differences in macrosomia incidence between groups
Jackson, 2010	Liberia	Prospective cohort	80	Generally healthy women with no previous antenatal care for current pregnancy	6 and 9 months	Third trimester GWG (kg) Third trimester GWG (kg/week)	3.18 1.06	Birth	Birth weight (g) (mean) LBW [*n* (%)]	3311 1 (1.3)	Infant birth weight weakly correlated with maternal weight at 6 ($r = 0.54$, $P = 0.01$) and 9 months ($r = 0.53$, $P = 0.01$) Net weight gain between 6 and 9 months was strongly correlated with birth weight ($b = 0.059$, $P < 0.001$)

LBW, low birth weight; GWG, gestational weight gain; BMI, body mass index; MUAC, mid-upper arm circumference; MO, morbidly obese (BMI 40–49.9 kg/m^2); SO, super obese (BMI ≥ 50 kg/m^2); IUGR, intrauterine growth restriction; RR, risk ratio.

[a]Median (interquartile range).

[b]Median (25th, 75th percentiles.).

In Zambia, where maternal overweight was more prevalent than the aforementioned studies, overweight and obesity were associated with 1.72 and 2.88 times greater odds of giving birth to a macrosomic infant, respectively.[31] In South African women with BMIs $\geqslant 40\,kg/m^2$, incidence of IUGR was significantly higher in those who had BMIs $\geqslant 50\,kg/m^2$ than those with BMIs between 40 and 49.9 kg/m^2.[33]

MUAC was associated with birth weight in two studies, with an MUAC < 23 cm (suggestive of maternal underweight)[37] increasing odds of LBW by 1.6 times.[19,23] In addition to the aforementioned findings, maternal height was identified as the strongest anthropometric predictor of neonatal outcomes in Liberia. Maternal height had positive associations with gestational age ($P<0.002$), limb length ($P<0.001$) and birth weight ($P<0.001$), whereas height < 156 cm increased the relative risk of LBW by 52%. In the same study sample, positive associations were found between maternal lean body mass and birth weight, body length and body circumference within 24 h of birth ($P<0.001$).[23]

The associations between MNS (nutritional biomarkers) and fetal growth and birth, neonatal and infant outcomes (Table 3)

Three studies met the inclusion criteria.[27,30,36] The publication years were 2006, 2010 and 2014. All studies included were prospective cohort studies and the sample size ranged between 80 and 320. All studies used biomarkers to assess anaemia and/or iron status of pregnant women, with two studies using Hb concentrations only and one study including haematocrit and serum ferritin concentrations.[30] The latter also assessed maternal vitamin A status using serum retinol concentrations. Birth weight was the outcome of interest in all studies (Table 3).

Data from Kenya reports pregnant women from pastoral communities having lower Hb concentrations and higher anaemia prevalences than those from farming communities [(119 *v.* 124 g/l, $P<0.05$); (42.2 *v.* 21.8%, $P<0.01$)], respectively, but serum ferritin concentrations were higher in the pastoral community (25.8 *v.* 24.4 µg/l, $P<0.05$). Mean infant birth weight was significantly lower (2.9 *v.* 2.8 kg, $P<0.01$) and prevalence of LBW significantly higher (31.3 *v.* 16.8%, $P<0.05$) for babies born to mothers from farming than from pastoral communities.[30] A weak correlation between maternal Hb concentrations at 6 months gestation and infant birth weight ($P = 0.042$) was shown in Liberia; however, this was not significant at 9 months (all women had been routinely supplemented with 180 mg iron/day between the 6- and 9-month assessment).[27] In Ghana, none of the women who were anaemic in the first trimester of pregnancy gave birth to LBW babies.[36]

The associations between MNS (dietary intake) and fetal growth and birth, neonatal and infant outcomes

No studies were identified which met the inclusion criteria.

Randomized/quasi-randomized clinical trials on the associations between maternal nutritional interventions and fetal growth, birth, neonatal and infant outcomes (Table 4)

Six studies met the inclusion criteria.[38–43] The publication years ranged between 1997 and 2011. Four studies were double-blind randomized controlled trials (RCTs),[40–43] one was a cluster RCT[38] and one study used data from both a double-blind RCT and a cluster RCT.[39] The sample sizes ranged between 125 and 2100 and gestational age of the subjects at baseline ranged between 20 and 28 weeks. Interventions included iron,[43] multiple micronutrient,[42] calcium[39–41] and protein-energy supplementation[38,39] (Table 4).

Protein-energy supplementation in chronically undernourished Gambian women from 20 weeks gestational age was associated with 136 g higher pregnancy weight gain than in the control group ($P<0.001$).[38] Increases were higher in the hungry (201 g, $P<0.001$) than in the harvest season (94 g, $P<0.01$). Odds of perinatal mortality (death within the first 7 days of life) (OR: 0.54, 95% CI: 0.35; 0.85, $P<0.01$) and LBW (OR: 0.61, 95% CI: 0.47; 0.79, $P<0.001$) were, respectively, lower in the supplementation group. There was also a 3.1 mm increase in head circumference ($P<0.01$) in those who received the intervention.[38] During the follow-up study in 11–17-year olds, no differences in BMI, fat mass, lean mass, blood pressure, insulin or cholesterol concentrations were found between those whose mothers had received protein-energy supplementation during pregnancy and controls; however, those born to supplemented mothers had 0.05 mmol/l (95% CI: −0.10; −0.001 mmol/l) lower fasting glucose concentrations.[39]

In Gambian women, no differences in weight, body length, head circumference or bone mineral content between infants born to women who received calcium supplementation and those who received a placebo from 20 weeks gestational age were observed. Follow-up of infants at 5–10 years of age showed no differences in blood pressure and no interaction between BMI and calcium supplementation for blood pressure variables.[39,40]

A trial of iron supplementation to a cohort of pregnant women with a high anaemia prevalence in Niger found no differences in birth weight between babies born to the intervention and control groups.[43] Birth length and Apgar scores were significantly higher in babies born to supplemented mothers; however, the difference in length did not persist at 3 and 6 months. Serum ferritin concentrations at 3 and 6 months of age were higher in infants whose mothers received iron supplementation compared with mothers who received the placebo ($P<0.05$).[43]

Pregnant women in Guinea-Bissau received either one of two possible interventions: a tablet with one recommended daily allowance (RDA) of 15 micronutrients (MN-1) or a tablet with two RDAs of the same micronutrients (but one RDA of iron) (MN-2), or a standard iron-folic acid supplement

Table 3. *Results from observational studies of the associations between maternal nutritional status (biomarkers) and fetal growth and birth, neonatal and infant outcomes*

					Biomarkers			Outcome			
First author, year	Country	Study design	Sample size	Participant characteristics	Timing	Type(s)	Mean (S.D.)/median (range)	Timing	Variable	Mean (S.D.)/ median (range)	Conclusions
Stephens, 2014	Ghana	Prospective cohort	320	Pregnant women from a low malaria transmission area of suburban, coastal Ghana who had not received intermittent preventive treatment for malaria prevention at enrolment	First antenatal visit, 18.5 weeks gestation (95% CI: 17.12; 19.05)	Hb (g/dl) Anaemia (Hb < 11 g/dl) [*n* (%)]	11.44 (95% CI 11.29; 11.80) 102 (32)	Birth	LBW [*n* (%)]	11 (3.3)	None of the LBW babies were born to women who had anaemia in the first trimester
Keverenge-Ettyang, 2006	Kenya	Prospective cohort	122 P, 128 F	Rural pregnant women in their third trimester from pastoral (P) and farming (F) communities	Third trimester (28–36 weeks gestational age)	Hb (g/l) Haematocrit Serum ferritin (SF) (µg/l) Serum retinol (SR) (µmol/l) Anaemia (Hb < 110 g/l) [*n* (%)] Low Fe stores (SF < 32 µg/l) [*n* (%)] Low Vit A status (SR < 0.70 µmol/l) [*n* (%)]	P: 119 (11.3); F: 124 (15.0) P: 33 (3.95); F: 32 (5.42) P: 25.8 (4.82); F: 24.4 (4.87) P: 0.92 (0.43); F: 0.92 (0.35) P: 49 (42.2); F: 27 (21.8) P: 95 (77); F: 110 (85.9) P: 34 (27.9); F: 31 (24.2)	Within 7 days of birth	Birth weight (kg) LBW [*n* (%)]	P: 2.9 (0.4); F: 2.8 (0.4) P: 19 (16.8); F: 35 (31.3)	Women from the pastoral community had lower Hb concentrations ($P < 0.05$) and higher anaemia prevalence ($P < 0.01$), but higher serum ferritin concentrations ($P < 0.05$) There were no differences in serum retinol levels Mean birth weight was significantly lower ($P < 0.01$) in the farming than in the pastoral community and a significantly higher proportion of newborns in the farming community were LBW ($P < 0.05$)
Jackson, 2010	Liberia	Prospective cohort	80	Generally healthy women with no previous antenatal care for the current pregnancy	6 and 9 months	Hb (g/dl)	6 months: 9.9 (1.1) 9 months: 11.5 (1.2)[a]	Birth	Birth weight (g) (mean) LBW [*n* (%)]	3311 1 (1.3)	There was a significant (but weak), positive correlation between Hb at 6 months and infant birth weight ($P = 0.042$), but the correlation was not significant at 9 months

LBW, low birth weight; Vit, vitamin; Hb, haemoglobin; Fe, iron.
[a]Routine Fe supplementation received between 6 and 9 months.

Table 4. *Results from randomized/quasi-randomized clinical trials on the associations between maternal nutritional interventions and fetal growth and birth, neonatal and infant outcomes*

First author, year	Country	Experimental design	Sample size	Baseline MNS	Intervention targeted	Gestational age at initiation (weeks)	Intervention prescribed/day	Intervention duration	Outcome assessment	Conclusions
Preziosi, 1997	Niger	Double-blind randomized, placebo-controlled trial	197 pregnant women (99 intervention, 98 control)	Apparently healthy low- or middle-class civil servants and rural women with no obstetric complications Anaemia (Hb < 110 g/l); intervention: 65.7%; control: 69.4%	Fe supplementation	28 (±21 days)	100 mg elemental Fe	Until delivery	Birth, 3, 6 months postpartum	No difference in birth weight Birth length significantly higher in intervention group ($P < 0.05$) No differences in infant length at 3 or 6 months postpartum Serum ferritin concentrations higher in infants born to supplemented mothers at 3 [99 (63) *v.* 80 (53) μg/l] and 6 months [26 (27) *v.* 15 (20) μg/l] ($P < 0.05$)
Kaestel, 2005	Guinea-Bissau	Double-blind randomized controlled trial	2100 pregnant women	Baseline BMI [mean (S.D.)]: micronutrient intervention (MN)-1: 23.3 (3.4); MN-2: 23.3 (3.3); control: 23.2 (3.3) Anaemia (Hb < 100 g/l); MN-1: 30%; MN-2: 31%; control: 31%	Multiple micronutrient supplementation	Mean (S.D.): MN-1: 22.3 (6.6); MN-2: 22.1 (6.8); control: 21.9 (6.9)	MN-1: one RDA of 15 micronutrients; MN-2: two RDA of 14 micronutrients (Fe at one RDA); control: standard Fe-folic acid supplement	Until delivery [mean (S.D.)]: 16.6 (7.1) weeks	Birth, neonatal	Mean birth weight was 53 g higher in MN-1 and 95 g higher in MN-2 than the control group Non-significant effect on LBW: 10.1% MN-2, 12% MN-1 and 13.6% control ($P = 0.33$) Birth weight increased by 218 g and risk of LBW decreased by 69% in anaemic women receiving MN-2 compared with the control group No effect on perinatal mortality
Ceesay, 1997	The Gambia	Cluster randomized controlled trial	1460 pregnant women (yielded 2047 live singleton births over 5 years)	Chronically undernourished, rural pregnant women	Protein-energy supplement	Intervention: 20; control: after delivery	Energy: 1015 kcal; protein: 22 g; fat: 56 g; calcium: 47 mg; Fe: 1.8 mg	Intervention: until delivery; control: 20 weeks	Birth, neonatal	GWG increased by 136 g in the supplementation group ($P < 0.001$): higher increases in the hungry (201 g, $P < 0.001$) than the harvest season (94 g, $P < 0.01$) Odds of LBW was 0.61 (95% CI: 0.47; 0.79, $P < 0.001$) and head circumference was 3.1 mm higher ($P < 0.01$) in the supplemented group Supplementation reduced perinatal mortality: OR: 0.54 (95% CI: 0.35; 0.85, $P = 0.01$) for all deaths in 1st week of life

Table 4. *Continued*

First author, year	Country	Experimental design	Sample size	Baseline MNS	Intervention targeted	Gestational age at initiation (weeks)	Intervention prescribed/day	Intervention duration	Outcome assessment	Conclusions
Hawkesworth, 2011			1267 term births followed up						Childhood (11–17 years)	No differences between groups, childhood body composition (BMI, fat mass or lean mass), blood pressure, insulin or cholesterol concentrations Children of pregnancy-supplemented mothers: 0.05 mmol/l (95% CI: −0.10; −0.001 mmol/l) lower fasting plasma glucose
Jarjou, 2006	The Gambia	Double-blind randomized, placebo-controlled trial	125 pregnant women (subsample of main study, $n = 536$)	Rural Gambian women with previously documented low calcium intakes (~350 mg/day)	Calcium	20	1500 mg	Until delivery	Birth, neonatal, infant (birth, <5 days, 2, 13, 52 weeks of age)	No differences in birth weight between groups No differences in infant weight, body length, head circumference or bone mineral status in the 1st year of life
Hawkesworth, 2010; Hawkesworth, 2011			350 term births followed up of main study sample						Childhood (5–10 years)	No differences in blood pressure between infants born to supplemented compared with unsupplemented mothers No interaction between childhood BMI and supplementation for blood pressure variables

MNS, maternal nutritional status; LBW, low birth weight; Fe, iron; GWG, gestational weight gain; BMI, body mass index; OR, odds ratio.

(control group) from ∼22 weeks gestation.[42] Mean birth weight was 53 and 95 g higher in the MN-1 and MN-2 groups, respectively, than in the control group, suggesting a dose–response effect of supplementation. Supplementation had a positive effect on LBW, with 10.1, 12 and 13.6% LBW prevalence found in the MN-2, MN-1 and control groups, respectively; however, this was not significant ($P = 0.33$). Birth weight was 218 g higher and risk of LBW 69% lower for babies born to anaemic women in the MN-2 group compared with the control group.[42]

Randomized/quasi-randomized clinical trials on the associations between nutritional interventions in the first 2 years of life and any adolescent and/or adult health outcomes

No studies were identified which met the inclusion criteria.

Discussion

Using a systematic approach, this review aimed to provide and report on available data on MNS among Africans and illustrate whether the first 1000 days of life are nutritionally important for Africa. We focussed on the role of MNS during this period and how it associates with fetal growth and birth, neonatal and infant outcomes. The results are conveniently discussed by sub headings addressing each specific objective set for this review.

MNS in Africa

Using BMI most African women in the reported studies were within the normal weight to overweight category during pregnancy, with maternal overweight or obesity being more prevalent than underweight. This was supported by high energy intakes in some countries; however, mean energy intakes varied greatly between populations. Carbohydrate, protein and fat contributed between 58–87, 5.9–14.5 and 6.3–27.9%, respectively, to total energy intake across study sites. The most prevalent micronutrient deficiency in African pregnant women was iron.

Studies included in this review indicate a low burden of maternal underweight, and comparatively high overweight and obesity prevalence, typical of the epidemiological health transition across African countries. Although GWG was approximately half the Institute of Medicine (IOM) recommended level for normal weight women in Malawi,[25] much higher weekly gain than recommended for any BMI category was found in Liberian pregnant women.[27,44] Though the above findings provide good proxies for maternal obesity status, interpretation of the findings should be done with care, as a limitation exits in that obesity status (being underweight, normal, overweight or obese) was categorized by using BMI cutoffs of non-pregnant women.

Nutritional biomarkers showed a persisting high prevalence of micronutrient deficiencies in pregnant African women. Data suggest anaemia and/or iron deficiency prevalence to be high. Although comparison between rural and urban sites in Ghana suggests significantly higher anaemia prevalence in rural women, close to 30% of pregnant women were anaemic in urban settings.[34] This is much higher than the prevalence seen in HICs (Europe: 16.2%, America and the Caribbean: 15.2%) and other LMIC (Asia: 19.8%) settings.[45] This may be owing to a chronic intake of low absorbable iron and insufficient iron stores to support both maternal and fetal requirements or to high levels of infection in African communities; or a combination of both.[6]

Reported dietary intakes of pregnant women varied significantly across African countries, with studies showing energy consumption below and above the American Dietetic Association recommended range of 2200–2900 kcal/day.[46] However, the shift towards higher energy intakes in populations with traditionally low food access was not reflected in adequate protein intake, which was lower than the IOM's RDA (71 g) in all but one study.[47] Mean dietary iron intakes were much lower than the IOM RDA of 27 mg/day[48] in all but two studies.[18,26] Folate intake was much lower, on average, than the 600 μg/day recommended for pregnant women,[49] with most studies reporting intakes less than half of the recommended intake. Majority of the women studied either did not receive or did not comply with micronutrient supplementation during pregnancy, even in countries where iron and/or folic acid supplementation should have been a routine part of antenatal care. Higher energy consumption, coupled with inadequate protein and micronutrient intakes, may be a result of poor diet quality and/or food availability in communities in transition. This was demonstrated in South Africa where one study showed pregnant women to consume predominantly cereal-based diets high in energy and refined sugar, with low intakes of more expensive protein/micronutrient-rich foods such as meat, poultry and seafood, as well as legumes and non-starchy vegetables.[29]

Associations of MNS (using anthropometric parameters) and fetal growth and birth, neonatal and infant outcomes

Maternal weight, BMI and weight gain during pregnancy were positively associated with birth weight in African studies. However, maternal overweight and obesity increased the risk of macrosomia in Zambia[31] and higher BMIs were associated with increased risk of IUGR in a sample of very obese women from South Africa (BMI > 40 kg/m^2).[33]

These findings are consistent with studies from other parts of the world. A systematic review including data from both HICs and LMICs showed a significant risk of LBW in women who were underweight during pregnancy compared with those who were within normal weight categories[9] and GWG has been positively associated with birth weight in a number of studies.[50–52] Substantial evidence supports the association between maternal obesity and macrosomia, with a two to three-fold increase in risk of macrosomia being observed in obese women.[2,3,10] There is also evidence to support the association

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between maternal obesity and IUGR; however, fewer studies have documented this.[53,54]

Although the findings of this review have been supported by literature from other settings, the strength of and comparability between the included studies is limited owing to differences in study design, exposure variables and sample sizes that were relatively low in prospective cohort designs. In addition, the timing in assessment of anthropometric parameters in pregnancy and outcome measurements varied greatly between studies, with maternal assessments being done between the first antenatal visit and delivery across studies and birth outcome measurements being taken any time between birth and the first 30 days of life.

Although the underweight prevalence was low overall in African settings, risk of adverse fetal and birth outcomes remained high in populations where low pre-pregnancy weight is a key issue, for example, in Ethiopia where 52.7% of women had MUAC measurements <23 cm, LBW prevalence was high (28.3%). However, as maternal overweight and obesity continue to rise, high pre-pregnancy weight and excessive GWG and their associated risks should become the pivotal focus for maternal and child nutrition.

Associations of MNS (nutritional biomarkers) and fetal growth and birth, neonatal and infant outcomes

Data on the associations between nutritional biomarkers and outcomes of interest were very limited. The limited data available seem to suggest associations between low Hb and serum ferritin concentrations with lower birth weights in African settings.[27,30]

Global evidence associating nutritional biomarkers with outcomes of interest show mixed results. Maternal anaemia in Indians was associated with increased risk of LBW and IDA predicted a three times higher risk of preterm birth.[55] Low maternal Hb, but not serum ferritin concentrations, were associated with lower birth weight in Iran.[56] However, in a multicentre study across four HICs (New Zealand, Australia, England and Ireland), as well as in Sri Lanka (LMIC), there were no associations observed between anaemia (Hb < 11 g/dl) and risk of preterm birth, LBW or small for gestational age (SGA) infants.[57,58]

Although all included studies focussed on the association between anaemia and birth weight using prospective cohort designs, the late assessment of biomarker status in two of the three studies provided poor proxies of pre-pregnancy status and the variation in timing of measurements between studies limited comparability. Sample sizes were low in all studies, which may have limited the power to detect associations between the biomarker(s) and outcome(s) of interest.

More evidence is needed to understand the associations between maternal micronutrient status and deficiencies on outcomes of interest in the first 1000 days; however, use of individual biomarkers of nutritional status in isolation may be impractical in Africa where diet quality is poor and pregnant women are likely to experience multiple nutrient deficiencies. Thus, identifying nutritional biomarker patterns using dimension reduction techniques could be essential to employ in such studies.

Associations of MNS (reported dietary intakes) and fetal growth and birth, neonatal and infant outcomes

Although no articles were retrieved for Africa on associations between reported dietary intakes and outcomes of interest, the use of reported dietary assessment (DA) has a number of challenges. Repeated 24 h recalls and food frequency questionnaires are the most commonly used methods for assessing habitual dietary intakes in Africa.[59] The inherent errors associated with reported dietary intakes and the strengths and limitations of different DA methods cannot be ignored.[59] Limitations include recall bias, assuming temporarily regular eating habits, seasonality and providing inaccurate estimations of portion size, etc.[60–62] However, very few DA tools used in Africa have been validated or tested for reliability that presents a huge challenge for effective assessment and monitoring of dietary intake, as well as for comparison of intakes within and between African settings.[59]

Randomized clinical trials of maternal nutritional interventions and fetal growth and birth, neonatal and infant outcomes

Evidence from an African study suggests positive associations between protein-energy supplementation during pregnancy and higher GWG, birth weight and lower risk of perinatal mortality.[38] However, no long-term effects were seen on CVD risk during the 11–17-year follow-up.[39] Multiple micronutrient supplementations had a dose–response effect on birth weight and significantly reduced LBW risk in anaemic women.[42] Although iron supplementation was associated with an increase in birth length, no improvement in birth weight was found.[43] Prenatal calcium supplementation had no effect on any birth, neonatal, infant or childhood health outcomes.[39–41]

A review on protein-energy supplementation trials including both HICs and LMICs showed positive effects on birth weight in the supplemented compared with control groups, with the greatest effects seen in undernourished populations.[63] This supports the findings of the Gambian study where pregnant women were chronically undernourished at baseline.[38] Similarly, a meta-analysis on multi-micronutrient supplementation trials[64] supported the data from Guinea-Bissau[42] by showing significant reductions in LBW, SGA incidence and increased mean birth weight for women in the intervention compared with the control group (mostly receiving iron-folate supplements).[64] Data from the iron supplementation trial in Niger[43] contradicted the general findings from a meta-analysis which showed that daily iron supplementation during pregnancy (alone or in combination with folate) reduced incidence of LBW by 20% compared with controls.[65] The effects of supplementation were most pronounced in populations with higher baseline anaemia prevalence.[65] Although positive effects on birth length were seen in the supplementation group in Niger, the lack of improvement in birth weight in this population with high anaemia prevalence is not a common finding compared with the literature. However, this finding could be, in part, attributed to the late start of the intervention during pregnancy (38 weeks, ±21 days) and/or the small sample size.[43] No studies in Africa were found that suggested any long-term benefits of nutritional supplementation during pregnancy.

RCTs are considered the most robust designs for assessing the relationship between exposure and outcome, because they ensure comparability between those exposed and those unexposed to the intervention and allow for causal links to be made as the intervention always precedes the outcome of interest. However, variability between RCT designs can alter the strength of individual studies. The following are important factors of concern associated with maternal nutritional intervention studies that make comparability of findings difficult: (i) sample size, (ii) dose of intervention, (iii) timing of intervention during pregnancy, (iv) baseline nutritional status of pregnant woman and (v) an appropriate control group. Cumulatively, the data available seem to suggest significant benefits of macronutrient and/or micronutrient supplementation during pregnancy on fetal/birth outcome (specifically birth weight), particularly in undernourished women.

The results presented in this review illustrate that data available for Africa ranges from 18 weeks gestational age onwards. This highlights that an important critical phase (<18 weeks) has not been investigated in this setting.

The most important nutrients of concern for the first 1000 days for African women

Energy and nutrient requirements increase during pregnancy in order to meet the needs of both the mother and the growing fetus. Inadequate intakes of macro- and/or micronutrients before and during pregnancy result in limited growth and development and therefore poor pregnancy outcomes. Nutrient sufficiency is similarly required during early infancy to prevent growth faltering. Certain nutrients are of particular importance, owing to the critical functions that they perform and the plasticity during the first 1000 days of life. Energy requirements increase during pregnancy to support increases in basal metabolic rate as a result of growth and expansion of new and existing tissue (fetus, placenta and maternal tissues), as well as the higher work rate of the maternal cardiovascular, respiratory and renal systems. Adequate energy is also needed to support periods of rapid growth and development in the first 2 years of life. Protein requirements are high during pregnancy and infancy for deposition and maintenance of maternal and fetal tissue.[6,66] Omega-3 and omega-6 fatty acids are essential to new tissue formation, owing to their structural role in cell membranes, with omega-3 fatty acids being particularly important for brain and central nervous system development.[67] Micronutrients of key concern in pregnancy are iron and folate, as they are unlikely to be in sufficient supply from the diet. Additional iron is required to support the increase in red cell mass and ensure sufficient oxygen supply during tissue synthesis and growth. Folate is an important co-factor in cellular function, including DNA and nucleic acid synthesis and cell division.[6,68,69]

Known consequences associated with poor MNS

Inadequate maternal nutrition – underweight and overweight – as well as micronutrient insufficiency has been strongly linked with adverse maternal and infant outcomes, with both short- and long-term consequences. Maternal obesity and adiposity and high GWG are associated with increased risk of GDM, pre-eclampsia, maternal weight retention postpartum and poor infant outcomes such as prolonged labour, birth trauma, neonatal death and contrasting burdens of both macrosomia and SGA. Higher neonatal fat mass has been associated with adiposity in childhood and adulthood and therefore increased metabolic risk in later life.[10,15] Premature delivery has been shown to be associated with both maternal underweight and overweight and is strongly associated with increased risk of perinatal morbidity and mortality, as well as impaired cognitive and emotional development later in childhood and adolescence.[8,9,70] Low maternal weight-for-height, poor GWG and micronutrient deficiencies such as IDA increase risk of IUGR, which is associated with neonatal mortality in the short term and sub-optimal growth and development in the long term; for example, in cognition, learning disabilities, academic achievement and psychosocial maturation.[71] For those infants defined as SGA, neonatal mortality risk is higher than those born appropriate for gestational age, even if born at term.[6] LBW, a result of preterm birth and/or growth restriction *in utero*, is associated with increased risk of perinatal morbidity and mortality, as well as of long-term health risk. Sufficient evidence exists to suggest that impaired growth *in utero* increases long-term risk of NCDs such as T2DM, hypertension and CVD, with the highest level of risk being seen in those who subsequently experience rapid and/or excessive of weight gain.[6]

Challenges of appropriate interventions in the first 1000 days to reduce childhood obesity and adult NCDs in African women

MNS, childhood obesity and adult NCD risk is complex and influenced by multiple factors at various life stages, making it difficult to reverse once highly prevalent in populations. Exposure to a poor nutrition environment in the first 1000 days (critical periods of plasticity) seems to have significant effects on body function, metabolism and a programming phenotypic effect, thereby influencing susceptibility to obesity, as well as to NCDs, in the longer term. This is of critical importance in the African setting where maternal obesity, coupled with poor micronutrient status and diet quality, continues to grow.[45,72,73] Although the plastic nature of this period makes it vulnerable to poor environmental exposures, it also provides a unique window for intervention. Ensuring optimal growth and development during this window, when women are highly motivated and tend to experience greater contact with health services, should therefore be prioritized in Africa to improve long-term health trajectories.[74] The main challenges for appropriate nutritional interventions in first 1000 days include (i) when to intervene to get the best returns (pre-pregnancy *v.* early pregnancy *v.* after birth *v.* infancy) and (ii) which nutrients and what doses to include. The *Lancet* series on maternal and child nutrition has provided a new conceptual framework that shows and elucidates on the means to optimum fetal and child growth and development.[45] This framework outlines the dietary, behavioural and health determinants of optimum nutrition, growth and development, and how they are affected by various underlying conditions, which are in turn shaped by economic and social conditions, national and global contexts, capacity, resources and governance. In addition, the series outlines and discusses how determinants can be changed to enhance maternal and childhood outcomes, including nutrition-specific interventions that address the immediate and underlying causes of malnutrition.[75,76]

There is a lack of data associating MNS with outcomes beyond birth in Africa. A need exists for longitudinal data from pregnancy through infancy to 2 years of age, and beyond. Without this evidence we cannot adequately influence policy or strengthen health systems.

Conclusion

Although improvements in MNS are evident in African countries, such as low maternal underweight prevalences, rapid transition has widened the spectrum of risk associated with maternal and child health to include high levels of overweight and obesity alongside sustained macro- and micronutrient insufficiency (hidden hunger). Although robust evidence to support the associations between MNS and fetal, birth, neonatal and infant outcomes is limited in Africa, data does support the relationships seen globally between maternal anthropometry and outcomes in this setting. In addition, the high prevalence of deficiencies in critical pregnancy-related nutrients, as well as the benefits seen in supplementation trials of women, does suggest that improvements in MNS could have significant effects on outcomes of interest. This review therefore confirms the importance of the first 1000 days within the African setting, but highlights that this area still remains underresearched as well as the need to focus on this window to optimize not only maternal and child health in the short term, but potentially reduce the burden of both undernutrition and NCD risk in current and future generations.

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Conflicts of Interest

None.

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