Public Health Nutrition: 24(12), 3698–3709 doi:10.1017/S1368980020002827

Livestock ownership and anaemia in Sub-Saharan African households

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Submitted 11 December 2019: Final revision received 1 July 2020: Accepted 13 July 2020: First published online 24 August 2020

Abstract

Objective: To determine the association between livestock ownership and Hb concentration of women of child-bearing age (WCBA) and preschool-aged children in Sub-Saharan Africa (SSA).
Design: A prospective analysis of publicly available cross-sectional data, using linear and logistic regressions controlling for potential confounders.
Setting: Twenty-eight countries in SSA.
Participants: 162 305 WCBA and 118 607 children aged 6–59 months.
Results: More than half of WCBA (62·5 %) and children (58 %) belonged to households that owned livestock. The average altitude-adjusted blood Hb concentration for WCBA and children was 12.23 and 10·24 g/dL, respectively. In adjusted models, higher number of livestock owned was associated with lower Hb concentration for children but not for WCBA. The magnitude of the association for children was small, with one additional unit of livestock owned reducing Hb concentration by 0·001 g/dL. Higher numbers of cattle, cows and bulls, sheep, and goats were associated with lower Hb concentration for both groups. The number of certain categories of livestock owned was associated with the consumption of relevant foods by children. There was no association between the consumption of animal-source foods and Hb concentration or between livestock ownership and diarrhoeal diseases or fever among children.
Conclusions: Livestock ownership in SSA had a net negative association with the Hb concentration of children and no association with that of WCBA. The results highlight the need for research aimed at clarifying the mechanisms linking livestock ownership and nutritional status, and identifying entry points for leveraging livestock ownership to improve the health of women and children in SSA.

Keywords
Sub-Saharan Africa
Anaemia
Livestock ownership
Women of child-bearing age
Under-five children

Livestock plays an important role as a source of income and nutrition in many low- and middle-income countries (LMIC). Several studies have shown that the availability of meat and milk through livestock ownership helps improve nutrition[1–7]. In contrast, livestock ownership can also be a risk factor for nutrition and health. There is increasing evidence that faecal contamination associated with human and animal faeces may raise the chances of a condition called environmental enteric dysfunction among children[8,9]. This condition, which is widespread among children and adults in LMIC, reduces the absorptive capacity and the barrier function in the small intestine[10,11], resulting in an overall poor health. The overall effect of these two channels – one affecting nutritional status adversely and another affecting it positively – is an empirical question.

Anaemia is a complex disease with multi-factorial determinants related to both dietary intake and infectious disease exposure. As such, it is a useful condition for examining the potential overall health implications of livestock ownership. Anaemia is highly prevalent among women of child-bearing age (WCBA) and young children throughout Sub-Saharan Africa (SSA). According to an estimate from the WHO, 60·2 % (or, approximately 84·5 million) of the children aged 6–59 months in Africa are anaemic, compared with a global average of 42·6 %[12]. Likewise, 37·6 % (or, approximately 95·3 million) women of reproductive age are anaemic in that continent,

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compared with 29·4 % globally[12]. Deficiency of nutrients, such as Fe, is a major cause of anaemia in LMIC[13], with the proportion of anaemia attributable to Fe deficiency in 2016 ranging between 25 % for preschool children and 37 % for WCBA[14] (WHO estimates from 2011 indicate that 42 % of anaemia in children and 50 % of anaemia in women could be eliminated by Fe supplementation[12]). Fe deficiency, often caused by monotonous plant-based diets, is estimated to be prevalent among two billion individuals worldwide[15].

A recent review, by Lambrecht *et al.* (2019), has shown mixed evidence on whether livestock ownership promotes or reduces anaemia[16], concluding that the evidence base for evaluating Fe and anaemia status, consumption of animal-source foods, and morbidity outcomes as they relate to animal production is weak. Strikingly, all of the studies available for that review were relatively small and from a specific country or setting. The small, context-specific studies have the advantage of generating evidence applicable to a given setting. However, an important limitation of such studies is that they may be underpowered because of their small sample size. In fact, two other previous reviews have noted insufficient statistical power as a limitation of many existing studies examining the association between animal production on anaemia and other nutritional outcomes[17,18].

In the current study, we attempted to fill this important gap in the literature by estimating the overall association of livestock ownership with Hb concentration in a large sample of WCBA and preschool-aged children aged 6–59 months in 28 countries in SSA. Our sample was sufficiently large to detect an association if one existed and rule out lack of statistical power as a reason for any lack of statistically significant association. A second key contribution of our study is that we were able to generate additional suggestive evidence on the potential mechanisms linking livestock ownership and Fe-deficiency anaemia. For example, we examined the association between the number of specific types of livestock owned and the consumption of food for which that type of livestock is a key source (e.g., ownership of poultry and consumption of eggs). Likewise, we examined the association between livestock ownership and health events that can influence anaemia status (e.g., incidence of diarrhoea). While many of these associations have been examined previously, we are unaware of any study that examines these relationships using the same sample.

Methods

Data

We used publicly available data from the Demographic and Health Surveys (DHS), a program that collects nationally representative data from LMIC worldwide on fertility, health and nutrition topics[19]. We compiled household member's and children's recode DHS data files from all countries in SSA for which the most recent standard DHS survey was completed in or after 2007. We excluded countries for which the DHS did not collect data on Hb concentration of both women and children (Kenya, Liberia and Nigeria). If data on Hb concentration of both women and children were collected in previous rounds of the DHS and not in the latest survey, we included the data from the previous round (Senegal). We included countries for which data on Hb concentration of either mother or their children were available (Angola). Data for Gambia were not publicly available so we did not include Gambia in our analysis. Data on livestock ownership, our key independent variable, were not available for Sao Tome and Principe. This resulted in 118 607 children aged 6–59 months from 13 494 clusters in 27 countries for the children sample. For the WCBA sample, data on smoking status of women were not available for Guinea, thus resulting in 162 305 non-pregnant women aged 15–49 years from 12 856 clusters in 25 countries. Online supplementary material, Appendix Table 1 shows the list of countries and number of clusters and individuals included in the analysis.

DHS data collection activities were approved by the Inner City Fund International (Calverton, MD) institutional review board and the country-level entities responsible for the ethical review of research on human subjects[20]. As the DHS data are de-identified and publicly available, a separate ethics approval was not required for the current study.

Measurement of outcome variables

The primary outcome that we assessed was the altitude-adjusted blood Hb concentration (in g/dL) of WCBA and preschool-aged children. In a supplementary analysis, we also assessed anaemia level as a binary outcome. Based on the Hb concentration, DHS provides four categories of anaemia status: severely anaemic (<7 g/dL), moderately anaemic (7–10 g/dL), mildly anaemic (10–11 g/dL) and not anaemic (>10 g/dL). For the binary outcome, we considered individuals in the first three categories to be anaemic.

In an effort to understand mechanisms, we examined the association between the consumption of animal-source food and the number of different types of livestock owned. We used a binary variable that measured whether the index child in a household consumed a food from the respective category of animal-source food during the 24 h preceding the survey (including meat, eggs and dairy foods). We conducted these analyses only for children because dietary data among WCBA were not available. Finally, for the child sample, we also assessed the association of the number of livestock owned with recent report (previous 2 weeks) of diarrhoea and fever, respectively.

Measurement of key independent variables

The primary independent variables examined in our analyses were the total number of livestock and the number of specific type of livestock owned by the household. The specific categories of livestock included cattle, cows or bulls, sheep, goats, pigs and chicken, which are available for all countries in our sample. The total number of livestock included all aforementioned categories (as well as a small number of other livestock, such as horses, information on which was available for only a subset of the countries). In the regressions of Hb concentration on animal-source food consumption, the independent variables were whether the respondent consumed egg, dairy or meat during the 24 h preceding the survey.

Measurement of covariates

We included several covariates in our analyses to adjust for potential confounding of the relationship between anaemia and livestock ownership. These covariates were selected *a priori* based on previous evidence of determinants of anaemia[21–23]. In the child-level analysis with Hb concentration as the outcome, the covariates included child sex, age and breast-feeding status, whether the child had had fever, helminth or diarrhoea during the 2 weeks preceding the survey and whether the child had received Fe or vitamin supplements. Other covariates included the highest attained education level of the child's mother, household access to an improved source of water and sanitation[24], the number of individuals living in the household and the gender of the household head. We also included the quintiles of wealth index available from the DHS for each household[25]. Household flooring, access to electricity and ownership of a radio, television, refrigerator, bicycle, motorcycle and car were used to develop the index. At the cluster level, we adjusted for whether the cluster was urban or rural based on DHS definitions. We further adjusted for country fixed effects and the month of the survey to account for differences in Hb concentration that may have been driven by specific country effects and seasonal variation in food availability. DHS child recode files provided data on whether the child had had fever, helminth or diarrhoea during the 2 weeks preceding the survey, and whether the child had received Fe or vitamin supplements. All other variables were taken from the household member's recode files.

In the WCBA analysis, we included all of the covariates mentioned above except the covariates related to the child (namely, the child's sex, age and breastfeeding status, whether the child had had fever, helminth or diarrhoea during the 2 weeks preceding the survey and whether the child had received Fe or vitamin supplements).

Statistical analysis

Means and proportions for key household- and child-level characteristics, Hb concentration and livestock ownership were calculated. The correlation between maternal and child Hb concentration as well as the binary measure of anaemia status was also calculated. To assess the relation between a child's Hb concentration and the number of livestock owned, we estimated the coefficients in a regression of the following form:

$$Y_{ijk} = \alpha + \beta_1 \text{Number Of Live stock Owned}_j + \delta \mathbf{X}_{ijk} + \eta + \omega + \varepsilon \quad (1)$$

In our main analysis, Y_{ijk} was the continuous variable indicating the altitude-adjusted blood Hb concentration of child i in household j living in cluster k. The number of livestock owned was the primary independent variable and varied by household. The coefficient β_1 reflected the association between number of livestock owned and the child's altitude-adjusted blood Hb concentration. Given the mixed evidence on the relationship between anaemia and livestock ownership in the existing literature, we had no priors about the sign of the coefficient β_1. If Hb concentration fell with the ownership of a higher number of livestock, β_1 would be negative; otherwise, it would be positive. $\boldsymbol{X}$ represented child-, household- and cluster-level covariates mentioned in the previous subsection. η represented the country of the child, while ω represented the month of the survey. We also estimated equation (1) by including Y_{ijk} as a binary measure of anaemia status (anaemic *v.* not) and reported the OR separately.

We estimated similar regressions for WCBA except that Y_{ijk} was the Hb concentration of woman i in household j living in cluster k, and the equation included a different set of covariates, as discussed above.

To assess the relationship between Hb concentration and the number of specific type of livestock owned, we estimated regressions similar to the one above by replacing the number of all livestock owned with the number of specific type of livestock owned.

Given the high prevalence of malaria in SSA and the established association between malaria and anaemia status[26], it would be important to control for incidence of malaria in our analysis. However, the surveys did not include information on whether the child or WCBA had had malaria. Data on the use of sprays and bed nets, which could potentially proxy for malaria occurrence, were missing for a large number of observations. Therefore, we decided not to control for these proxies in the main analysis. However, as a robustness check, we conducted a separate analysis on the smaller sample for which we had data on the use of sprays and bed nets, and compared these results to the results from the larger sample.

To estimate the association between livestock ownership and consumption of animal-source food, we estimated an equation similar to (1), where Y_{ijk} was a binary variable indicating whether child i in household j living in cluster k consumed a specific animal-source food. The independent

https://doi.org/10.1017/S1368980020002827 Published online by Cambridge University Press

variable was a continuous measure of the number of the relevant type of livestock owned.

In all models, we clustered the SE at the level of the DHS enumeration cluster to account for arbitrary correlation between observations within each cluster. Clustering SE at the level of DHS sampling units also accounts for intra-household correlations for households with multiple children in the sample. The statistical significance of associations is reported at the $P < 0.05$, $P < 0.01$ and $P < 0.001$ levels. Given current debates on the arbitrary nature of these cut-offs[27], we reported 95 % CI for all major findings. We carried out all analyses using the Stata statistical software package version 15[28].

Results

In the analytic sample, the livestock ownership rate was 58 % for WCBA and 62·5 % for children. Approximately, 39·7 % WCBA and 64·9 % children were anaemic. The average altitude-adjusted blood Hb concentration was 12·23 and 10·24 g/dL for WCBA and children, respectively. In the WCBA analytic sample, the average number of livestock owned was 11·28. The number of cattle, cows or bulls, sheep, goats, pigs and chicken owned were, respectively, 2·55, 0·86, 0·96, 1·84, 0·38 and 5·17. In the children sample, the average number of livestock owned was 12·48. The number of cattle, cows or bulls, sheep, goats, pigs and chicken owned were, respectively, 2·69, 1·29, 1·35, 2·05, 0·34, and 5·29 (Table 1). The correlation between maternal and child Hb concentration was 0·22, while the correlation between maternal and child anaemia status was 0·16 (not shown).

For children, after adjusting for the covariates, higher number of livestock owned was associated with lower Hb concentration (Table 2). This negative association was true for the total number of livestock as well as the number of specific type of livestock, including cattle, cows and bulls, sheep, and goats. However, the magnitude of the association was very small. On average, one additional unit of livestock owned was associated with a reduction in Hb concentration of 0·001 g/dL. There was no association between the number of pigs or chicken owned and the Hb concentration. The coefficients for covariates were all in the expected direction. For example, larger household size, living in a rural area and having fever recently were associated with lower Hb concentration while higher age, access to improved sanitation and more wealth were associated with lower Hb concentration.

For WCBA, there was no association between the total number of livestock owned and the Hb concentration (Table 3). The association between the number of specific type of livestock and Hb concentration varied by the type of livestock. There was no association between the number of pigs owned and Hb concentration. There was a negative association between numbers of cattle, cows and bulls, sheep, and goats, and Hb concentration. The association between the number of chicken owned and the Hb concentration was positive. Similar to the results for the child sample, the magnitude of the association in the WCBA sample was small (for all livestock as well as the specific type of livestock). The coefficients on the covariates were, again, in the expected direction except on the number of cigarettes smoked.

In online supplementary material, Appendix Table 2, we show OR for logistic regressions with anaemia as the outcome, separately for children and WCBA. These regressions controlled for the same set of covariates as those reported in Tables 2 and 3. Consistent with the results in Tables 2 and 3, in adjusted regressions, higher number of livestock owned was associated with higher odds of anaemia for children (OR 1·001 (95 % CI 1·000, 1·002)) but not for WCBA. In online supplementary material, Appendix Table 3, we show coefficients from estimating the main regression in the smaller sample for which data on the availability of mosquito spray and bed net were available. The substantive results remained unchanged.

Table 4 reports OR from logistic regressions of food consumption on number of specific categories of livestock owned among children aged 5–59 months. The number of chicken owned was associated with higher odds of eggs consumption (OR 1·005 (95 % CI 1·002, 1·008)). Higher number of cows and bulls was associated with higher odds of dairy consumption among children (OR 1·012 (95 % CI 1·005, 1·019)). Higher numbers of chicken and sheep were associated with higher odds of meat consumption (OR 1·003 (95 % CI 1·000, 1·006)) and 1·006 (95 % CI 1·000, 1·012)), respectively. However, the number of goats owned was associated with lower odds of meat consumption (OR 0·990 (95 % CI 0·983, 0·996)). The number of pigs owned was not associated with meat consumption.

Table 5 reports coefficients from the regression of Hb concentration on the consumption of animal-source foods (specifically, eggs, daily and flesh) among children. The table shows that there was no association between Hb concentration and the consumption of animal-source foods.

As mentioned earlier, diarrhoea and fever are important risk factors for anaemia[29,30]. In our analysis, however, we found no association between livestock ownership and incidence of diarrhoea or fever among children (Table 6), suggesting that, while these symptoms were associated with Hb concentration among children (see Table 2), the pathway linking anaemia and these conditions did not seem to operate through livestock ownership in this context.

Discussion

Many NGO currently provide livestock as a way to improve the livelihoods of poor households in LMICs[5]. Whether such interventions have the intended health effects matters

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Table 1 Descriptive statistics of the analytic sample

	Children aged 5–59 months				Women aged 15–49 years			
Variables	*n*	Mean	SD	%	*n*	Mean	SD	%
Sample size	118 607				162 305			
Dependent variables								
Anaemic status†	77 023			64·90	64 393			39·70
Hb concentration (g/dL)		10·24	1·65			12·23	1·71	
Principal independent variable								
Own livestock	74 089			62·50	94 127			58·00
Number of livestock		12·48	24·80			11·28	23·55	
Number of cattle		2·69	9·49			2·55	9·06	
Number of cows and bulls		1·29	5·94			0·86	4·51	
Number of sheep		1·35	5·39			0·96	4·54	
Number of goats		2·05	5·99			1·84	6·00	
Number of pigs		0·34	2·19			0·38	2·27	
Number of chickens		5·29	10·75			5·17	10·83	
Child-level covariates								
Child age, months		31·33	15·58					
Child sex								
Female	58 792			49·60				
Male	59 815			50·40				
Highest attained education of mother								
None	50 219			35·30				
Primary	41 839			20·70				
Secondary	24 552			1·70				
Post-secondary	1997							
Food consumption in the last 24 h				9·40				
Egg	7074			33·70				
Dairy	3998			23·20				
Meat	25 463			59·60				
Fever in the last 2 weeks	27 530			10·30				
Vitamin A in the last 6 months	70 694			43·00				
Fe supplement in the last 7 d	12 170			16·20				
Intestinal parasites drugs in the last 6 months	51 053							
Diarrhoea in the last 2 weeks	19 206			59·10				
Breastfed for at least 6 months				9·00				
Breastfed but not currently	70 135							
Never breastfed	10 626							
Still breastfeeding	37 846							
Birth order		3·64	2·37					
Woman-level covariates								
Age in years						28·70	9·70	
Highest attained education								
None					46 768			28·80
Primary					58 323			35·90
Secondary					51 812			31·90
Post-secondary					5402			3·30
Number of cigarettes smoked in the last 24 h						0·43	6·18	
Weight (kg)						58·67	42·45	
Household-level covariates								
Wealth quintiles								
Lowest	38 025			32·10	42 455			26·20
Low	22 755			19·20	26 335			16·20
Middle	21 627			18·20	26 237			16·20
High	18 624			15·70	28 760			17·70
Highest	17 576			14·80	38 518			23·70
Household size		7·48	4·65			6·41	3·55	
Household head sex								
Female	25 430			21·40	49 043			30·20
Male	93 177			78·60	113 262			69·80
Household access to improved water source	75 807			63·90	113 522			69·90
Household access to improved sanitation	53 244			44·90	84 082			51·80
Location								
Urban	33 665			71·60	58 625			36·10
Rural	84 942				103 680			63·90

†Altitude-adjusted Hb concentration below 11 g/dL.

https://doi.org/10.1017/S1368980020002827 Published online by Cambridge University Press

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Table 2 Coefficients from linear regressions of Hb concentration on the number of livestock owned (children aged 5–59 months)

Variables	All livestock	Cattle	Cows and bulls	Sheep	Goats	Pigs	Chicken
Number of livestock owned	−0·001***	−0·004***	−0·006***	−0·005***	−0·005***	0·000	0·000
	(0·000)	(0·001)	(0·001)	(0·001)	(0·001)	(0·003)	(0·001)
Household-level covariates							
Household size	−0·011***	−0·012***	−0·012***	−0·012***	−0·012***	−0·012***	−0·013***
	(0·001)	(0·002)	(0·001)	(0·001)	(0·001)	(0·002)	(0·001)
Household head sex							
Male (reference)							
Female	0·003	−0·017	0·005	0·005	0·005	0·009	0·006
	(0·012)	(0·015)	(0·013)	(0·012)	(0·012)	(0·013)	(0·012)
Location							
Urban (reference)							
Rural	−0·053**	−0·110***	−0·070***	−0·059***	−0·056**	−0·045*	−0·065***
	(0·017)	(0·019)	(0·018)	(0·017)	(0·017)	(0·019)	(0·017)
Wealth quintiles, %							
Lowest (reference)							
Low	0·094***	0·102***	0·090***	0·093***	0·093***	0·122***	0·092***
	(0·016)	(0·020)	(0·017)	(0·016)	(0·016)	(0·017)	(0·016)
Middle	0·084***	0·090***	0·080***	0·081***	0·080***	0·112***	0·079***
	(0·016)	(0·019)	(0·016)	(0·016)	(0·016)	(0·018)	(0·016)
High	0·164***	0·157***	0·167***	0·163***	0·161***	0·193***	0·160***
	(0·017)	(0·021)	(0·018)	(0·017)	(0·017)	(0·019)	(0·017)
Highest	0·347***	0·335***	0·352***	0·345***	0·344***	0·351***	0·341***
	(0·020)	(0·024)	(0·021)	(0·020)	(0·020)	(0·022)	(0·020)
Household access to improved water source							
No (reference)							
Yes	0·019	0·021	0·027	0·020	0·019	0·013	0·021
	(0·014)	(0·017)	(0·015)	(0·014)	(0·014)	(0·016)	(0·014)
Household access to improved sanitation							
No (reference)							
Yes	0·123***	0·147***	0·132***	0·126***	0·125***	0·118***	0·128***
	(0·014)	(0·016)	(0·014)	(0·014)	(0·014)	(0·015)	(0·014)
Child age, months	0·023***	0·025***	0·023***	0·023***	0·023***	0·022***	0·023***
	(0·000)	(0·001)	(0·000)	(0·000)	(0·000)	(0·000)	(0·000)
Child sex							
Male (reference)							
Female	0·118***	0·127***	0·117***	0·118***	0·118***	0·112***	0·117***
	(0·009)	(0·011)	(0·009)	(0·009)	(0·009)	(0·010)	(0·009)
Highest attained education of mother							
None (reference)							
Primary	0·150***	0·204***	0·137***	0·150***	0·149***	0·121***	0·155***
	(0·014)	(0·017)	(0·014)	(0·014)	(0·014)	(0·015)	(0·014)
Secondary	0·227***	0·237***	0·222***	0·227***	0·227***	0·215***	0·230***
	(0·017)	(0·021)	(0·018)	(0·017)	(0·017)	(0·019)	(0·017)
Post-secondary	0·334***	0·352***	0·341***	0·330***	0·329***	0·323***	0·333***
	(0·035)	(0·042)	(0·039)	(0·036)	(0·036)	(0·038)	(0·036)
Fever in the last 2 weeks							
No (reference)							
Yes	−0·357***	−0·320***	−0·358***	−0·357***	−0·357***	−0·365***	−0·357***
	(0·012)	(0·015)	(0·013)	(0·012)	(0·012)	(0·014)	(0·012)
Vitamin A in the last 6 months							
No (reference)							
Yes	0·064***	0·047***	0·061***	0·064***	0·064***	0·068***	0·065***
	(0·012)	(0·014)	(0·012)	(0·012)	(0·012)	(0·013)	(0·012)
Missing	0·144*	0·093	0·146*	0·136*	0·141*	0·168*	0·146*
	(0·065)	(0·085)	(0·066)	(0·065)	(0·065)	(0·070)	(0·065)
Fe supplement in the last 7 d							
No (reference)							
Yes	0·040*	0·078***	0·045*	0·042*	0·042*	0·033	0·043*
	(0·019)	(0·023)	(0·019)	(0·019)	(0·019)	(0·020)	(0·019)
Missing	0·074	0·118	0·075	0·076	0·071	0·082	0·077
	(0·098)	(0·130)	(0·099)	(0·098)	(0·098)	(0·098)	(0·099)
Intestinal parasites drugs in the last 6 months							
No (reference)							
Yes	0·021	0·013	0·021	0·022	0·022	0·044***	0·022
	(0·012)	(0·014)	(0·012)	(0·012)	(0·012)	(0·013)	(0·012)
Missing	−0·044	−0·038	−0·050	−0·043	−0·041	−0·065	−0·042
	(0·072)	(0·093)	(0·075)	(0·072)	(0·072)	(0·078)	(0·072)

https://doi.org/10.1017/S1368980020002827 Published online by Cambridge University Press

Table 2 *Continued*

Variables	All livestock	Cattle	Cows and bulls	Sheep	Goats	Pigs	Chicken
Diarrhoea in the last 2 weeks	−0·047***	−0·025	−0·043**	−0·047***	−0·047***	−0·045**	−0·047***
	(0·013)	(0·016)	(0·014)	(0·013)	(0·013)	(0·014)	(0·013)
Breastfed for at least 6 months							
Never breastfed (reference)							
Breastfed but not currently	−0·003	−0·003	−0·010	−0·002	−0·003	0·020	−0·002
	(0·023)	(0·027)	(0·024)	(0·023)	(0·023)	(0·025)	(0·023)
Still breastfeeding	−0·024	0·007	−0·026	−0·023	−0·024	0·007	−0·023
	(0·025)	(0·028)	(0·025)	(0·025)	(0·025)	(0·026)	(0·025)
Missing	−0·242	−0·244	−0·237	−0·239	−0·236	−0·086	−0·239
	(0·260)	(0·258)	(0·261)	(0·260)	(0·260)	(0·226)	(0·260)
Birth order	0·010***	0·004	0·010***	0·010***	0·010***	0·009***	0·010***
	(0·002)	(0·003)	(0·002)	(0·002)	(0·002)	(0·002)	(0·002)
Sample size	118 607	76 551	110 391	118 475	118 431	97 330	118 110

* $P<0·05$, ** $P<0·01$, *** $P<0·001$. Standard errors are shown in parentheses below the coefficients.

Table 3 Coefficients from linear regressions of Hb concentration on the number of livestock owned (WCBA)

Variables	All livestock	Cattle	Cows and bulls	Sheep	Goats	Pigs	Chicken
Number of livestock owned	−0·000	−0·002*	−0·005***	−0·003*	−0·005***	−0·001	0·003***
	(0·000)	(0·001)	(0·001)	(0·001)	(0·001)	(0·002)	(0·000)
Household-level covariates							
Household size	−0·007***	−0·011***	−0·007***	−0·007***	−0·006***	−0·006***	−0·009***
	(0·001)	(0·002)	(0·001)	(0·001)	(0·001)	(0·002)	(0·001)
Household head sex							
Male (reference)							
Female	−0·061***	−0·080***	−0·046***	−0·061***	−0·061***	−0·070***	−0·057***
	(0·011)	(0·013)	(0·011)	(0·011)	(0·011)	(0·012)	(0·011)
Location							
Urban (reference)							
Rural	0·044**	0·026	0·044**	0·044**	0·049**	0·050**	0·032*
	(0·016)	(0·020)	(0·017)	(0·016)	(0·016)	(0·018)	(0·016)
Wealth quintiles, %							
Lowest (reference)							
Low	0·066***	0·126***	0·074***	0·066***	0·066***	0·083***	0·064***
	(0·016)	(0·020)	(0·017)	(0·016)	(0·016)	(0·017)	(0·016)
Middle	0·047**	0·093***	0·053***	0·047**	0·048**	0·049**	0·042**
	(0·015)	(0·019)	(0·016)	(0·015)	(0·015)	(0·017)	(0·015)
High	0·074***	0·098***	0·071***	0·074***	0·074***	0·097***	0·073***
	(0·016)	(0·020)	(0·017)	(0·016)	(0·016)	(0·018)	(0·016)
Highest	0·159***	0·186***	0·168***	0·159***	0·160***	0·176***	0·156***
	(0·019)	(0·022)	(0·019)	(0·019)	(0·019)	(0·021)	(0·019)
Household access to improved water source							
No (reference)							
Yes	0·007	0·012	0·007	0·006	0·005	0·019	0·008
	(0·013)	(0·017)	(0·014)	(0·013)	(0·013)	(0·015)	(0·014)
Household access to improved sanitation							
No (reference)							
Yes	0·049***	0·070***	0·049***	0·049***	0·048***	0·030*	0·051***
	(0·012)	(0·015)	(0·013)	(0·012)	(0·012)	(0·014)	(0·012)
Woman-level covariates							
Age in years	0·000	−0·000	0·001	0·000	0·000	0·000	0·000
	(0·000)	(0·001)	(0·000)	(0·000)	(0·000)	(0·001)	(0·000)
Number of cigarettes smoked in the last 24 h	−0·003***	−0·003**	−0·003***	−0·003***	−0·003***	−0·003**	−0·003***
	(0·001)	(0·001)	(0·001)	(0·001)	(0·001)	(0·001)	(0·001)
Weight (kg)	0·000***	0·001**	0·000**	0·000***	0·000***	0·000*	0·000***
	(0·000)	(0·000)	(0·000)	(0·000)	(0·000)	(0·000)	(0·000)
Highest attained education							
None (reference)							
Primary	0·163***	0·217***	0·163***	0·161***	0·159***	0·151***	0·165***
	(0·013)	(0·017)	(0·014)	(0·013)	(0·013)	(0·015)	(0·014)
Secondary	0·164***	0·227***	0·157***	0·162***	0·161***	0·162***	0·164***
	(0·015)	(0·019)	(0·016)	(0·015)	(0·015)	(0·017)	(0·015)
Post-secondary	0·222***	0·256***	0·243***	0·220***	0·218***	0·219***	0·219***
	(0·028)	(0·033)	(0·030)	(0·028)	(0·028)	(0·030)	(0·028)
Sample size	162 305	110 083	147 646	162 135	162 046	129 453	161 516

* $P<0·05$, ** $P<0·01$, *** $P<0·001$. Standard errors are shown in parentheses below the coefficients.

Table 4 OR from logistic regressions of food consumption (binary) on the number of specific livestock owned (children aged 5–59 months)

	Egg	Dairy	Flesh
Chickens	1·005**		1·003*
95 % CI	1·002, 1·008		1·000, 1·006
Cows and bulls		1·012***	
95 % CI		1·005, 1·019	
Sheep			1·006*
95 % CI			1·000, 1·012
Goats			0·990**
95 % CI			0·983, 0·996
Pigs			1·003
95 % CI			0·993, 1·013
N	75 192	71 013	62 063

* $P<0·05$, ** $P<0·01$, *** $P<0·001$.

Table 5 Coefficients from regression of Hb concentration on specific food consumption (children aged 5–59 months)

	Hb concentration
Egg	0·032
	(0·022)
Dairy	0·003
	(0·027)
Flesh	–0·005
	(0·014)
n	75 413

All regressions include the same set of covariates as in Table 2. Standard errors are shown in parentheses below the coefficients.

significantly for meeting Goals 2 (Zero Hunger) and 3 (Health) of the Sustainable Development Goals. Yet, the literature on the relationship between livestock ownership and anaemia in SSA continues to evolve, with the evidence so far largely mixed. The current study aimed to fill this gap by examining the relationship between livestock ownership and Hb concentration, a measure of anaemia, across a diverse geographic region and a large sample of women and children.

In summary, our findings first indicate that higher number of livestock owned by a household (total as well as specific types) was associated with lower Hb concentration among children in that household. This was true except in the case of pigs and chicken where there was no such association. Secondly, a higher number of livestock, with the exception of pigs and chicken, was associated with lower Hb concentration among WCBA. For WCBA, a higher number of chicken was associated with higher Hb concentration. Likely in part because of the offsetting effect of these two associations, there was no association between the total number of livestock and Hb concentration. Finally, the negative associations between livestock ownership and Hb concentration, while statistically significant for children, were quite small. Take sheep as an example. An average household in the children sample owned 1·35 sheep and the Hb concentration of an average child was 10·24 g/dL. At these means, owning an extra sheep reduced the Hb concentration by 0·005 g/dL. This means that for the child's Hb concentration to fall to 9·24 g/dL (i.e., a decrease of 1 g/dL), the number of sheep owned by the household would have to increase by 200 (=1/0·005). The associations of owning higher number of specific types of livestock with Hb concentration of WCBA were similarly very small.

Our exploration of the mechanisms linking livestock ownership and Hb concentration underscores the need for additional research on the livestock-anaemia nexus. The number of diverse categories of animals owned (including cows and bulls, and chicken) was associated with higher odds of consuming the respective category of animal-source food. For example, consumption of eggs by children increased with the number of chicken owned by household. This suggests that a dietary pathway (i.e., higher consumption of animal-source foods) may predominate over an infectious disease pathway in underlying the overall association between livestock ownership and Hb concentration. But this assertion needs to be further assessed as we found no statistically significant associations between number of livestock owned and the incidence of diarrhoea or fever among young children.

We also found no association between consumption of animal-source foods and Hb concentration among children. One can hypothesise that, although a child may be more likely to consume an animal-source food when the household owns more livestock, the amount of the animal-source food consumed may not change by a quantity that is large enough to alter Hb concentration. Likewise, it may be that households substituted away from other nutrient-rich foods when animal-source foods were available, thus offsetting any gains in nutrients from the consumption of animal-source foods. Finally, it is possible that consumption of animal-source foods does not address the underlying cause of anaemia (if the cause was not nutrition-related) for a considerable number of women and children for which infection, genetics and lifestyle factors, such as smoking and alcohol consumption[31,32], may be the primary drivers of Hb concentration. Unfortunately, the available data did not allow us to explore these hypotheses.

It is difficult to compare our findings with those of previous studies, given that most studies have examined the association with livestock ownership as a binary variable or referred to a specific country or setting. Nonetheless, a rough comparison of the key findings points to the emerging nature of the research on this topic. In a study similar to the current study, Kaur *et al.* used data from 30 Sub-Saharan African countries to assess the association between livestock ownership and the prevalence of diarrhoea, stunting and mortality among under-five children[33]. In their pooled data, they found a positive association between livestock ownership and mortality, thus contradicting our assertion about the dominance of the dietary pathway. However, they reported no association between livestock ownership

https://doi.org/10.1017/S1368980020002827 Published online by Cambridge University Press

Table 6 OR from logistic regression of diarrhoea and fever on livestock ownership (children aged 5–59 months)

Variables	Diarrhoea	Fever
Number of livestock owned	1·000	1·000
95 % CI	0·999, 1·000	0·999, 1·001
Household-level covariates		
Household size	1·006*	1
95 % CI	1·001, 1·010	0·996, 1·004
Household head sex		
Male (reference)		
Female	1·001	1·034
95 % CI	0·960, 1·044	0·996, 1·073
Location		
Rural	0·898***	1·073**
95 % CI	0·851, 0·946	1·021, 1·126
Urban (reference)		
Wealth quintiles, %		
Lowest (reference)		
95 % CI		
Low	0·981	0·994
95 % CI	0·932, 1·032	0·948, 1·042
Middle	0·954	1·028
95 % CI	0·906, 1·005	0·982, 1·076
High	0·918**	1·015
95 % CI	0·865, 0·974	0·963, 1·069
Highest	0·857***	0·914**
95 % CI	0·801, 0·917	0·859, 0·973
Household access to improved water source		
No (reference)		
Yes	0·982	1·006
95 % CI	0·941, 1·024	0·968, 1·047
Household access to improved sanitation		
No (reference)		
95 % CI		
Yes	0·911***	0·916***
95 % CI	0·871, 0·952	0·880, 0·954
Child age, months	0·965***	0·993***
95 % CI	0·964, 0·967	0·991, 0·994
Child sex		
Male (reference)		
95 % CI		
Female	0·912***	0·983
95 % CI	0·884, 0·942	0·956, 1·010
Highest attained education of mother		
None (reference)		
Primary	1·037	1·092***
95 % CI	0·991, 1·085	1·049, 1·136
Secondary	0·967	1·063*
95 % CI	0·913, 1·024	1·009, 1·121
Post-secondary	0·591***	0·927
95 % CI	0·506, 0·689	0·815, 1·055
Fever in the last 2 weeks		
No (reference)		
Yes	3·463***	
95 % CI	3·337, 3·593	
Vitamin A in the last 6 months		
No (reference)		
Yes	1·075***	1·047*
95 % CI	1·032, 1·119	1·009, 1·086
Missing	0·827	1·02
95 % CI	0·666, 1·026	0·837, 1·244
Fe supplement in the last 7 d		
No (reference)		
Yes	1·152***	1·163***
95 % CI	1·085, 1·223	1·102, 1·227
Missing	1·476**	0·884
95 % CI	1·112, 1·960	0·671, 1·166

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Table 6 *Continued*

Variables	Diarrhoea	Fever
Intestinal parasites drugs in the last 6 months		
No (reference)		
Yes	1·065**	1·072***
95 % CI	1·023, 1·110	1·034, 1·112
Missing	1·008	1·232*
95 % CI	0·810, 1·255	1·009, 1·504
Diarrhoea in the last 2 weeks		3·453***
95 % CI		3·327, 3·583
Breastfed for at least 6 months		
Never breastfed (reference)		
Breastfed but not currently	0·954	1·136***
95 % CI	0·878, 1·037	1·057, 1·221
Still breastfeeding	0·958	1·198***
95 % CI	0·879, 1·044	1·111, 1·291
Missing	2·859*	1·729
95 % CI	1·124, 7·270	0·782, 3·825
Birth order	0·979***	1·015***
95 % CI	0·972, 0·986	1·008, 1·022
Sample size	133 301	133 301

*$P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.

and incidence of diarrhoea, as we did in the current study. This lack of a significant relationship between livestock ownership and diarrhoeal diseases, in turn, contradicted a recent review[34], which found a positive association between livestock ownership and diarrhoeal diseases, although the authors noted substantial heterogeneity across studies in terms of the effect size and the strength of the association.

Our study had several limitations. First, although we controlled for a range of child-, household- and cluster-level factors hypothesised to be associated with anaemia status, the observational nature of the current analysis precludes the interpretation of the coefficients as causal estimates of the effect of number of livestock owned on Hb concentration – the shortcoming common to the vast majority of previous studies on this topic. For a number of potential factors (specifically, the availability of mosquito nets – as a proxy for exposure to malaria – and the timing of complementary feeding), we were able to perform additional analysis on a smaller sample for which information on these variables was available. The overall findings did not change. Nonetheless, we cannot rule out the possibility of substantial residual confounding from unobserved factors (e.g., where animals are kept, within-household allocation of animal-source foods and the consumption of Fe supplements by mothers). This limitation also applies to our exploration of the mechanisms.

Second, we were not able to explore the effect of livestock ownership on income, an important intermediate factor linking livestock ownership to consumption and overall health. Data on income are not available from the DHS. It has been documented that livestock ownership helps households accumulate savings as well as assets and offset unexpected expenditures[35]. Higher income may improve nutrition and health outcome indirectly, such as by enabling households to buy necessary food and drugs. Although we assessed *whether* a child was given certain type of food, information on income could have provided a better reflection of consumption, including the quantities consumed. In our analysis, following previous literature[36], we included quintiles of the wealth index available from the DHS as a covariate to reduce confounding. However, to use the wealth index as the measure of income (thus as a dependent variable), we would need to make several assumptions about saving and consumption behaviour of households, which are not possible to test with existing data. For example, we would need to assume that any increase in income from additional livestock would translate to higher ownership of the durable assets (e.g., furniture and type of flooring) that are used to create the wealth index. Given the lack of data, we were also not able to explore the effect of livestock ownership on nutritional benefits other than anaemia status (e.g., protein deficiency).

Finally, information on the number of livestock owned – our key independent variable – was self-reported by the respondents and is therefore vulnerable to reporting error. Some individuals may be reluctant to reveal the exact number of livestock. However, this problem is unlikely to substantially bias our estimates on the relationship between Hb concentration and number of livestock, as there were no clear benefits or harm to the respondents from overstating or understating the number of livestock. The DHS is performed as privately as possible[20].

Although our study had several limitations, it contributes to the burgeoning literature on livestock ownership and anaemia in several ways. As noted earlier, to our knowledge, this is the first study to address the research

https://doi.org/10.1017/S1368980020002827 Published online by Cambridge University Press

question using such a large and representative sample, and we also generated suggestive evidence on potential mechanisms linking livestock ownership and anaemia. In addition, we made an important methodological contribution. The vast majority of prior studies on this topic have examined the relationship between *whether* a household owns livestock and anaemia status using logistic regression and have reported the OR. We used the *number* of livestock a household owned as the independent variable and conducted the analysis using a linear regression with both independent and dependent variables as continuous. The distinction is not trivial because our approach enables a more meaningful comparison of the association across studies. Although OR have been used extensively in the literature, they are often mistaken for relative risk ratios[37,38], and the two diverge by large amounts when the baseline prevalence of the outcome exceeds 10 % (as discussed below, the prevalence of anaemia among children in SSA is approximately 65 %). Norton and Dowd provide a detailed discussion of the limitations of using OR[39,40]. Briefly, the magnitudes of the OR from a logistic regression are scaled by an arbitrary factor and adding more covariates to the model increases the OR of the variable of interest. More importantly, our analysis allows governments and non-government organisations to estimate the extent of the support they need to provide in a population to achieve a desired outcome – for example, how many chicken they need to provide to a household to raise Hb concentration of a child in the household by 1 g/dL.

While our study fills an important gap in the literature by addressing important limitations of existing studies, the need for rigorous studies that test the *causal* relationship between livestock ownership and Hb concentration as well as the two main mechanisms hypothesised in the literature – one raising Hb concentration and another reducing it – cannot be overemphasised. The vast majority of the studies discussed in the two reviews we referenced earlier[16,34] were cross-sectional, with varying degrees of vulnerability to bias. The mixed evidence from the current study also points to the need for researchers to move beyond examining associations.

Conclusions

This research, suggesting a substantively small linkage between livestock ownership and anaemia among mothers and young children in SSA, adds to the growing body of empirical evidence that livestock ownership has an important role to play in supporting human nutrition and health. Our observational results suggest that the net effect of owning livestock might be negative, although additional research will be required to clarify the mechanisms.

Acknowledgements

Acknowledgements: The authors would like to thank the Demography and Health Surveys Program for making the data available. *Financial support:* None. *Conflict of interest:* None. *Authorship:* Y.A. and A.D.J. conceptualised the study. Y.A. and D.Y. prepared the data set and conducted the data analysis. All authors contributed to the drafting of the manuscript and approved the final version for submission. *Ethics of human subject participation:* DHS data collection activities were approved by the ICF International (Calverton, MD) institutional review board as well as the country-level entity that approves research on human subjects. A separate ethics approval was not required for the current study as it uses publicly available de-identified data.

Supplementary material

For supplementary material accompanying this paper visit https://doi.org/10.1017/S1368980020002827.

References

1. Darapheak C, Takano T, Kizuki M *et al.* (2013) Consumption of animal source foods and dietary diversity reduce stunting in children in Cambodia. *Int Arch Med* **6**, 29–39.
2. Dror DK & Allen LH (2011) The importance of milk and other animal-source foods for children in low-income countries. *Food Nutr Bull* **32**, 227–243.
3. Iannotti L & Lesorogol C (2014) Animal milk sustains micronutrient nutrition and child anthropometry among pastoralists in Samburu, Kenya. *Am J Phys Anthropol* **155**, 66–76.
4. Leroy JL & Frongillo EA (2007) Can interventions to promote animal production ameliorate undernutrition? *J Nutr* **137**, 2311–2316.
5. Rawlins R, Pimkina S, Barrett CB *et al.* (2014) Got milk? The impact of Heifer International's livestock donation programs in Rwanda on nutritional outcomes. *Food Policy* **44**, 202–213.
6. Hossain MB & Khan JR (2020) Association between household livestock ownership and childhood stunting in Bangladesh–a spatial analysis. *J Trop Pediatr* **66**, 248–256.
7. Kabunga NS, Ghosh S & Webb P (2017) Does ownership of improved dairy cow breeds improve child nutrition? A pathway analysis for Uganda. *PLoS One* **12**, 1–17.
8. Syed S, Ali A & Duggan C (2016) Environmental enteric dysfunction in children: a review. *J Pediatr Gastroenterol Nutr* **63**, 6–14.
9. Budge S, Parker AH, Hutchings PT *et al.* (2019) Environmental enteric dysfunction and child stunting. *Nutr Rev* **77**, 240–253.
10. Crane RJ, Jones KDJ & Berkley JA (2015) Environmental enteric dysfunction: an overview. *Food Nutr Bull* **36**, S76–S87.
11. Owino V, Ahmed T, Freemark M *et al.* (2016) Environmental enteric dysfunction and growth failure/stunting in global child health. *Pediatrics* **138**, 1–10.
12. WHO (2015) The global prevalence of anaemia in 2011. https://www.who.int/nutrition/publications/micronutrients/global_prevalence_anaemia_2011/en/ (accessed June 2020).

13. Pasricha S-R, Drakesmith H, Black J *et al.* (2013) Control of iron deficiency anemia in low- and middle-income countries. *Blood* **121**, 2607–2617.
14. Petry N, Olofin I, Hurrell RF *et al.* (2016) The proportion of anemia associated with iron deficiency in low, medium, and high human development index countries: a systematic analysis of national surveys. *Nutrients* **8**, 1–17.
15. Zimmermann MB & Hurrell RF (2007) Nutritional iron deficiency. *Lancet* **370**, 511–520.
16. Lambrecht NJ, Wilson ML & Jones AD (2019) Assessing the impact of animal husbandry and capture on anemia among women and children in low-and middle-income countries: a systematic review. *Adv Nutr* **10**, 331–344.
17. Masset E, Haddad L, Cornelius A *et al.* (2012) Effectiveness of agricultural interventions that aim to improve nutritional status of children: systematic review. *BMJ* **344**, d8222.
18. Girard AW, Self JL, McAuliffe C *et al.* (2012) The effects of household food production strategies on the health and nutrition outcomes of women and young children: a systematic review. *Paediatr Perinat Epidemiol* **26**, 205–222.
19. Rutstein SO & Guillermo Rojas MCS (2006) Guide to DHS statistics. https://dhsprogram.com/pdfs/Guide_DHS_Statistics_Sept2006.pdf (accessed June 2020).
20. The DHS Program: Protecting the Privacy of DHS Survey Respondents. https://dhsprogram.com/What-We-Do/Protecting-the-Privacy-of-DHS-Survey-Respondents.cfm (accessed August 2019).
21. Pasricha S-R, Black J, Muthayya S *et al.* (2010) Determinants of anemia among young children in rural India. *Pediatrics* **126**, e140–e149.
22. Suchdev PS, Williams TN, Sadumah I *et al.* (2013) Determinants of anemia among preschool children in rural, Western Kenya. *Am J Trop Med Hyg* **88**, 757–764.
23. Khan JR, Awan N & Misu F (2016) Determinants of anemia among 6–59 months aged children in bangladesh: evidence from nationally representative data. *BMC Pediatr* **16**, 1–12.
24. WHO/UNICEF (2015) Joint Monitoring Programme for Water Supply and Sanitation. https://sustainabledevelopment.un.org/index.php?page=view&type=400&nr=2081&menu=1515 (accessed August 2019).
25. Rutstein SO, Johnson K & MEASURE ORCM (2004) The DHS Wealth Index. https://dhsprogram.com/publications/publication-cr6-comparative-reports.cfm (accessed June 2020).
26. Wallace AS, Ryman TK & Dietz V (2012) Experiences integrating delivery of maternal and child health services with childhood immunization programs: systematic review update. *J Infect Dis* **205**, S6–S19.
27. Wasserstein RL, Schirm AL & Lazar NA (2019) Moving to a world beyond "$P < 0.05$". *Am Stat* **73**, 1–19.
28. StataCorp (2017) *Stata Statistical Software: Release 15*. College Station, TX: StataCorp LLC.
29. Semba RD, de Pee S, Ricks MO *et al.* (2008) Diarrhea and fever as risk factors for anemia among children under age five living in urban slum areas of Indonesia. *Int J Infect Dis* **12**, 62–70.
30. Hassan K, Sullivan KM, Yip R *et al.* (1997) Factors associated with anemia in refugee children. *J Nutr* **127**, 2194–2198.
31. Subramoney S & Gupta PC (2008) Anemia in pregnant women who use smokeless tobacco. *Nicotine Tob Res* **10**, 917–920.
32. Ioannou GN, Dominitz JA, Weiss NS *et al.* (2004) The effect of alcohol consumption on the prevalence of iron overload, iron deficiency, and iron deficiency anemia. *Gastroenterology* **126**, 1293–1301.
33. Kaur M, Graham JP & Eisenberg JNS (2017) Livestock ownership among rural households and child morbidity and mortality: an analysis of demographic health survey data from 30 sub-Saharan African countries (2005–2015). *Am J Trop Med Hyg* **96**, 741–748.
34. Zambrano LD, Levy K, Menezes NP *et al.* (2014) Human diarrhea infections associated with domestic animal husbandry: a systematic review and meta-analysis. *Trans R Soc Trop Med Hyg* **108**, 313–325.
35. Nyantakyi-Frimpong H, Colecraft EK, Awuah RB *et al.* (2018) Leveraging smallholder livestock production to reduce anemia: a qualitative study of three agroecological zones in Ghana. *Soc Sci Med* **212**, 191–202.
36. Jones AD, Colecraft EK, Awuah RB *et al.* (2018) Livestock ownership is associated with higher odds of anaemia among preschool-aged children, but not women of reproductive age in Ghana. *Matern Child Nutr* **14**, e12604.
37. Schwartz L, Woloshin S & Welch H (1999) Misunderstandings about the effects of race and sex on physicians' referrals for cardiac catheterization. *N Engl J Med* **341**, 279–283.
38. Holcomb WL, Chaiworapongsa T, Luke DA *et al.* (2001) An odd measure of risk : use and misuse of the odds ratio. *Obstet Gynecol* **98**, 685–688.
39. Norton EC, Dowd BE & Maciejewski ML (2018) Odds ratios: current best practice and use. *JAMA* **320**, 84–85.
40. Norton EC & Dowd BE (2018) Log odds and the interpretation of logit models. *Health Serv Res* **53**, 859–878.