

*Original Research Article***Maternal Hemoglobin Depletion in a Settled Northern Kenyan Pastoral Population**

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**Objectives:** This study examines maternal hemoglobin depletion in a cross-sectional sample of Ariaal women living in northern Kenya. Maternal hemoglobin depletion occurs when women do not have enough dietary iron to replace the high levels of iron allocated to the fetus during pregnancy.

**Methods:** To study this phenomenon, reproductive histories, socioeconomic status, anthropometry, and hemoglobin levels were collected from a cross-section of 200 lactating Ariaal women in northern Kenya.

**Results:** Ariaal women show increasing levels of hemoglobin with increasing time since birth and lower hemoglobin levels with increasing parity, indicating an incomplete repletion of dietary iron over women's reproductive lifetime. Women who lived in a more livestock-dependent village had higher hemoglobin levels and lower prevalence of clinical anemia than women who lived in villages more dependent on agriculture, indicating that differences in diet may alleviate the effects of iron depletion.

**Conclusions:** These data demonstrate that Ariaal women are iron depleted due to pregnancy, incompletely replete hemoglobin during the course of lactation, and show depletion of hemoglobin with increasing parity. Women in this community may be able to improve their iron status through a greater reliance on food sources rich in dietary iron. *Am. J. Hum. Biol.* 22:768–774, 2010. © 2010 Wiley-Liss, Inc.

Evolutionary theory predicts that energy spent on reproduction takes away from an organism's total energy, reducing the amount of energy available for somatic maintenance. This forms the basis for life history studies in both humans and other animals (Stearns, 1992). As part of our life history, humans have high energetic depletion during reproduction. Human pregnancy costs up to 300–500 kcal/day (Butte et al., 2004) and lactation costs up to 500 kcal/day (Goldberg et al., 1991) on top of basal metabolic expenditures. In addition, pregnancy and lactation requires a high level of micronutrient investment to support the needs of the growing fetus and infant. In populations with insufficient macro- and micronutrients to replace the resources lost in reproduction, women may experience temporary or permanent depletion. These effects may compound with increasing numbers of offspring, a phenomenon known as maternal depletion (Jelliffe and Maddocks, 1964).

Evidence for maternal depletion in human populations is mixed. Among women in low resource environments, some studies confirm the existence of maternal fat depletion with increasing parity (e.g. Adair and Popkin, 1992; Little et al., 1992; Tracer, 1991) while others, particularly women in well-nourished populations, see the opposite pattern of fat deposition with increasing pregnancies; women gain fat stores with each successive pregnancy (e.g. Brown et al., 1992; Harris et al., 1997; Prentice et al., 1981; Smith et al., 1994). Because maternal depletion is not consistent among women, researchers have indicated that a single model of maternal depletion is not appropriate. Rather, there are four patterns of reproduction-associated weight change (Shell-Duncan and Yung, 2004; Winkvist et al., 1992).

1. Nondepleted women: food intake is equal to or higher than activity levels and reproductive costs; women can maintain or improve nutritional stores throughout the

reproductive cycle and show no parity-related deficiencies. Women who maintain or gain weight with each pregnancy could be considered nondepleted (e.g. Harris et al., 1997).

2. Repleted women: experience decrease in nutritional stores due to costs of reproduction but are able to completely recover after each reproductive cycle; they do not show long-term parity-related depletion. Women in Lesotho, for example, experience decline in fat stores during lactation, which they then recover before their next pregnancy. They have no parity-related decline in adiposity (Miller and Huss-Ashmore, 1989).
3. Incompletely repleted women: demonstrate decrease in nutritional status and only partially replete between reproductive cycles; these women show patterns of both short-term and long-term depletion. One example would be Au women in Papua New Guinea, who experience declines in nutritional status that become more pronounced with greater parity (Tracer, 1991).
4. Nonrepleted women: have chronic depletion of nutritional stores independent of reproductive costs; costs of reproduction are masked by high levels of malnutrition. For example, a study of mobile and small-town Rendille women of northern Kenya showed no change in adiposity during lactation, indicating that energy

Contract grant sponsor: Leakey Foundation and National Science Foundation Doctoral Dissertation Improvement Grant; Contract grant number: BCS-0750779.

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Received 20 February 2010; Revision received 1 June 2010; Accepted 2 June 2010

DOI 10.1002/ajhb.21078

Published online 18 August 2010 in Wiley Online Library (wileyonlinelibrary.com).

stores were not being depleted or repleted due to high levels of malnutrition. The authors conclude that these women are nonrepletable even though women showed parity-related declines in adiposity. (Shell-Duncan and Yung 2004).

While both groups two and three show reproductive-related depletion, only women in group three show parity-related declines in nutritional stores. Although this model of maternal depletion was proposed with overall energy stores in mind, evidence suggests that both high and low resource women may face micronutrient maternal depletion. For example, bone density decreases with increasing duration of lactation in Western women and is a subtle form of maternal depletion. However, it appears that Western women are able to replete their calcium stores, with bone density returning to baseline levels 12 months after giving birth (Sowers et al., 1993). Iron (Bothwell, 2000) and folate (Smits and Essed, 2001) are both heavily depleted during pregnancy. Researchers have found that if interbirth intervals are too short, folate will not fully replete before the next pregnancy (Smits and Essed, 2001). Data on micronutrient depletion during lactation are less available; however likely candidates include vitamin A, B6, and C, zinc, and iodine (Dewey, 2004). This evidence suggests that exploration of micronutrient depletion should be examined in more depth in reproductive women.

Iron, a nutrient that is critical for oxygen transport, is located in several places in the body, including major stores in bone marrow, liver, and spleen. Smaller stores of iron are located in the blood within ferritin molecules, which can be readily mobilized to synthesize hemoglobin, the oxygen-transporting molecule that comprises red blood cells. The primary source of iron in the body is dietary, with heme-rich foods such as red meat having more easily absorbed sources of iron than nonheme foods such as vegetables or grains (Hallburg, 1981). Iron deficiency can be detected in the blood using numerous biomarkers; however, a recent synthesis of several population studies indicate that hemoglobin concentrations followed by serum ferritin concentrations are the most sensitive measures for monitoring changes in the iron status of a population (Mei et al., 2005).

Pregnancy exacts a large cost on a woman's iron stores. It requires significant iron investment averaging 4.4 mg of iron per day, with 0.8 mg per day needed in the first trimester increasing to 7.5 mg per day by the third trimester (Bothwell, 2000). In addition, iron can be depleted from blood loss during childbirth. Researchers estimate that women need approximately 500 mg of bodily iron stores prepregnancy to avoid anemia during pregnancy (Milman, 2006). While there is evidence that the body absorbs iron at a higher rate during pregnancy, women experience significantly lower levels of both serum ferritin levels and hemoglobin levels as pregnancy progresses (Bothwell, 2000). Women in low-resource settings and women who do not take iron supplements experience more severe iron deficiency during pregnancy than women with greater access to dietary iron (Beaton, 2000). In addition, parasitic blood and intestinal infections can contribute to low hemoglobin levels and anemia in women who are not iron deficient (Ndyomugenyi et al., 2008; Santiso, 1997). Evidence suggests that iron depletion during pregnancy can have a permanent effect on iron stores;

multiparous Dutch women have significantly lower ferritin levels than nulli- and primiparous women (Milman et al., 1992).

Women may replete iron during other reproductive stages. Lactation appears to have a protective effect on iron repletion (Dewey, 2004), possibly due to the increased bioavailability and thus need for lower concentration of iron in lactoferrin-rich breastmilk (Brock, 1980; Lönnerdal, 1984). Women's iron requirements are much lower during breastfeeding, approximately 0.3 mg per day, and become slightly higher when women lose blood when menstruation resumes (Bothwell, 2000). Some research has indicated that menstruation depletes iron through blood loss, both through comparisons of pre- and postmenopausal women and through estimates of menstrual blood loss (Beard, 2000; Milman et al., 1992). However, recent research has demonstrated that higher iron stores are associated with greater endometrial thickness, suggesting that blood loss due to menstruation is a marker of greater maternal energy availability rather than a pathway to iron depletion (Clancy et al., 2006).

This study will add to the maternal depletion literature by investigating the association between hemoglobin levels and reproductive, individual, and socioeconomic variables in lactating Ariaal mothers. The Ariaal are an ideal population for studying questions of incomplete repletion of iron because they are rarely, if ever, supplemented with iron during pregnancy, and they have variable access to dietary sources of iron. There are three goals: 1) to examine short-term hemoglobin repletion in women in the postpartum stage of reproduction 2) to examine long-term effects of multiple pregnancies on hemoglobin levels and 3) to examine how subsistence patterns may play a role in maternal hemoglobin levels. This leads to two hypotheses. First, Ariaal women will replete iron during lactation but will show parity-related declines in hemoglobin, conforming to a model of incomplete maternal repletion. Second, hemoglobin levels will be improved in Ariaal communities that may have greater access to animal products due to higher commitment to a pastoral lifestyle.

## STUDY POPULATION

The Ariaal (sometimes referred to as "Southern Rendille") are a group of settled pastoralists that reside on Marsabit Mountain in Marsabit District, Kenya. The Ariaal share cultural features, language, and kinship with both Samburu and Rendille groups while maintaining a distinct society (Fratkin, 1998). The arid climate of northern Kenya, too harsh for agriculture, has traditionally supported a mobile pastoralist lifestyle. During severe periods of drought in the 1970s, however, the Ariaal were attracted to the available water and relatively fertile ecology of Marsabit Mountain. Missions and non-governmental organizations sponsored development projects and famine relief that eventually lead to the formation of permanent villages. The women in this study tend to primarily identify as Ariaal, Samburu, or Rendille (41.5% Ariaal, 25.5% Samburu, 28% Rendille, 3% Turkana, and 2% blacksmith or "other").

The Ariaal mix pastoralism with subsistence agriculture and a market economy. Most (88.5%) of the study women indicate that they have used famine relief foods supplied by NGOs within the past month, indicating that

the settled lifestyle has brought only marginal improvements to the available resource base of the Ariaal. Women, in particular, have less access to iron-rich animal meat and blood compared to men (Fratkin et al., 1999). In addition, previous research has found that women in both mobile and settled pastoralist communities experience parity-related declines in nutritional status (Shell-Duncan and Yung, 2004). Finally, research in Rendille women indicates that mean parity is fairly high at 6.1 in post-reproductive women (Roth, 2004), making the Ariaal an ideal population for exploring maternal micronutrient depletion.

Three communities on Marsabit Mountain were included in this study. The village of Karare and the nearby agricultural scheme is the largest community in this study. This community relies on subsistence agriculture, pastoralism, and the market economy for subsistence. The second community, Parkishon, is a relatively recent settlement farther down the mountain from Karare. The ecology of Parkishon is not well-suited for farming and has been settled by Ariaal who prefer to rely more on pastoralism (Adano and Witsenburg, 2008). The final community is Kituruni, located several kilometers off of the main road. Kituruni has a similar subsistence system to Karare. Two hundred and fifty-one lactating women were enrolled in the study but hemoglobin levels were taken from just two hundred, leaving a final  $n$  of 200. Due to the small number of women in Kituruni ( $n = 8$ ), they are grouped with women from Karare. This decision was made on the basis of similar ecology, heavier reliance on subsistence farming and access to medical care. By contrast, the ecology of Parkishon is less suitable for farming, the community relies more heavily on pastoralism, and there is no local medical clinic.

## METHODS

This study is a cross-sectional survey of 200 lactating women and their infants in Marsabit District. The study consisted of a questionnaire, anthropological measurements, and hemoglobin levels. Study protocol was approved by the Institutional Review Board at the University of Michigan and the Kenyatta National Hospital Ethical Review Committee.

The questionnaire was developed by the author in English and orally translated into Samburu by two female research assistants. The questions were designed to assess women's reproductive history, family and household structure, socioeconomic status, and maternal health. Anthropometric measurements were collected using methods described by Frisancho (2008). Height was determined to the nearest 0.1 cm using a stadiometer on a level floor. Weight was determined by a digital scale to the nearest 0.1 kg. Weights were adjusted for women who were wearing elaborate traditional necklaces. The mean weight of a sample of five necklaces is 2.2 kg (S.D. = 1.2 kg). Triceps skinfolds (average of three measurements) and mid-upper arm circumferences were converted into upper arm fat area (UAFA) as an indicator of available energy stores.

Hemoglobin levels were determined by analyzing capillary blood with a portable HemoCue 201+. Women's left middle fingers were cleaned with alcohol and pierced with a sterile disposable lancet. The second blood drop was drawn into the microcuvette, wiped clean, and placed in

the HemoCue within 5 min of collection. Results appeared on-screen within two minutes. The cutoff for anemia using this method is 12.0 g/dl or lower (WHO, 2008).

Wealth is substantially livestock-based even in settled pastoralist communities. Therefore, the number of household cattle, camels, and small livestock were calculated into livestock units for sub-Saharan Africa, a measurement developed by the Food and Agriculture Organization (FAO) to adjust for the feed requirements of different types of livestock (Food and Agriculture Organization, 2003). Under this scheme, individual cattle are multiplied by 0.5, sheep and goats by 0.1, and camels by 1.10 and the total added together for each mother. Total livestock units were included in analyses both as a measure of socioeconomic status and as a potential iron-rich food source.

In order to control for the effects of illness on hemoglobin levels, women were asked if they had experienced either a fever, diarrhea, or respiratory infection within the past month. When analyzed separately, each illness was not significantly associated with hemoglobin levels. Results were combined to create a "reported illness" covariate in regression models.

Because age and parity are generally highly correlated, they often cannot both be included in the same model without producing significant collinearity effects. Parity and age are significantly related in Ariaal women ( $R^2 = 0.5$ ), so a statistical method described by Tracer (1991) was used to create an age-adjusted measure of parity. In this method, age is regressed against parity in a regression model and the residuals are used as an age-independent measure of parity. In addition, a model with both age and parity were included to assess the both the effects of collinearity and the individual contributions of age and parity to hemoglobin levels. Variance inflation was less than 2.0 in this model, indicating that age and parity can be analyzed as separate predictors in this population.

Data were analyzed in SAS 9.2 with  $\alpha = 0.05$ . Maternal hemoglobin level was the dependent variable. Age-adjusted parity (or age and parity), time since birth, and living in Parkishon (versus Karare and Kituruni as the reference category) were the main independent variables. Resumption of menses, UAFA and livestock units were included as covariates. All variables were checked for normal distribution; all variables were normal except livestock units and UAFA which were log-transformed. Variance inflations for all study variables were  $<2$ , indicating no collinearity of predictors. Several predictor interactions were tested; however, this artificially inflated estimates and increased variance inflation measures beyond acceptable levels and were thus eliminated from the models.

## RESULTS

Descriptive statistics of women in the communities of Karare and Kituruni versus Parkishon can be found in Table 1. There were considerable differences between Karare and Kituruni versus Parkishon in socioeconomic differences. Less than 5% of Parkishon women have ever attended school compared to over 14% in Kituruni and Karare. Women were asked if they considered themselves "poor" or "not poor"; despite the high levels of malnutrition and widespread use of famine relief food less than 20% of women referred to themselves as poor. A higher percentage of "poor" women live in Karare and Kituruni, probably due to the higher levels of livestock ownership in Parkishon.

TABLE 1. Characteristics of study participants

Mean ± S.D. or %	Total (n = 200)	Karare and Kituruni (n = 132)	Parkishon (n = 68)
<b>Maternal Characteristics</b>			
Age	28.2 ± 6.3	29.1 ± 6.4	26.3 ± 5.9
Parity	3.5 ± 2.2	3.5 ± 2.0	3.6 ± 2.4
Months since birth	10.8 ± 6.1	10.5 ± 5.9	11.4 ± 6.5
% Resumed menses	38.0	37.1	39.7
% Reported illness within past month	40.5	48.5	25.0
<b>Iron status</b>			
Hemoglobin (g/dL)	13.0 ± 1.8	12.7 ± 1.8	13.4 ± 1.8
% Anemic (<12.0 g/dL)	28.0	31.8	20.6
<b>Nutritional status</b>			
Height (cm)	160.9 ± 6.1	160.6 ± 5.9	161.4 ± 6.4
Weight (kg)	49.3 ± 6.7	48.3 ± 6.7	51.0 ± 6.5
BMI	18.4 ± 2.3	18.2 ± 2.2	18.8 ± 2.4
Triceps skinfold (mm)	15.7 ± 6.4	15.2 ± 5.7	16.7 ± 7.6
Mid-upper arm circumference (cm)	24.2 ± 2.4	24.0 ± 2.3	24.6 ± 2.6
<b>Socioeconomic status</b>			
% "poor"	19.5	22.0	14.7
% grow a garden	44.2	53.4	26.5
% ever attended school	11.5	14.4	4.4
Household size	4.32 ± 1.29	4.27 ± 1.34	4.41 ± 1.17
Livestock Units	4.4 ± 4.8	3.6 ± 3.5	6.1 ± 6.3

TABLE 2. Regression estimates and p-values for predictors with hemoglobin level as dependent variable

	Estimate (β)	P-value
<b>Model with age-adjusted parity (R<sup>2</sup> = 0.13)</b>		
Age-adjusted parity	-0.177	0.036
Months since birth	0.066	0.005
Returned to menstruation <sup>a</sup>	0.576	0.048
Upper arm fat area (log)	0.076	0.789
Livestock units (log)	0.024	0.894
Parkishon <sup>b</sup>	0.817	0.004
Reported illness <sup>c</sup>	0.449	0.086
<b>Model with age and parity modeled separately (R<sup>2</sup> = 0.18)</b>		
Age	0.115	<0.001
Parity	-0.188	0.022
Months Since Birth	0.064	0.004
Returned to Menstruation <sup>a</sup>	0.471	0.098
Upper Arm Fat Area (log)	0.172	0.534
Livestock Units (log)	-0.010	0.953
Parkishon <sup>b</sup>	1.000	0.004
Reported Illness <sup>c</sup>	0.348	0.173

<sup>a</sup>Variable is coded 0 = no menses, 1 = menses.

<sup>b</sup>Karare and Kituruni is the reference category.

<sup>c</sup>Variable is coded 0 = no reported illness, 1 = reported illness.

Conversely, women in Karare and Kituruni were more likely to keep a garden.

Women's BMIs are lower compared with values found by Shell-Duncan and Yung (2004) in a study that took place in Marsabit District in 1995–1996. However, the mean triceps skinfold measurement is higher in this study (11.3 versus 15.7 mm) compared with Shell-Duncan and Yung. The reason for these differences is not known, but there are three possibilities. First, Shell-Duncan and Yung included all nonpregnant women in their sample while the current study contains only lactating women. It is possible that lactating women have different adiposity and lean body mass profiles compared to the general population due to their higher energy needs. Second, the available food resources in this community may have changed with time. High reliance on famine-relief foods compared to animal products may have reduced mothers' BMI while increasing the ratio of fat to muscle tissue. Finally, measurement methods may be different between the two stud-

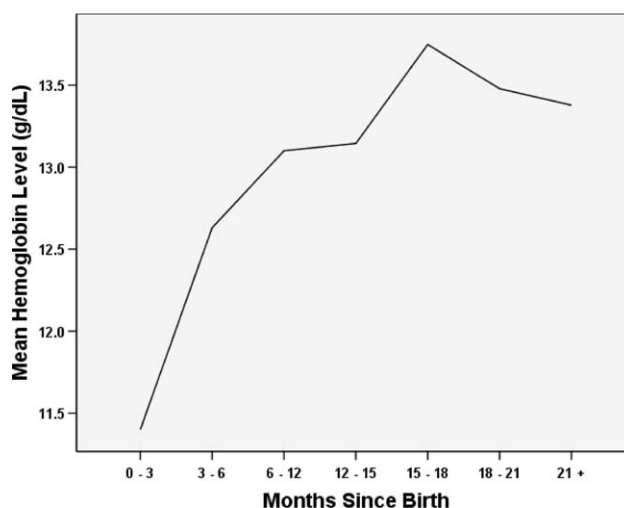


Fig. 1. Mean hemoglobin levels in Ariaal women by number of months since birth.

ies. This is unlikely because the anthropometric equipment used in both studies is similar and similar methodology was followed. Preliminary analyses in the current study did not find evidence of pregnancy or parity-related body fat decline, indicating that reasons one and two are more likely causes for disparities found between the two studies.

Table 2 shows estimates and P-values for multivariate regression models. Hemoglobin levels significantly increase with increasing number of months since birth of infant, illustrated in Figure 1. Both models (age and parity regressed separately and age-adjusted parity only) have similar negative estimates and P-values for parity, indicating that hemoglobin levels decrease with increasing numbers of births. Interestingly, hemoglobin levels significantly increase with age independent of parity. Women who live in Parkishon have significantly higher hemoglobin levels than women in Karare and Kituruni.

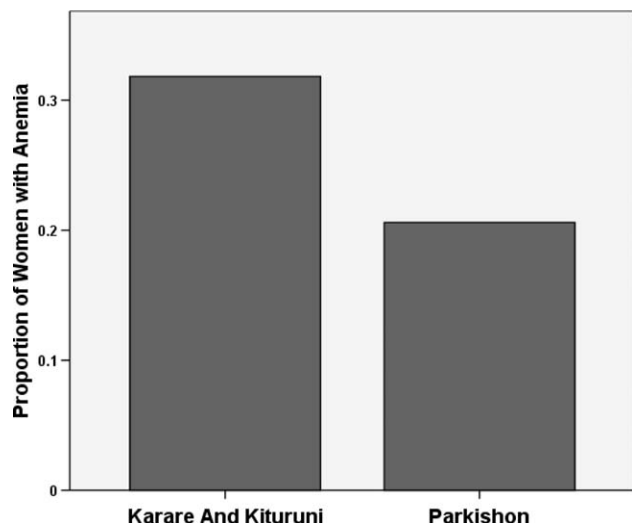


Fig. 2. Proportions of anemic (hemoglobin < 12.0 g/dl) Ariaal women living in Karare and Kituruni versus Parkishon.

This relationship can be seen in Figure 2, which shows a higher proportion of anemic women in Karare and Kituruni versus Parkishon. However, this relationship does not appear to be directly related to household TLU. Resumption of menstrual periods was significantly positively associated with hemoglobin in the age-adjusted parity model but not the age and parity model. UFAA was not associated with hemoglobin levels.

### DISCUSSION

As the results indicate, lactating Ariaal women show patterns of incomplete iron repletion. They demonstrate increasing levels of hemoglobin as time from giving birth increases, indicating that they do in fact replete some of the hemoglobin that is lost in pregnancy. However, increasing parity is associated with lower hemoglobin levels, indicating that women are not able to completely replete hemoglobin with each successive birth. The pattern of hemoglobin depletion and repletion is illustrated in Figure 3. It appears that resumption of menstrual periods has a positive effect on mothers' hemoglobin status; this finding appears to support the finding of Clancy et al. (2004) that indicates that endometrial thickness is positively correlated with serum hemoglobin levels and by extension, available somatic resources. Unfortunately, the data could not accurately assess the impact of menstrual cycling on hemoglobin levels in this population, but future investigations should consider menstrual cycle frequency and duration as possible sources of variation in women's hemoglobin status.

Maternal hemoglobin levels are significantly higher in Parkishon versus Karare and Kituruni. However, because Parkishon is more heavily reliant on a pastoralist lifestyle than Karare, they may have more access to iron-rich animal products during and after their pregnancies. On the other hand, hemoglobin levels are not influenced by the number of livestock a woman's household owns. Unfortunately, there was no dietary recall component to this study that could directly assess variation in dietary intake, although Shell-Duncan and Yung (2004) do

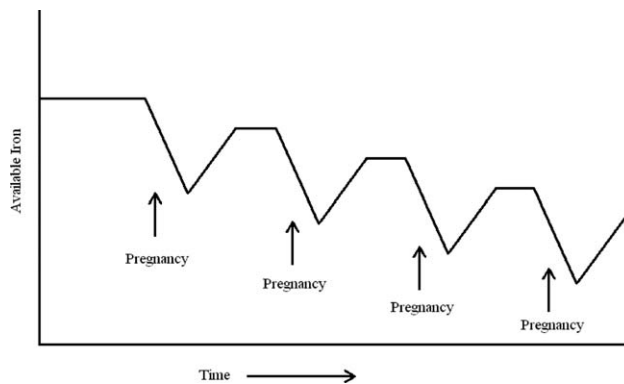


Fig. 3. Model of short- and long-term iron depletion in Ariaal women.

provide some data on women's iron intake in several Ariaal communities, including Karare (Parkishon is too recent a community to have been included). They analyzed the average dietary iron intake in five Rendille/Ariaal communities in Marsabit District and found that it ranged between 6 and 14 mg iron per day, well under the >19 mg recommended by the FAO/WHO (FAO and WHO, 2005). Although meat and blood tend to be preferentially allocated to men and boys (Shell-Duncan and McDade, 2005), Shell-Duncan and Yung did find that meat did comprise a small proportion of women's total dietary intake in Ariaal and Rendille communities. They noticed differences in percentages of energy intake from meat between different communities, with nomadic groups consuming a slightly higher percentage of energy from meat than settled communities. On the other hand, nomadic women had the lowest daily dietary iron intake, likely attributable to the greater access to nonheme sources of dietary iron in settled communities as well as the lower overall energy intake by nomadic women. Given Parkishon's settled status but higher reliance on pastoralism, residents may follow meat-eating patterns more similar to nomadic communities while consuming higher levels of nonheme staple foods from famine relief sources. Finally, Shell-Duncan and Yung note a fairly high percentage of dietary energy from milk for women in all communities, ranging from 24% to 50% of total daily energy intake, with the highest levels found in Karare. Since calcium is known to inhibit the absorption of iron (FAO and WHO, 2005), high milk consumption may also contribute to iron deficiency in the Ariaal community, particularly in Karare. There are therefore two likely dietary causes for community differences: (1) meat and blood, high-quality sources of absorbable heme, may be more readily available to women who live in Parkishon or (2) women who live in Karare consume more foods that inhibit iron absorption, particularly milk.

A dietary interpretation does not necessarily exclude other causes for community differences in anemia rates, however. For example, interview data suggest that, on average, women in Parkishon spend significantly less time fetching water than women in Karare and Kituruni, a major household chore (58.7 vs. 81.5 min/day,  $P < 0.001$ ). It is unclear from the available data how time spent at work influence iron stores or the ability to do work, if it does at all. There may also be differences in

infection rates between communities which may contribute to difference in iron status, discussed more in depth below. Further research on iron status in this population should investigate the proximate causes of hemoglobin differences in Ariaal communities.

While this study examined hemoglobin levels in women, there are no data currently available on the bioavailability of iron in Ariaal women's bodies in the form of ferritin. Serum ferritin has been found to correlate statistically significantly with blood hemoglobin levels (although perhaps not clinically significantly; Milman and Kirchoff, 1991); however, hemoglobin levels do not always track serum ferritin levels (Yip, 2000). In the one other study documenting parity-related iron depletion, the authors only discussed the effects of parity on serum ferritin but made no mention of potential effects of parity on hemoglobin levels (Milman et al., 1992). Future research should consider using multiple biomarkers to more completely assess iron deficiency in reproductive women.

Low iron stores in the form of ferritin are one of the possible explanations for low hemoglobin. Hemoglobin levels also can be lowered by infectious diseases such as malaria or hookworms and associated inflammation, possibly masking the true effect of reproductive-related iron depletion. Previous research in Ariaal and Rendille children found very low overall prevalence of malaria and schistosomiasis as well as no association between parasite infection and iron deficiency indicating that infection by these parasites may not play a large role in iron deficiency in this region (Shell-Duncan and McDade, 2005). There is no reason to suspect that infection is associated with a particular postpartum month or parity status in Ariaal women, although there may be differences in parasite infection rates between communities. The data show a higher percentage of women in Karare and Kituruni reporting an illness within the last month compared with women in Parkishon, although many of these illnesses may not be parasitic in nature. It is important to note that community differences in hemoglobin levels persisted even after adjusting for reported illness. Future research should address the possibility of depletion of total circulating iron stores and the role of blood loss from parasitic infections in reproducing mothers, forming a more complete picture of maternal depletion of iron.

Interestingly, low iron stores may also protect against infection. Many infectious agents use bodily stores of iron to reproduce (Weinberg, 1978). Supplementing populations in malaria-endemic Papua New Guinea, for example, increases the prevalence of malaria and the intensity of its effects (Oppenheimer et al., 1986). Previous research in Ariaal/Rendille children found that children with moderate iron deficiency had a lower likelihood of having an infection than children who were iron sufficient (Wander et al., 2009). Studies suggest that hematological indices may be somewhat lower in East African populations, but do not assess diet, infection, or the relative likelihood of anemia at these lower levels (Lusanga et al., 2004), making population-specific iron recommendations as of yet an unknown quantity. Furthermore, even if lower iron levels are adaptive in Ariaal women, it is not necessarily true that reproductive-related iron depletion is protective against infection. Further research should investigate the role of iron, infection, and pregnancy to make population-specific recommendations for hemoglobin levels and iron supplementation.

These results indicate that poor maternal nutrition is an ongoing problem in Ariaal society. Ariaal women experience both short-term and long-term depletion of hemoglobin during their reproductive careers, a loss that can impact both women and their infants. Although iron is preferentially diverted to the developing fetus during pregnancy, severely anemic women have higher risk of preterm and low-birth weight babies or may have infants who are themselves anemic (Chaparro, 2008). In addition, anemic women may be easily fatigued and experience more difficult births than nonanemic women (Christian, 2002). Ideally, women should be encouraged to increase consumption of animal meat and blood during pregnancy to avoid anemia. Women may also be encouraged to increase consumption of less-easily absorbed sources of iron such as green kale or staple foods to overcome the inhibitory effect of milk on iron absorption. This strategy can help avoid maternal iron depletion in Ariaal women.

## CONCLUSION

Evolutionary theory predicts that reproduction will exact a cost on an organism's available somatic resources. Maternal iron stores are a costly somatic resource that is considerably depleted during pregnancy, and thus can be studied using an evolutionary framework. This study found evidence of short- and long-term reproductive hemoglobin depletion in a sample of Ariaal women. Analysis of community variables suggest that the village that are more oriented toward pastoralism experience less anemia than villages that are more oriented toward agriculture. Improving access to animal meat and blood or reducing the percentage of milk consumed for reproductive-aged women may help reduce the proportion of anemic women in settled Ariaal communities.

## ACKNOWLEDGMENTS

Two anonymous reviewers greatly improved the quality of this manuscript. Bettina Shell-Duncan and Masako Fujita generously introduced me to northern Kenya and the Ariaal/Rendille. I would like to thank my field assistants Korea Leala, Rapheala Leado, Selena Gambare, and the Abdulai Khalifa for their dedicated, careful work. Finally, I would like to thank the Ariaal women and infants who generously participated in this study.

Ethical permissions were granted by the Kenyatta National Hospital Ethical Review Committee and the University of Michigan's Institutional Review Board. Permission for this research was generously given by the Ministry of Science and Technology of the Republic of Kenya (Permit Number MOST 13/001/37C 717), the District Commissioner of Marsabit District, and the chiefs of Karare, Parkishon, and Kituruni.

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