AMERICAN JOURNAL OF HUMAN BIOLOGY 20:174–184 (2008)

Original Research Article

Adiposity and Height of Adult Hmong Refugees: Relationship with War-Related Early Malnutrition and Later Migration

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ABSTRACT This study investigated whether historical proxies for poor nutrition early in life were associated with differences in body composition and height among adult Hmong refugees. Life history and anthropometric data were collected from a sample of 279 Hmong aged 18–51 years who were born in Laos or Thailand and resettled in French Guiana or the United States following the Second Indochina War. Overall, 30.5% were born in a war zone in Laos, while 38.8% were displaced as infants; these individuals were presumed to have experienced malnutrition in the perinatal and infant periods, respectively. Resettlement in urban areas in the US was utilized as a proxy for greater exposure to excessive energy balance, compared with Hmong who resettled in rural areas in French Guiana. In multiple linear regression models, being displaced in infancy was negatively associated with height after controlling for confounders, while being born in a war zone was associated with higher adiposity and centralized body fat distribution. Resettlement in the US was associated with a higher centralization of subcutaneous fat, but not overall adiposity. These findings may be of interest to the study of the developmental origins of obesity, in a population that has undergone early malnutrition followed by migration and rapid nutritional transition. Am. J. Hum. Biol. 20:174–184, 2008.

The prevalence of obesity has increased in recent decades in both developed and developing nations (Lobstein, 2004; Mendez et al., 2005; WHO, 2000). While the rapidity of the increase, particularly among developing nations, points to changes in behavioral factors such as diet and activity levels (Popkin, 2001), evidence also suggests prenatal malnutrition can have enduring effects on body composition, predisposing the individual to develop centralized or frank obesity later in life (Law et al., 1992; Ravelli et al., 1976). Such observations are pertinent to the developmental origins of health and disease paradigm, which asserts that intrauterine and perinatal challenges, such as malnutrition, may have long-term or permanent effects on disease risk (Gluckman et al., 2007). For example, epidemiological evidence and experimental studies in animals provide substantial support that intrauterine and infant malnutrition at critical periods of development may "program" long-term health (Lucas, 1998), increasing risk for later type 2 (noninsulin dependent) diabetes and cardiovascular disease in adulthood (Barker, 1998; Bertram and Hanson, 2001; Forsén et al., 2000; Hales et al., 1991; Joseph and Kramer, 1996; Langley-Evans, 2006).

From an evolutionary perspective, developmental plasticity allows the fetus to increase its chances for survival and reproduction through modifications in growth trajectory in terms of size and physiology not only to avoid immediate negative energy balance, but possibly in expectation of the future nutritional environment as well (Bateson et al., 2004; Kuzawa, 2005). Such "predictive adaptive responses" serve the individual well when the postnatal environment follows that which is predicted, but may lead to a maladaptive phenotype should conditions change (Gluckman and Hanson, 2005). Thus, populations that have experienced poor nutrition followed by a rapid nutritional transition and excessive energy imbalance may be particularly susceptible to developing chronic diseases (Frisancho, 2003; Moore, 1998). For example, when faced with malnutrition, fetal muscles may become insulin-resistant, effectively sparing glucose for the brain and red blood cells, resulting in a "thrifty phenotype" that could lead to impaired glucose tolerance and diabetes in adulthood (Hales and Barker, 2001). Similarly, rats whose mothers who were underfed during pregnancy developed greater adiposity compared to those whose mothers received a normal diet, suggesting a mismatch between expected and actual postnatal conditions (Anguita et al., 1993; Vickers et al., 2000).

The relationship between prenatal malnutrition and later adiposity in humans is less clear. In developed nations, birth weight has been found to have either a positive or J- or U-shaped correlation with adult body mass index (BMI; kg/m^2) (Curhan et al., 1996a,b; Leong et al., 2003; Oken and Gillman, 2003; Parsons et al., 2001; Rasmussen and Johansson, 1998; Seidman et al., 1991; Sørensen et al., 1997). However, while BMI provides a rough estimate of adiposity, prenatal malnutrition may affect lean and adipose tissue differently. Experimentally induced prenatal malnutrition in rats and guinea pigs has been linked with reduced lean mass in the neonate and later in life, perhaps as a result of peripheral insulin resistance and a sacrificing of muscle mass in favor of other tissues (Bedi et al., 1982; Desai et al., 1996; Dwyer et al., 1995). In humans, low-birth-weight neonates in developed and developing nations generally have smaller body dimensions and less lean mass than their normal birth weight counterparts, though subcutaneous fat tends to be well preserved (Akinyinka et al., 1999; Hediger et al., 1998; Yajnik, 2000). This suggests that the fetus may favor the preservation of adipose tissue when faced with

Contract grant sponsor: Wenner-Gren Foundation for Anthropological Research; Contract grant number: 6709; Contract grant sponsor: National Science Foundation; Contract grant number: BCS-0118984.

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Received 21 August 2006; Revision received 29 May 2007; Accepted 30 May 2007

DOI 10.1002/ajhb.20711

Published online 2 January 2008 in Wiley InterScience (www.interscience.wiley.com).

prenatal malnutrition, a particularly adaptive phenotype for the human infant, given its metabolically expensive brain and high dependence upon parental provisioning of sustenance (Kuzawa, 1998; Yajnik et al., 2003). Moreover, these effects on body composition may be lasting. Studies of children and adults in various populations have found lower birth weight to be associated with reduced lean body mass and/or proportionately greater subcutaneous and visceral fat (Byberg et al., 2000; Kahn et al., 2000; Li et al., 2003; Loos et al., 2001, 2002; Murtaugh et al., 2003; Okosun et al., 2000; Rogers et al., 2003; te Velde et al., 2003).

Another consideration is that programming of body fat may be triggered by environmental stimuli that do not affect birth weight. In sheep, modest malnutrition in utero had no effect on birth weight, but was associated with increased postnatal adiposity (Budge et al., 2005). This effect appeared greatest in early gestation, perhaps by increasing adipocyte sensitivity to insulin-like growth factor (Symonds et al., 2004). Similarly, in a study of more than 300,000 19-year-old Dutch male conscripts, those exposed to famine in the first two trimesters of gestation during the Second World War had a higher rate of obesity compared to unexposed controls, while those exposed in the third trimester had a lower rate compared to controls (Ravelli et al., 1976). Thus, although birth weight is a better estimate of nutrition in late gestation (Neufeld et al., 1999; Stein et al., 1975), the propensity for greater adipose accumulation may be set earlier in gestation.

The purpose of the current study was to investigate the relationship between war-related malnutrition in the perinatal and infant periods and the body composition, body fat distribution, and height of adult Hmong refugees living in French Guiana and the United States. Using a biocultural approach, life history events during military conflict in Laos served as proxies for malnutrition. The Hmong refugee diaspora was hypothesized to be particularly vulnerable to developing chronic disease in general, and obesity and central obesity in particular, given its exposure to early malnutrition in Laos, followed by resettlement and rapid nutritional transition.

METHODS

Background and study design

The First and Second Indochina Wars (1945–54 and 1958–75, respectively) severely disrupted the precarious traditional economy in rural Laos, particularly for the ethnic minority groups in the northeastern highlands such as the Hmong (Branfman, 1972; Stuart-Fox, 1997; USAID, 1976). Specifically, the Hmong swidden agricultural system was exacerbated by military conflict through the forced displacement of villagers for extended periods, the destruction of trade routes, the terrorization of the farming population, and the depletion of male labor through casualties and military recruitment (USAID, 1976; Weldon, 1999; Yang, 1993). During the Second Indochina War, over two million tons of bombs were dropped on Laos by US air planes, while fighting between rightist, communist, and neutralist ground forces led to $\sim$200,000 deaths and the displacement of 750,000 civilians, in a nation of roughly three million people (Morikawa, 1998; Stuart-Fox, 1997). Poor security during the war led to an estimated 15% reduction in the number of hectares under rice cultivation from 1968 to 73, while livestock production also fell precipitously (Nutrition Committee of Laos, 1974; Yang, 1993).

Importantly, exposure to warfare and malnutrition in Laos was not geographically uniform, as most of the conflict occurred in the south, along the Ho Chi Minh Trail, and in the northeast (Fig. 1). While infant mortality rates were high throughout the country, they were much higher in war-torn areas, reaching up to 500 per 1,000 births in some locales, compared to towns along the Mekong or internal refugee centers supplied with food (as low as 60 per 1,000 births) (Hankin et al., 1972; Weldon, 1999; WHO, 1970). Displaced individuals commonly went without food for sustained periods, though many received humanitarian aid upon making it to safe areas (USAID, 1976; US Congress, 1970). Often, persons displaced from war-zone areas were reported to be starving, with protein, calorie, and micronutrient deficiencies (Weldon, 1999: 125; Yang, 1993: 51), a pattern consistently seen in mass population displacements from armed conflict (Salama et al., 2004; Toole and Waldman, 1997). Therefore, being born in a war zone and being displaced from one's village before age 2 years were used as proxies for perinatal and infant malnutrition, respectively. Age 2 years was chosen as the cutoff for infancy, as most growth retardation occurs before this age (Adair, 1999; Martorell and Habicht, 1986).

After the formation of the Lao People's Democratic Republic in May 1975, over 340,000 people of varying ethnicities eventually fled Laos, principally to refugee camps in Thailand, to await repatriation or resettlement in a third country (Quincy, 2000; Robinson, 1998). The greatest number of Hmong refugees resettled in the United States, where between 170,000 and 300,000 live today; smaller numbers resettled in Australia, France, Germany, Canada, Argentina, and French Guiana (Hmong National Development Council, 2004; Martin, 1992; Yang, 2003). The current study focused on the Hmong in the United States and French Guiana, because of differences in lifestyle and risk factors for obesity, including diet and physical activity levels.

The Hmong in French Guiana reside in rural, ethnically homogeneous farming villages, with the majority living in Cacao and Javouhey (900 and 1,100 residents, respectively). Adults in most households work as a family in the fields for 9–10 h a day, 5–6 days a week (Clarkin, 2005a). Reliance on mechanized agricultural equipment is low and most activities require manual labor. This is because of the terrain of the fields (particularly in mountainous Cacao) and to the partial retention of traditional "slash-and-burn" agricultural practices from Laos. Crops include a wide array of fruits and vegetables, which are both consumed by Hmong families and sold to the Creole and French populations in the city marketplaces. Rice, meat, and to a lesser extent sweets are purchased from local village stores or from larger markets in the cities. Planting and harvest seasons are not clearly delineated. While the rainy season lasts from November to July, the workday remains much the same year-round, because of the reliance on profits from sold produce to pay for electricity, taxes, gasoline, phones, and other expenditures. Given the diverse diet and high energy expenditures, Hmong health in French Guiana appears good overall. Though epidemiological studies are lacking, a French physician in Javouhey estimated that there were just a few cases each

Fig. 1. Provinces of modern Lao People's Democratic Republic. Shaded areas represent recorded instances of ordnance dropped by US air strikes during the Second Indochina War, illustrating different exposure to military conflict between the northeast and northwest parts of the country. The southern region marks the location of the Ho Chi Minh Trail. Reproduced with permission from UXO-Lao (n.d.), http://www.uxolao.org/, 2006.

of hypertension, gout, and diabetes in the village in 2001; infectious diseases were also rare.

By contrast, data from the 2000 US Census reveal that Hmong adults and/or children in the US have experienced high rates of obesity (Clarkin, 2005b; Himes et al., 1992; Hyslop et al., 1996), type 2 diabetes (Her and Mundt, 2005), and elevated blood pressure (Clarkin, 2005a; Kunstadter, 2000; Munger et al., 1991). In addition, compared to national percentages, Hmong in the United States had higher poverty rates (38% vs. 12%), lower per capita income ($6,613 vs. $21,587), and were more likely to be linguistically isolated (35% vs. 4%), though these figures have improved since the 1990 Census (Hmong National Development Council, 2004). Therefore, place of residence was used as a proxy for diet and physical activity postmigration, given the difference in lifestyles between these two endpoints of the refugee diaspora.

While proxies are less than ideal, their use in the current study helped to streamline the questionnaire and perhaps aided in recruiting participants. Additionally, the use of place of migration as an estimate of changes in diet, growth, and overall health has a long history in physical anthropology and human biology (Mascie-Taylor and Little, 2004). Further, it was felt the differences between Hmong in the US and French Guiana was sufficient to warrant a summary categorization. In French Guiana, there was a high degree of homogeneity in occupation and thus physical activity, as most participants were full-time farmers. Given the reliance on farming for sustenance in French Guiana, it was observed that dietary intakes were comprised largely of locally grown produce. By contrast, the Hmong in the US resided in urban areas, and just one Hmong male participant in the US listed his occupation as farmer.

Data collection

Prior to conducting research, this study was approved by the Institutional Review Board at Binghamton University (SUNY). Overall, 279 Hmong adults aged 18–51 years (mean 34.3 ± 6.9) participated, including 74 males and 26 females in the US and 92 males and 87 females in French Guiana. From April to June of 2001, during a lull in the rainy season, study participants were recruited opportunistically from three rural villages in French Guiana (Cacao, Javouhey, and Regina). In the US, participants were recruited from urban areas in two northeastern states (RI and MA) and two Midwestern states (MN and WI) in the US from February to December of 2002. In both countries, the principal investigator and a Hmong interpreter/liaison recruited participants by working through local social hierarchies. Appointments were made in person or by phone at potential participants' homes and typically entailed the administration of questionnaires and anthropometric measurements to a married couple, in addition to any adult volunteers present during the visit. Potential participants were excluded if they were pregnant, injured, an amputee, currently ill, or not of Hmong ethnicity.

Questionnaires were administered orally by the interpreter, with the P.I. present in all cases. This was followed by the anthropometric measurements, taken by the P.I. The entire process required 15–45 min per participant. Questions pertained to place and date of birth, whether one was displaced from their village by war before age two years, the total number of times (up to six) one was displaced, whether a parent had died during the participant's childhood, the number of siblings and whether any had died in childhood, number of years in a refugee camp, and age at first resettlement in France, French Guiana, or the United States. Participants were also asked whether they were happy with their current living conditions and whether they wished to return to Laos to live there permanently. Anthropometric measures included height, weight, circumferences (abdominal, hip, and upper arm), and the sum of four skinfolds (triceps, suprailliac, subscapular, and medial calf). Weight and body fat percentage (BF%) were measured to the nearest 0.1 kg and 0.1%, respectively, using a Tanita TBF-551 Body Fat Monitor/Scale (Jebb et al., 2000). The machine calculates BF% via bioelectric impedance analysis, based on the principal that adipose tissue is comprised of a lower percentage of water than lean tissue (Baumgartner, 1996). The impedance level is then entered into a regression equation standardized against dual energy X-ray absorptiometry, along with data on the individual's height, sex, and age. On request, the machine in this study utilized regression equations based on a sample of Asian ethnicity, as some research suggests that Asians may have a higher BF% for a given BMI than Whites (Deurenberg et al., 1999; He et al., 2001). Derived measures included the abdominal/hip ratio and a central skinfold ratio (two truncal skinfolds divided by the peripheral skinfolds), which served as estimates of centralized adiposity. Body mass index (BMI) was calculated as kg/m^2, and upper arm muscle area (cm^2) was calculated using the formula, following Frisancho (1990):

$$\frac{(\text{upper arm circum} - \text{triceps skf} \times \pi)^2}{4 \times \pi}$$

Categorization of birthplaces

Participants were born in Laos or Thailand between 1951 and 1984, encompassing the Indochinese Wars, as well as a guerilla resistance period that commenced after 1975. All birthplaces in Laos were in the north, above the panhandle. Birthplaces were categorized as "safe zone" or "war zone" not solely on the basis of presence or absence of military conflict, but rather on food security. For example, some places categorized as safe were refugee centers or military outposts that housed civilians and were in close proximity to conflict, but remained food secure, primarily through American provisions. Displaced persons in refugee centers received an average of 500 g of glutinous rice per day (1,800 kcal), in addition to other supplementary foods such as occasional canned meat (USAID, 1973: 26; Weldon, 1999: 200). Hunger was reported to exist only among newly arrived refugees (USAID, 1971).

Specifically, the categories "war zone" and "safe zone" were determined as follows. First, participants were asked for their actual, rather than legal, date of birth (month and year) and place of birth (country, province, and village). They were then asked to categorize their place of birth into one of four categories: safe village, military outpost, refugee center, or village in a war area, the first three of which were considered food secure and condensed into the category "safe zone" for analysis purposes. Birthplaces were categorized as "war zone" if they were vulnerable to food insecurity as a result of nearby conflict and were not receiving food supplies at any point in the nine months prior to the date of birth. All named birth villages were cross-checked against the historical record, which was given priority (Conboy, 1995; Kuhn, 1995; Pfaff, 1995; Quincy, 2000; Robbins, 1987; Schanche, 1970; US Congress, 1970; Weldon, 1999; Yang, 1993). Information was difficult to find for 70 birthplaces (25.1%). In these cases, assistance with categorization was sought from three individuals familiar with the wars in Laos, including a former USAID employee integral in distributing food to refugees in Laos (Mr. Ernest C. Kuhn), a Hmong historian/sociologist (Dr. Yang Dao), and a former Hmong military officer (Mr. Chue Toua Kue). Unanimity was achieved for 61 of these, leaving nine (3.2% of total sample) categorized by majority opinion.

Table 1 summarizes how birthplaces were categorized by country and province. Laotian provinces are listed by their official status at the time of the Second Indochina War. All birthplaces in Thailand (the majority of which were refugee camps) and the Laotian province of Sayaboury (which was buffered from the war by the Mekong River and distance from the Vietnam border) were classified as safe-zone (Fig. 1). Xieng Khouang province, which at the time of the war included modern-day Saysomboune region, had the highest rate of birthplaces categorized as war-zone (47.1%), followed by Luang Phrabang (which included modern Oudomxay province), and Vientiane (prefecture and province). Four individuals (1.4%) did not know their province of birth; in these cases, birthplace

TABLE 1. Categorization of birth places by province of birth

Country and province	N	Classified as war zone
Thailand	15	0 (0%)
Laos[a]		
Houa Phan	6	0 (0%)
Luang Nam Tha	3	0 (0%)
Luang Phrabang (includes Oudomxay)	51	16 (31.4%)
Sayaboury	40	0 (0%)
Vientiane prefecture/province	22	3 (13.6%)
Xieng Khouang (includes Saysomboune)	138	65 (47.1%)
Missing	4	1 (25%)
Total	279	85 (30.5%)

[a]Provinces in Laos are grouped as they appeared on maps at the time of the Second Indochina War.

was categorized using the self-description of the participant. For a full list of how each birthplace was categorized, see Clarkin (2004).

Statistical analyses

Statistical analyses were performed using SPSS 11.5 software (Chicago, Illinois). The anthropometric and life history variables are presented using descriptive statistics, while various markers of infant and child distress were tested for effects on adult height using *t*-tests. Multiple regression analysis was used to assess the relationship between being born in a war zone and being displaced by war in infancy on the dependent, anthropometric variables, including height, lean body mass (arm muscle area), overall adiposity (body fat percentage, sum of four skinfolds), and central adiposity (abdominal/hip ratio, central skinfold ratio). Both unstandardized and standardized regression coefficients are presented to allow comparison among the different predictors. BMI was not used as an outcome variable in any regression model, as the attempt was to look at more direct measures of body composition. Covariates included age and sex, along with the migration variables (country of residence and age at resettlement), which acted as proxies for diet and physical activity. Interactive terms (e.g., birthplace × country of resettlement; birthplace × being displaced in infancy) were tested, but they were excluded because none was shown to be a confounder in any model. Nominal predictor variables were "dummy" coded as 0 and 1, and continuous variables were checked for skewness. Pearson correlation coefficients were used to assess the relationship between age at first resettlement abroad and adult height, while analysis of variance (ANOVA) was used to assess the relationship between being born in a war zone and body fat percentage.

RESULTS

A summary of the anthropometrics and life history variables is presented in Table 2. In general, Hmong adults of both sexes were relatively short compared to US reference data, with mean heights below the US 5th percentile (Frisancho, 1990). Mean BMI for both sexes was above 25 kg/m^2, the threshold for overweight (Flegal et al., 1998). Markers of overall adiposity were higher for females, while males had greater central adiposity and arm muscle area.

The life history variables reveal that many participants suffered from harsh living conditions at some point in their lives. Overall, 30.5% of participants were born in a war zone, while 38.8% were displaced from their village as infants. The mean number of times a person was displaced was 2.5, though 39.4% were displaced three times or more, and 17.3% were displaced six times or more. Three-fourths (76.8%) had a sibling who died in childhood, while 24.2% lost a parent as a child. Of the 212 responses for cause of childhood sibling death, the most common was "infection/sickness" (78.3%), followed by "unspecified" (15.6%) and "starvation" (6.1%). On average, participants spent 3.7 years in a refugee camp and 19.2 years resettled abroad, with the average age at first resettlement being 15.1 years old. Hmong in the US were more likely to express unhappiness than those in French Guiana (17.3% vs. 3.4%; $\chi^2 = 16.2$; $P < 0.001$), as well as a desire to return to Laos (48.5% vs. 13.0%; $\chi^2 = 41.4$; $P < 0.001$; data not shown in table).

TABLE 2. Descriptive statistics of participants (means ± SD and percentages)

	Females ($n = 113$)	Males ($n = 166$)
Current age and anthropometrics		
Age (yrs)	34.2 ± 7.2	34.4 ± 6.8
Height (cm)	148.0 ± 5.8[a]	159.5 ± 6.2
BMI (kg/m^2)	26.5 ± 4.5[a]	26.1 ± 3.5
BF%	37.9 ± 8.8[a]	27.2 ± 5.7
Sum 4 skf (mm)	86.7 ± 23.4	67.5 ± 21.4
Abdom/hip ratio (×100)	85.2 ± 6.3	89.6 ± 5.3[a]
Central skinfold ratio[b]	1.1 ± 0.2	1.8 ± 0.5
Arm muscle area (cm^2)	27.5 ± 5.8	41.3 ± 8.3
Life history variables (all participants; $n = 279$)		
Born in a war zone	30.5%	
Displaced from village < age 2 years	38.8%	
Total number of times displaced[c]	2.5 ± 1.9	
Number of siblings[d]	8.2 ± 4.0	
Sibling died as a child[d]	76.8%	
Parent died in subject's childhood[c]	24.2%	
Number of years lived in a refugee camp[d]	3.7 ± 3.2	
Age first resettled abroad[d]	15.1 ± 7.9	
Total number of years resettled abroad[d]	19.2 ± 4.6	
Unhappy with current living conditions[d]	8.3%	
Desire to one day live in Laos permanently[c]	25.5%	

[a]One case missing.
[b]Central/periph skf.
[c]Six cases missing.
[d]Two cases missing.

In addition, 178 Hmong in French Guiana gave their primary occupation; 69.7% listed theirs as farmer (data not shown). Other occupations included teacher/student/office worker (12.4%), business owner (6.7%); manual laborer (5.1%), and homemaker (4.5%), though virtually all Hmong in Cacao, Javouhey, and Regina, including teachers and restaurant owners, farm at least part of the time. In the US, 96 gave their primary occupation, including manual laborer/factory worker (42.7%), teacher/student/office worker (35.4%), unemployed (12.5%), and homemaker (6.3%).

Table 3 displays the relationship between markers of infant and childhood distress on adult height. Though most markers of distress were negatively associated with height (with the exception of loss of a parent in childhood), this failed to reach statistical significance consistently for both sexes. For females, being born in a war zone and having a childhood sibling who died were both significantly associated with shorter height, while being displaced as an infant just missed being statistically significant for both sexes.

TABLE 3. Mean height (cm) of Hmong refugees according to markers of infant and child distress

	Males				Females			
	n	Mean ± SD	*t*	*P*	n	Mean ± SD	*t*	*P*
Born in a war zone								
Yes	51	158.6 ± 6.1	−1.3	0.204	34	146.0 ± 6.2	−2.5	0.014**
No	115	159.9 ± 6.3			78	148.9 ± 5.4		
Displaced while an infant								
Yes	70	158.4 ± 7.1	−1.9	0.061†	35	146.4 ± 5.5	−1.9	0.062*
No	93	160.3 ± 5.4			74	148.6 ± 5.8		
Lost a childhood sibling								
Yes	129	159.1 ± 5.9	−1.3	0.250	82	147.2 ± 5.9	−2.3	0.024**
No	34	160.7 ± 7.4			30	150.0 ± 5.1		
Lost a parent as a child								
Yes	40	159.7 ± 5.1	0.3	0.758	25	147.8 ± 5.4	−0.3	0.740
No	122	159.4 ± 6.5			85	148.2 ± 5.8		

*$P \leq 0.10$.
** $P \leq 0.05$.

TABLE 4. Linear regression models for height and upper arm muscle area, with unstandardized (β) and standardized (Beta) regression coefficients

	Height ($n = 268$)			Arm muscle area ($n = 270$)		
	β	*Beta*	*P*	β	*Beta*	*P*
Constant	161.37		<0.001***	45.06		<0.001***
Early life variables						
Born in war zone	−1.48	−0.08	0.088*	0.36	0.02	0.732
Displaced as infant	−1.67	−0.10	0.043**	0.10	0.01	0.919
Covariates						
Female sex	−11.71	−0.70	<0.001***	−14.52	−0.73	<0.001***
Age	0.08	0.07	0.373	−0.05	−0.03	0.682
Resettled in US	0.76	0.04	0.364	−2.89	−0.14	0.004***
Age at resettlement	−0.25	−0.24	0.002***	−0.06	−0.05	0.565
R^2		0.536			0.518	
R^2 without sex in model		0.079			0.014	

*$P \leq 0.10$.
**$P \leq 0.05$.
***$P \leq 0.01$.

Linear regression models

In the regression models, being displaced as an infant had a significant inverse relationship with final adult height after controlling for the covariates (Table 4). Age at resettlement abroad was also a significant predictor of height, with individuals who resettled at younger ages being taller, as they spent more of their growing years spent in better environmental conditions than those faced in Southeast Asia. This inverse relationship is significant for both sexes and is expressed graphically in Figure 2. Upper arm muscle area was negatively associated with resettlement in the United States, though neither early life variable was a significant predictor. The relationship between the predictor variables and the adiposity variables is shown in Table 5. Being born in a war zone had a consistent relationship with greater overall and centralized adiposity, though displacement in infancy was not a significant predictor in any model. This relationship is illustrated in Figure 3; with body fat percentage being significantly higher for males and females who were born in a war zone, after controlling for sex (ANOVA, $F = 4.59$, $P = 0.033$). Contrary to what was expected, place of resettlement was associated only with the central skinfold ratio, with Hmong in the US having higher values. The total variance (R^2) explained by the variables ranged from 21.0% to 53.6% in the various

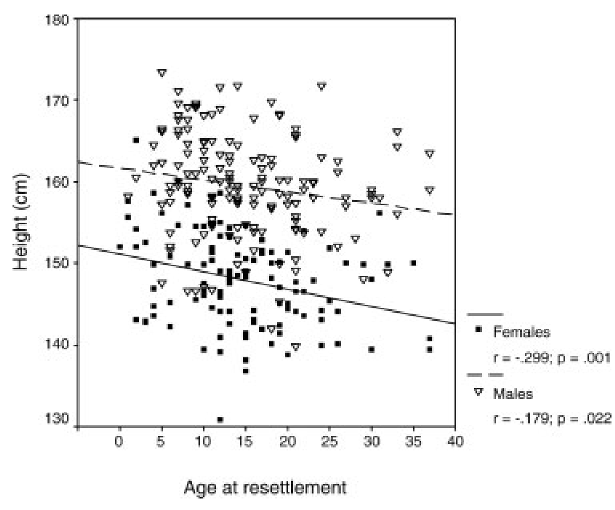

Fig. 2. Scatterplot of age at resettlement and adult height. *R*-values refer to Pearson correlation coefficients. For both males ($n = 165$) and females ($n = 111$), migrating at younger ages to either French Guiana or the United States was significantly correlated with greater adult height.

TABLE 5. Linear regression models for adiposity, with unstandardized (β) and standardized (beta) regression coefficients

	Body fat % ($n = 270$)			Sum of four skinfolds ($n = 270$)			Central skf ratio ($n = 270$)			Abdominal/hip ratio ($n = 269$)		
	β	*Beta*	*P*	β	*Beta*	*P*	β	*Beta*	*P*	β	*Beta*	*P*
Constant	22.25		<0.001***	36.78		<0.001***	1.36		<0.001***	80.37		<0.001***
Early life variables												
Born in war zone	2.37	0.12	0.032**	7.25	0.14	0.029**	0.15	0.14	0.006***	1.93	0.15	0.020**
Displaced as infant	−0.29	−0.02	0.782	−1.22	−0.02	0.696	−0.06	−0.06	0.214	0.13	0.01	0.863
Covariates												
Female sex	11.05	0.60	<0.001***	20.22	0.41	<0.001***	−0.63	−0.62	<0.001***	−4.17	−0.34	<0.001***
Age	0.14	0.11	0.224	1.08	0.31	0.002***	0.01	0.15	0.054*	0.26	0.30	0.003***
Resettled in US	0.28	0.01	0.793	0.15	0.00	0.963	0.23	0.21	<0.001***	−0.47	−0.04	0.555
Age at resettlement	−0.05	−0.04	0.654	−0.54	−0.18	0.091*	−0.01	−0.09	0.285	−0.01	−0.01	0.926
R^2		0.375			0.212			0.498			0.210	
R^2 without sex in model		0.036			0.053			0.140			0.100	

*$P \leq 0.10$.
**$P \leq 0.05$.
***$P \leq 0.01$.

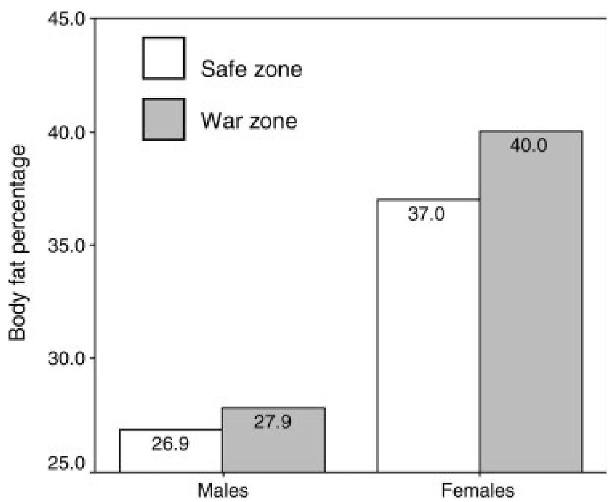

Fig. 3. Mean body fat percentage for adult Hmong by place of birth. After controlling for sex, being born in a war zone was significantly associated with higher body fat in adulthood following migration (ANOVA, $P = 0.033$)

models. However, after removing the predictor variable sex from each model, the amount of variance explained declined precipitously. Relatively small sample sizes prevented separate models being performed for each sex.

DISCUSSION

Height

The aim of this study was to investigate the relationship between proxies for early malnutrition and height, body composition, and body fat distribution of adult Hmong refugees, while using place of resettlement as a marker for current and recent diet and physical activity. In the univariate analyses, being displaced in infancy (before age 2 years) was associated with shorter height, though this just missed statistical significance for both sexes. Being born in a war zone and experiencing the loss of a childhood sibling was associated with shorter height for females only. This disparity between the sexes could represent a real biological difference, or may represent an effect of the nonrandom sample and selection bias. In the multiple regression analysis, being displaced in infancy was negatively associated with height after controlling for other confounders, while being born in a war zone approached significance ($P = 0.088$). It is not surprising that both proxies for early malnutrition would be associated with shorter adult height, as they are indicative of poor living conditions. Although height may be affected by environmental conditions throughout the growth period, it seems particularly vulnerable before age 2 years, as shorter adult height has been correlated with low birth weight and exposure to famine in infancy or even late gestation (Li et al., 2003; Sørensen et al., 1999; Stein et al., 1975). However, age at resettlement was inversely related to height in the current study, suggesting that the potential for increased height or catch-up growth increased the earlier that resettlement occurred.

Height is often viewed as a reflection of living conditions and population health (Bogin et al., 2002; Komlos, 1994; Tanner, 1990). In the past century, conditions created by warfare consistently have been linked with reduced stature in children and adults (Bogin and Keep, 1999; Keys et al., 1950; Kimura, 1984; Vlastovsky, 1966). This appears true of the current study as well, as proxies for malnutrition in early life were associated with reduced height in adulthood. Hmong and other ethnic groups in Laos trapped in war-zone areas were mostly poor, subsistence farmers who faced broken agricultural cycles and long, arduous journeys on foot to places of safety. Nutrition surveys revealed that even in safe areas during the wars in Laos the intake of calories and some micronutrients was often barely adequate (Gerhold, 1967; Hankin et al., 1972; Ireson, 1969). Therefore, it is likely that the majority of individuals in the current study endured at least some degree of malnutrition, though military conflict certainly caused these deficiencies to deteriorate further. Unfortunately, few other studies have examined the long-term effects of the wars in Southeast Asia on growth and maternal/child health (but see: Hop, 2003; Savitz et al., 1993).

Body composition

The results also revealed that Hmong born in a war zone had greater adiposity (body fat%, sum of four skinfolds) and central adiposity (central skinfold ratio, abdominal/hip ratio) after controlling for confounders. This is consistent with other studies that have linked prenatal malnutrition or low birth weight with greater adiposity in adulthood (Law et al., 1992; Loos et al., 2001, 2002; Rasmussen et al., 2005; Ravelli et al., 1976; te Velde et al., 2003). Notably, in the regression models birthplace was associated with greater adiposity, while being displaced in infancy was associated with shorter height. This lends credence to the validity of these proxies, as research suggests that the first two trimesters of gestation are a critical period for developing elevated adiposity (Ravelli et al., 1976) while height is vulnerable before age 2 years (Adair, 1999; Martorell and Habicht, 1986). Importantly, the current study tested whether being born in a war zone was associated with adiposity as a continuous variable, rather than obesity, per se. The rationale for this is that studies in India have demonstrated that infants and adults faced with prenatal malnutrition tend to have fairly low BMI values but have elevated adiposity, a pattern referred to as the "thin and fat" phenotype (Yajnik, 2000; Yajnik et al., 2003).

Further, being born in a war-zone was a slightly better predictor of the central adiposity variables ($P = 0.006$ to 0.020) than the overall adiposity variables ($P = 0.029$ to 0.032). Similarly, Rogers et al. (2003) reported that birth weight and the intrauterine environment tend to be more highly correlated with central adiposity than general adiposity. This has biological plausibility, as intra-abdominal fat is metabolically more labile than subcutaneous adipose tissue (Snijder et al., 2006), though low birth weight has been linked with greater centralization of subcutaneous fat as well (Bavdekar et al., 1999; Malina et al., 1996; Valdez et al., 1994). The adaptive significance of developmental plasticity and intra-abdominal fat deposition as a means to stave off starvation has been emphasized by Gluckman and Hanson (2005), where a fetus faced with malnutrition may alter its metabolism to better retain body fat, particularly abdominal or truncal fat, in expectation of future energy shortage. Similar patterns have been observed in rats, where prenatal food restriction has led to postnatal alterations in appetite and greater centralization of adiposity (Bellinger et al., 2004; Vickers et al., 2000).

It has been suggested that the effects of prenatal malnutrition on obesity "may be detectable only among subjects who move across the plane of nutrition from scarcity early in life to abundance or even excess in adulthood" (Martorell et al., 2001: 878S). The historical circumstances of the Hmong, who faced hardship via poverty and warfare, coupled with migration experiences later in life fit this scenario and provide a unique opportunity to study the effects of early malnutrition on body composition. Given the very high infant mortality rates in Laos during the war, it is possible that Hmong infants that were better able to make metabolic adaptations to store body fat were more likely to survive stresses that accompany weaning. This implies a cohort effect, where survival through infancy and childhood was correlated with growth performance. If such adaptations were permanent, a positive shift in the nutritional milieu following resettlement could lead to the development of greater adiposity. From a public health perspective, as populations shift from conditions of nutritional deprivation to excess, whether through local economic transition or physical migration to a new environment, negative health outcomes resulting from obesity may emerge. For example, central obesity in particular is an independent predictor of later cardiovascular disease and type 2 diabetes (Bjorntorp, 1992).

Alternatively, the links between being born in a war zone and elevated adiposity may have a nonphysiological explanation. For example, Guggenheim (1977) referred to "obesogenic" parents who had memories of premigration nutritional scarcity. Such parents may overfeed their children to protect them from experiencing feelings of hunger. This possibility could account for the discrepancy in the relationship between birthplace with adipose and muscle tissue. While being born in a war zone was associated with elevated adiposity, it was not associated with the expected reductions in arm muscle area. Ostensibly, this study could have benefited from more direct estimates of muscularity and at more sites on the body.

It is also true that early malnutrition is neither sufficient nor necessary in gaining excessive adipose tissue; current diet and physical activity are obviously important as well, and populations obviously have high rates of obesity without experiencing prenatal malnutrition. However, an attempt was made to control for some of these factors, using place of resettlement as a proxy for current energy balance. It is surprising that this was not a predictor of overall adiposity. This may be due to the nonrandom samples recruited, which may not be wholly representative of their larger populations. Further, while the majority of Hmong in French Guiana are rural farmers, they tend to live fairly well. It is estimated that the Hmong supply more than half of the fruits and vegetables in the country, allowing them a steady source of income and a degree of material comfort (Clarkin, 2005a; Géraud, 1997).

Resettlement in the US, however, was associated with a greater central skinfold ratio and lower arm muscle area compared with French Guiana. Others have reported that central and peripheral skinfolds in children have been affected by postnatal environmental factors, including place of migration and socio-economic status (Bogin and Sullivan, 1986; Ramirez and Mueller, 1980). The greater arm muscle area among Hmong in French Guiana could possibly be indicative of higher physical activity levels due to their reliance on manual labor for farming, though post-hoc analyses revealed no significant difference between nonmanual vs. farming and manual occupations for arm muscle area after controlling for sex and place of residence ($F = 0.052$; $P = 0.820$; data not shown).

Limitations

As this is a retrospective study with a nonrandom sample, the links between war-related markers of perinatal or infant distress and later adiposity and height cannot be proven to be causal. Additionally, this study is limited by the potential for faulty recall on the part of participants and the use of indirect proxies for early nutrition and current diet and physical activity levels. The ideal data would be direct observations of dietary intakes of pregnant Hmong mothers and their infants; in the absence of these, proxies must suffice. Moreover, although birthplaces were confidently categorized as safe-zone or war-zone, this study could not account for individual nutritional variation within a village, or for degree or duration of perinatal malnutrition. Other potentially important missing information includes length of gestation of participants and where mothers resided throughout gestation, as opposed to solely at birth.

In addition, the various stressors accompanying war make it difficult to isolate nutrition as the sole factor affecting height and body composition in the current study. Warfare consistently leads to malnutrition, but it also creates a suite of experiences that are detrimental to child growth and development, including increased risk of injury, infection, and psychological stress, particularly in developing countries (Cohen and Pinstrup-Andersen, 1999; Guha-Sapir and van Panhuis, 2003; Toole and Waldman, 1993; Yip and Sharp, 1993). Hmong mothers in war zones likely faced psychological stress, the effects of which may impact fetal development (Zhang et al., 2004), while refugees moving from the highlands to valleys in Laos faced greater exposure to mosquito-borne diseases such as malaria. However, some Hmong born in safe zones, such as refugee or military centers remained food secure, but also likely faced psychological stress during military conflict. Therefore, an effort was made to focus primarily on perinatal and infant nutrition, though other factors cannot be discounted.

CONCLUSIONS

Individuals born in war-zone areas or who were displaced by war as infants were presumed to have experienced malnutrition in the perinatal and infant periods, respectively. Being born in a war zone was associated with higher adiposity and central adiposity in regression analyses, while being displaced in infancy was associated with shorter height, suggesting long-term effects of war on Hmong growth and development. Few studies have addressed the developmental origins of chronic disease in populations like the Hmong, i.e., those who faced poor early nutrition followed by migration and rapid change in environment (Frisancho, 2003; Moore, 1998), though this may be changing. For example, King et al. (2005) suggested that the elevated rates of diabetes in Cambodia could be, in part, a legacy of the Khmer Rouge period. Future research should address whether early malnutrition may have affected the health of other war-exposed populations, including sedentes and refugee migrants, particularly in other populations from Southeast Asia.

ACKNOWLEDGMENTS

KaLy Yang and Sing Yang acted as project interpreters, while Ernie Kuhn, Dr. Yang Dao, Chue Toua Kue, and Mike Little provided valuable advice. The author also thanks the anonymous reviewers for the helpful comments on an earlier version of this article and the Tanita Corporation for donating equipment used in this study. Finally, the author is extremely grateful to the Hmong participants of this study.

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