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Health Consequences of Social and Ecological Adversity among Indigenous Siberian Populations

Biocultural and Evolutionary Interactions

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Anthropological Perspectives on Human Biological Variation and Health

In studying human health and well-being, biological anthropologists differ from most biomedical scientists in that we draw explicitly on both evolutionary and biocultural models (Stinson et al. 2000). As anthropologists we are interested in understanding the origin and nature of biological variation as well as the proximate social, political, and economic determinants of variation in human health. Thus, we recognize that human biological variation in health is shaped by adaptive responses to stress and adversity in our evolutionary past, as well as by ongoing social and ecological challenges to our health in the modern world.

Increasing rates of obesity and cardiovascular (CV) disease are among the most pervasive threats to human health throughout the world. Today we find that these problems are emerging in many traditional societies where they were virtually unknown less than a generation ago. This is true of the indigenous populations of the vast Siberian region of Russia (Leonard et al. 1996, 2002b; Snodgrass 2004; Sorensen et al. 2005). In their traditional subsistence lifestyle, these populations were relatively

protected from obesity and associated metabolic diseases by virtue of their high levels of physical activity and daily energy expenditure (see Shephard and Rode 1996). Today, as these native Siberian groups adopt more sedentary lifestyles, overweight and obesity have emerged as growing problems (Snodgrass et al. 2006a). Yet, while many of the factors contributing to these health changes (e.g., changes in activity patterns and food availability) are the same as in other parts of the world, unique sociopolitical events in Soviet and Russian history have produced patterns that are distinct to indigenous Siberian groups.

Since the early 1990s, we have been studying aspects of human biological variation and health change among indigenous Siberian populations. Indigenous Siberians face multiple, interacting sources of adversity and risk, including: 1) a severe, marginal environment characterized by extremes in temperature and low biological productivity; and 2) ongoing social, economic, and political changes that constrain adaptive options and threaten health and well-being. In our work, we have examined both ecological and social determinants of health in native Siberians, specifically addressing three major issues: 1) biological adaptations to arctic climes, 2) the health consequences associated with lifestyle "modernization," and 3) the impact of post-Soviet political-economic changes on health. As initially conceptualized, these three research domains were largely independent of one another. However, as our research has continued, it has become clear that these domains are interconnected. We have found that key adaptations to cold stress appear to play important roles in shaping how lifestyle changes influence health in native Siberians. In other words, we have seen that basic aspects of human biological variation have important implications for determining how lifestyle and environmental factors may influence health.

This chapter will summarize some of the key findings from our Siberian work, highlighting the interplay between the evolutionary and biocultural domains. Our work has shown that the ecological and social dimensions of risk faced by native Siberians do not impact the biology and health of all segments of population in the same way. Indeed, whereas the initial post-Soviet period was associated with increased rates of obesity in many adult Siberians, children showed higher rates of *under*nutrition and growth stunting (Leonard et al. 2002b).

Additionally, we have also seen that the health consequences of lifestyle change among native Siberians differ from those observed in other "modernizing" groups. Despite increasing rates of obesity, native Siberians continue to have low cholesterol and triglyceride levels, whereas high blood pressure (hypertension) has emerged as a major cardiovascular health problem. Variation in blood pressure and plasma lipid levels are jointly influenced by variation in body composition, lifestyle factors, and metabolism. Both blood pressure and lipid levels are positively associated with body weight and body fatness (Leonard et al. 2002a; Snodgrass 2004; Sorensen 2003). Conditions of marginalization and poverty that have emerged in post-Soviet Russia also contribute to elevated lipid levels (Sorensen et al. 2005) and blood pressure (Snodgrass 2004; Snodgrass et al. 2005b). In addition, as a means of adapting to

their cold, marginal environments, native Siberians have elevated basal metabolic rates (BMR) (Leonard et al. 2002, 2005). These elevated BMRs exert a significant positive influence on blood pressure while having a depressing effect on cholesterol levels. These effects persist after controlling for the influence of body composition and lifestyle variables.

These findings suggest that in the face of nutritional and lifestyle changes, elevated metabolic turnover in native Siberian populations may protect them against hyperlipidia while predisposing them to hypertension. The clustering of cardiovascular risk factors in native Siberians is, in many respects, the mirror image of what is observed among acculturating populations such as the Pima Indians of the southwestern US. With the Pima we see low BMRs associated with moderate to high cholesterol levels, very high rates of diabetes, and yet relatively low rates of hypertension (Ravussin 1995; Spraul et al. 1993; Weyer et al. 2000). The differences between the Pima and indigenous Siberians appear to be the product of the unique historical changes in lifestyle and socioeconomic status of the two groups and underlying differences in metabolism shaped by adaptation to different environmental stressors.

Our research underscores the importance of linking biocultural and evolutionary perspectives in studying variation in human biology and health. Moreover, it highlights the critical roles that biological anthropologists can play in addressing major global health problems.

Indigenous Siberians: Historical and Ethnographic Context

Siberia spans over 13 million square kilometers and has one of the world's lowest population densities, with a total native population of only about 1.3 million. The initial human settlement of most of Siberia occurred relatively recently; although some evidence suggests an early settlement of Arctic Siberia (c. 30,000 years ago; Pitulko et al. 2004), most studies point to a more recent date (less than 20,000 years ago) (Goebel 1999; Mote 1998).

Prolonged contact between Russian and indigenous Siberian populations began in the late sixteenth century as Russian explorers and traders expanded eastward across the Siberian plain in search of animal pelts to procure for the burgeoning European fur market (Forsyth 1992; Slezkine 1994). With the emergence of the Soviet State, native Siberians experienced major transformations in their traditional ways of life. Starting in the 1930s, the Soviet government began the process of collectivizing the indigenous populations of the north. These reforms were designed to "modernize" native Siberian groups by drawing them directly under the control of the Soviet state (Slezkine 1994). With collectivization, animal herds (e.g., reindeer) were no longer held by individual families but were placed into communal herds that were controlled by state-run collectives. As a result, the native populations were forced to shift from their nomadic lifeways and give up key aspects of their traditional culture (e.g.,

language, shamanism). This transition also resulted in the restructuring of subsistence roles. With the traditional nomadic lifeway, indigenous groups had an unstructured division of labor, with both men and women contributing to subsistence production. After collectivization, gender roles were much more clearly defined, with men being largely responsible for subsistence food production (herding, farming) while women were responsible largely for domestic tasks.

The collapse of the USSR in 1991 created conditions of economic hardship and unprecedented declines in life expectancy throughout Russia and the former Soviet states (Leon et al. 1997; Notzon et al. 1998; McKee and Shkolnikov 2001). These reductions in life expectancy have been attributed to a number of factors, most notably increased alcohol consumption (Leon et al. 1997; McKee and Shkolnikov 2001), impoverishment and material deprivation (Bobak et al. 1998), social stress and lifestyle changes (Carlson 2000), and the deterioration of the health-care system (Field 1995).

In Siberia, the fall of the Soviet Union resulted in the dismantling of many of the indigenous herding and farming cooperatives. Under the collective system, the Soviet government funded the transport of food and medical supplies into remote villages and herding brigades (Forsyth 1992; Hannigan 1991; Slezkine 1994). Following the collapse of the Soviet system, these shipments were greatly reduced or eliminated entirely, resulting in a return to traditional subsistence activities among many of the more remote populations (Fondahl 1997; Leonard et al. 2002a,b; Snodgrass 2004). Today in Siberia, we are seeing the emergence of greater heterogeneity in lifestyles. While many families have shifted away from traditional subsistence-based activities to move to larger villages and towns, many of these same families continue to herd, hunt, forage, and/or farm in order to supplement their diets. These social and economic changes continue to have important yet variable impacts on health among indigenous Siberian populations. Our research has documented increased mortality rates (Leonard et al. 1997), declining levels of childhood nutritional status (Leonard et al. 2002), and increased risks of CV disease (Snodgrass 2004; Sorensen 2003; Sorensen et al. 2005) among indigenous Siberians during the post-Soviet period.

Over the last sixteen years, we have studied four different indigenous Siberian groups: 1) the Evenki reindeer herders, 2) the Ket fisherman, 3) the Buryat cattle herders, and 4) the Yakut cattle and horse herders. The geographic locations of these four populations are shown in Figure 1.1. Brief ethnographic descriptions of each group are presented in Box 1.1.

These groups live in communities that span wide variation in lifestyles, ranging from small herding encampments (brigades) of 35–50 individuals, to villages of 400–600 residents, up to larger towns with population sizes of more than 1,000 individuals. Those living in traditional herding units continue to pursue largely a subsistence-based lifestyle. Those living in small collective villages and larger towns have greater access to market goods and the wage economy.

Ethnographic Background of Select Siberian Populations

In our research in Siberia, we have worked with four indigenous populations: 1) the Evenki, 2) the Ket, 3) the Buryat, and 4) the Yakut. The Evenki are a Tungusic-speaking population of reindeer herders from the northern regions of the Siberian boreal forest (taiga) (Forsyth 1992). The Evenki population numbered approximately 30,000 at the last major census (Fondahl 1997). Additional information on the study population, as well as on the Evenki in general, can be found in Leonard and coworkers (1994, 1996, 2002a).

The Ket are a central Siberian population structured around fishing. They are extremely small in number, and in the 1989 census numbered less than 1,200 (Fondahl 1997). The Ket are apparently a remnant of a considerably larger population, which was centered in the Yenisey valley at the time of initial Russian contact but which was subsequently decimated by epidemics of infectious disease (Forsyth 1992). The Ket language is unique and, based on available evidence, appears to be unrelated to any known languages.

The Buryat are descendants of Mongol populations that settled in the meadow-steppe region around Lake Baikal at the boundary of the northern forest (Forsyth 1992). The Buryat language belongs to the Mongolic language family. At the time of initial Russian contact, the Buryat population was relatively large and increased substantially during the Russian and Soviet periods; at the last census, the Buryat population numbered over 400,000 (Fondahl 1997; Forsyth 1992). Most rural Buryat today subsist off the products of cattle, which are fed through locally cultivated crops (Humphrey and Sneath 1999).

The Yakut (Sakha), members of the Turkic language family, number nearly 400,000 and are concentrated in northeastern Siberia (Fondahl 1997; Forsyth 1992; Snodgrass 2004). The Yakut traditionally practiced a complex and locally variable subsistence strategy that was largely dependent upon regional ecological conditions (Tokarev and Gurvich 1964). In remote parts of the taiga, the Yakut subsisted by hunting and fishing, while in the Lena River Valley the primary subsistence activity was transhumant pastoralism (primarily horse and cattle).

Figure 1.1. Map of Siberia showing the geographic locations of the Buryat, Evenki, Ket, and Yakut.

Health Consequences of Social and Ecological Adversity

Nutritional Consequences of the Post-Soviet Transition in the Evenki

Social and economic changes in Russia appear to have strikingly different nutritional consequences for children and adults. This point is most evident when we examine our data from the Evenki, whom we studied from 1991 through 1995 during the initial phases of the post-Soviet transition, when Evenki reindeer herding cooperatives were being dismantled. During the years immediately following the fall of the Soviet Union, anthropometric indicators of childhood undernutrition dramatically increased in the Evenki. Table 1.1 shows the percentage of Evenki children under the age of 6 years who were classified as "stunted" (height-for-age Z-score < –2), "underweight" (weight-for-age Z-score < –2), or "wasted" (weight-for-height Z-score < –2) during the Soviet and post-Soviet periods. Rates of stunting (a measure of chronic, mild-to-moderate undernutrition) increased from 34 to 61 percent between 1991 and 1995. Similarly, the prevalence of underweight children more than doubled during this period, rising form 18 to 43 percent. Wasting, an index of acute undernutrition, also rose dramatically from 2 to 17 percent. These levels of childhood undernutrition are comparable to those seen among impoverished populations of the developing world (see de Onis et al. 2000).

In contrast, among Evenki adults overweight and obesity are much more common than conditions of undernutrition. Based on body-mass indices (BMI), only 2 percent men and 5 percent of women were classified as "underweight" (BMI < 18.5

Table 1.1. Indicators of growth status in Evenki children measured between 1991 and 1995, during the "Soviet" and initial "Post-Soviet" periods (adapted from Leonard et al. 2002b).

Measures	Soviet (n=101)	Post-Soviet (n=54)
Low Height-for-Age ("stunting")	34%	61%***
Low Weight-for-Age ("underweight")	18%	43%***
Low Weight-for-Height ("wasting")	2%	17%***

Differences between the "Soviet" and "Post-Soviet" groups are statistically significant at: ***P < 0.001 (Chi-Square Analyses).

kg/m^2), whereas rates of overweight and obesity (BMI $\geq$ 25 kg/m^2) were 11 percent and 32 percent in men and women, respectively. As shown in Table 1.2, mean BMIs of adults remained relatively stable between 1991 and 1995 during the initial post-Soviet transition. However, levels of body fatness significantly increased in both men and women during this time period.

The reasons for the sharp declines in growth status and nutritional health for children likely stem from the increased isolation that Evenki experienced during the initial post-Soviet period. The shift away from the collectivized herding system coupled with the general economic decline in post-Soviet Russia resulted in less regular contact between the small Evenki settlements (villages, herding brigades) and larger urban centers in Siberia. Plane and helicopter transport into these remote areas were much less common during the early post-Soviet transition. Thus, medical supplies and nonlocal foodstuffs that were regularly brought in by plane or helicopter during the Soviet era, became more scarce after the herding collectives were dismantled. As a consequence, access to important high-quality weaning foods (e.g., condensed milk, cereals) and health care became more limited during this period.

Table 1.2. Adult nutritional status of Evenki men and women (>18 years) measured between 1991 and 1995, during the "Soviet" and initial "Post-Soviet" periods.

	Males		Females	
Measures	Soviet (n=123)	Post-Soviet (n=46)	Soviet (n=67)	Post-Soviet (n=123)
BMI (kg/m2)	22.6+2.4	22.2+2.8	24.0+4.6	24.3+4.9
Body fat (%)	14.2+4.7	17.1+6.2**	29.9+5.7	33.3+7.3***

Differences between the "Soviet" and "Post-Soviet" groups are statistically significant at: **P < 0.01, ***P < 0.001.

The increasing levels of adiposity among adult Evenki between 1991 and 1995 was an unexpected result in light of the dramatic declines in children's nutritional status. For the adults, it appears that while the quality of the diet declined, energy intake did not dramatically change. Rather, the more important change for many of the Evenki adults resulted from the shift away from reindeer herding and the adoption of a more sedentary lifestyle. This shift in activity levels helps to explain why percent body fatness significantly increased among Evenki adults during the initial post-Soviet period, while BMIs remained constant. Reductions in activity levels and relative stability in energy intake resulted in higher levels of fatness (and reduced muscularity) without substantial increases in overall body mass.

Reductions in energy expenditure and physical activity levels associated with modernization/urbanization of lifestyle are trends that are evident throughout native Siberian groups and appear to be contributing to the relatively high rates of overweight and obesity now seen in the region. The correlates and health consequences of these adult lifestyle changes are explored in the subsequent sections.

Lifestyle Correlates of Overweight and Obesity in Native Siberians

The emergence of "overweight" and "obesity" in adulthood is a problem now common among all native Siberian groups, not just the Evenki (Snodgrass et al. 2006a). Table 1.3 presents the prevalence rates of overweight and obese adults based on the BMI for the four indigenous groups we have studied. Rates of overweight and obesity are systematically and significantly higher in women than in men (36 percent of women are overweight and obese versus 25 percent of men; $P < 0.01$).

Table 1.3. Percent overweight and obese among indigenous Siberian populations (adapted from Snodgrass et al. 2006).

Population	Sex	n	Overweight[a]	Obese[b]
Evenki	M	148	10	1
	F	174	22	10
Ket	M	14	21	7
	F	19	37	5
Buryat	M	51	22	8
	F	80	29	15
Yakut	M	150	25	11
	F	264	24	13
Combined	M	363	18	7
	F	537	24	12

[a] BMI: 25.0 – 29.9
[b] BMI > 30.0

Urbanization of lifestyle is associated with greater body mass (BMI) and higher levels of adiposity in native Siberians. Figure 1.2a shows variation in the BMI by residence location. Women have systematically higher BMIs than men (24.5 vs. 23.4 kg/m^2; $P < 0.001$), but the degree of urbanization has a stronger influence on men's body mass, with those living in the towns having significantly higher BMIs than those living in the brigades or villages ($P < 0.05$).

When we look at percent body fatness (Figure 1.2b), as estimated from the sum of four skinfolds, a slightly different picture emerges. In this case, town residence is associated with significantly greater adiposity in both men and women ($P < 0.01$ for both sexes). Thus, female BMIs do not vary significantly with residence location, while levels of body fatness do vary.

Influence of Energy Expenditure on Risks of Overweight and Obesity

The marked gender differences in body weight and obesity levels between men and women appear to be partly attributable to differences in energy expenditure and activity patterns. Men have significantly higher BMRs than women, a difference that is, in part, attributable to differences in body size. In addition, both men and women have BMRs that are elevated above reference values. Figure 1.3 shows the relationship between BMR and fat-free mass (FFM; kg) in men and women, compared to

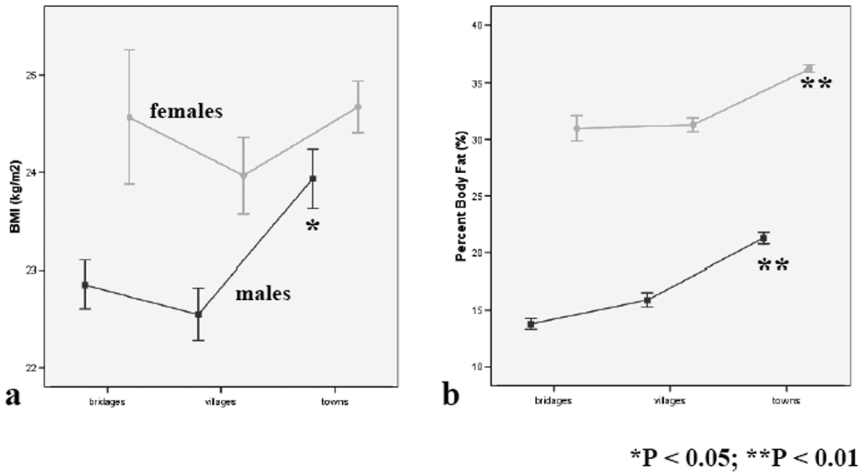

Figure 1.2. Mean (+SEM) (a) BMI (kg/m2) and (b) percent body fat of indigenous Siberian men and women living in different size communities. Town-dwelling men have significantly higher BMIs than their counterparts living in either the herding brigades or villages ($P < 0.05$). For body fatness, town-dwelling men and women both have significantly greater adiposity than their counterparts living in less urbanized settings ($P < 0.01$).

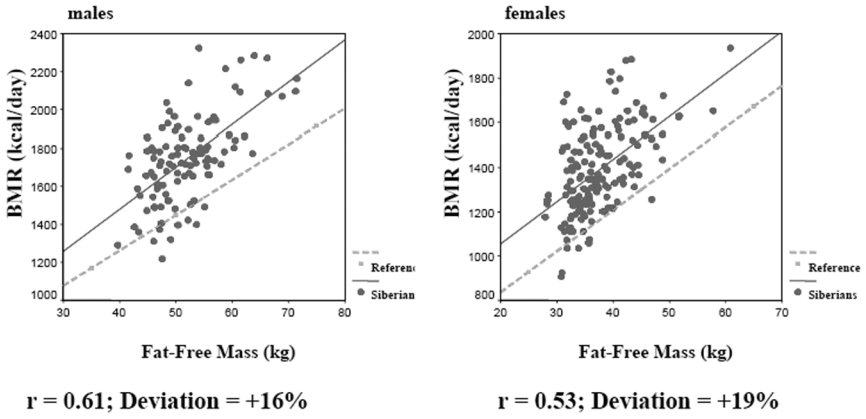

Figure 1.3. Relationship between basal metabolic rate (kcal/day) and fat-free mass (kg) in indigenous Siberian men and women compared to estimated values from reference equations of Poehlman and Toth (1995). BMRs of Siberian men average 1,746 kcal/day (7,400 kJ), 16 percent higher than predicted values. Siberian women average 1,388 kcal/day (5,800 kJ), 19 percent higher.

reference norms compiled by Poehlman and Toth (1995). Men have average BMRs of 1,746 kcal/day (7,400 kJ), as compared to 1,388 kcal/day (5,800 kJ) in women ($P < 0.01$). Siberian men have metabolic rates that are, on average, 16 percent above predicted values, whereas Siberian women deviate by +19 percent ($P < 0.01$, for both sexes).

Total energy expenditure (TEE; kcal/day) varies markedly by gender and level of urbanization. Men have significantly higher levels of TEE. This pattern is true for the sample as a whole, and is true for each of the groups that we have studied (see Table 1.4). Men's daily energy expenditure averages 600–700 kcal/day (2,500–2,900 kJ) more than women's (2,773 kcal/day [11,600 kJ] vs. 2,106 [8,810 kJ] kcal/day; $P < 0.001$). These differences are consistent across all the ethnic groups we have studied and reflect gender differences in both body weight and activity levels.

Activity patterns also appear to be influenced by lifestyle differences. Table 1.4 shows variation in the Physical Activity Level (PAL) ratio—the ratio of TEE to BMR (FAO/WHO/UNU 1985; James and Schoefield 1990)—in men and women by residence location. Men show only small declines in PAL with urbanization. Brigade and village dwellers have similar PALs (about 1.74), and those of town residents are slightly lower (1.66). In contrast, women show significant and marked declines associated with residence location. Women living in the brigades and villages have moderate daily activity levels (PALs = 1.62–1.66), whereas those living in towns have significantly lower PALs, consistent with very sedentary lifestyles (1.4–1.5; $P < 0.05$).

Table 1.4. Body weight, basal metabolic rate (BMR), total energy expenditure (TEE) and physical activity levels (PAL) of adult men and women of native Siberian populations (adapted from Leonard et al. 2005).

Population	Sex	Weight (kg)	BMR (kcal/d)	TEE (kcal/d)	PAL (TEE/BMR)
Evenki, herders	M	61.3	1619	2805	1.74
	F	50.6	1363	2211	1.62
Evenki, village	M	57.5	1543	2669	1.73
	F	51.7	1278	2101	1.67
Evenki, town	M	56.4	1622	2316	1.55
	F	63.7	1346	1664	1.23
Ket, village	M	62.3	1622	2727	1.69
	F	50.1	1233	1860	1.51
Yakut, town	M	72.2	1848	3102	1.68
	F	65.2	1533	2298	1.50

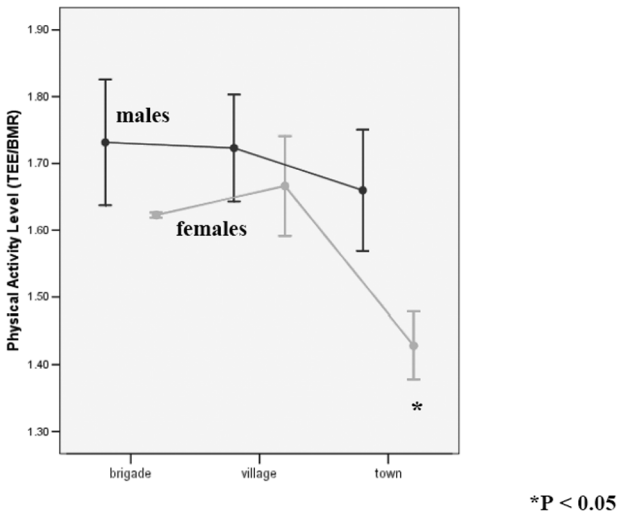

Figure 1.4. Mean (+SEM) physical activity levels (TEE/BMR) of indigenous Siberian men and women living in different size communities. Town-dwelling women have significantly lower ($P < 0.05$) daily activity levels than women living in either the herding brigades or small villages. Men show more modest declines in activity levels with urbanization.

More fine-grained analyses from our most recent work among the Yakut provides additional support for the link between energy expenditure and changes in subsistence patterns. In particular, Snodgrass et al. (2006b) have shown that greater participation in subsistence activities (e.g., hay cutting, fishing, hunting, foragers) is associated with higher levels of daily energy expenditure. Conversely, greater reliance on market food items is associated with lower levels of daily activity and energy expenditure.

Overall, the patterns of variation in energy expenditure are consistent with those observed in body weight and body composition. Women have significantly lower levels of basal and total energy expenditure than men. Lifestyle urbanization also appears to be associated with reductions in physical activity levels; however, these declines are more dramatic in women than men.

Cardiovascular Health Risks

Plasma lipids. Despite the increasing levels of overweight and obesity in native Siberians, we have found that plasma lipid levels are generally quite low (Leonard et al. 1994, 2002a; Mosher 2002; Sorensen et al. 2005). Figures 1.5 and 1.6 compare total and low-density lipoprotein cholesterol (LDL-C) levels in the Evenki, Buryat, and Yakut to the US 50th centiles from the US NHANES III survey (NIH, 2002). Total cholesterol levels of all the Siberian groups fall well below the US median values. The Evenki and Buryat track at about the US 5th centile; whereas the Yakut fall about about the 25th centile.

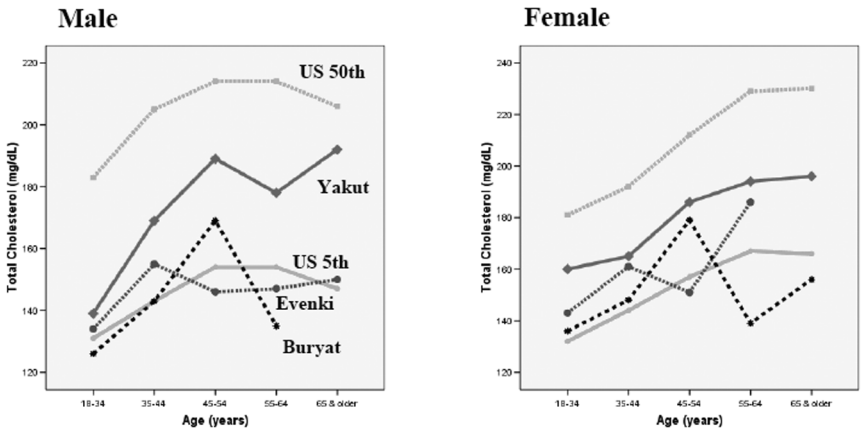

Figure 1.5. Total cholesterol levels (mg/dL) by age group for men and women of three indigenous Siberian populations (Buryat, Evenki, and Yakut) compared to the US 5th and 50th centiles.

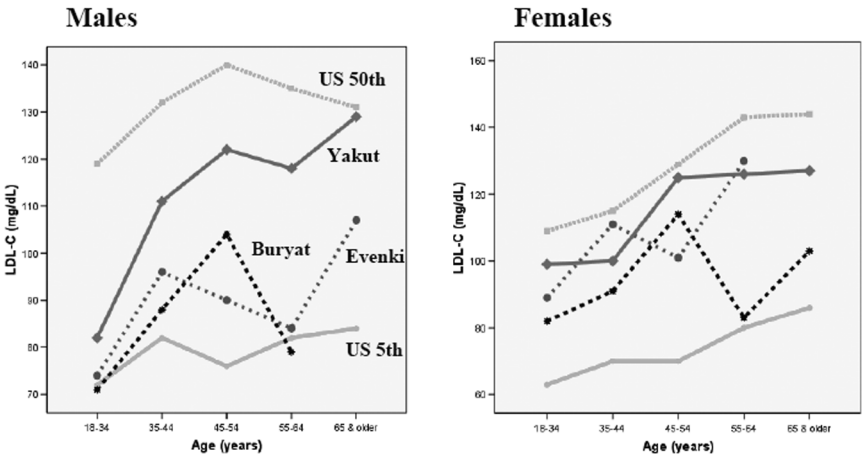

Figure 1.6. LDL-cholesterol levels (mg/dL) by age group for men and women of three indigenous Siberian populations (Buryat, Evenki, and Yakut) compared to the US 5th and 50th centiles.

LDL cholesterol levels are also low and show a similar pattern of variation to total cholesterol. For the Evenki and Buryat, men have LDL levels that that approximate the US 15th centile, whereas women approximate the 25th centile. Among the Yakut, both men and women have LDL levels that fall between the 25th and 50th US centiles.

Blood pressure. In contrast to the plasma lipid levels, Siberian men and women have blood pressure levels that fall above the US reference values. Figures 1.7 and 1.8 show systolic and diastolic blood pressure values of Evenki, Buryat, and Yakut men and women compared to the US 50th centiles (Drizd et al. 1986). With few exceptions, systolic and diastolic blood pressure levels fall at or above the US median values for both men and women. Mean blood pressures (systolic/diastolic) in men are 135/86 mmHg in the Buryat, 133/80 mmHg in the Yakut, and 126/81 mmHg in the Evenki. Among women, the averages are: 136/84 mmHg in the Buryat, 127/82 mmHg in the Evenki, and 120/75 mmHg in the Yakut. Overall, 57 percent of men and 47 percent of women have elevated blood pressure (i.e., systolic BP $\geq$ 120 mmHg and diastolic BP $\geq$ 80 mmHg), as defined by most recent NIH (2004) recommendations.

Correlates of cardiovascular risk factors. The cluster of cardiovascular risk factors observed in native Siberian groups—rising rates of obesity with the persistence of low lipid levels but elevated blood pressure levels—are distinct from what we find in many other "modernizing" populations around the world (e.g., the Pima Indians; see Weyer et al. 2000). This may reflect the fact that the types of lifestyle changes

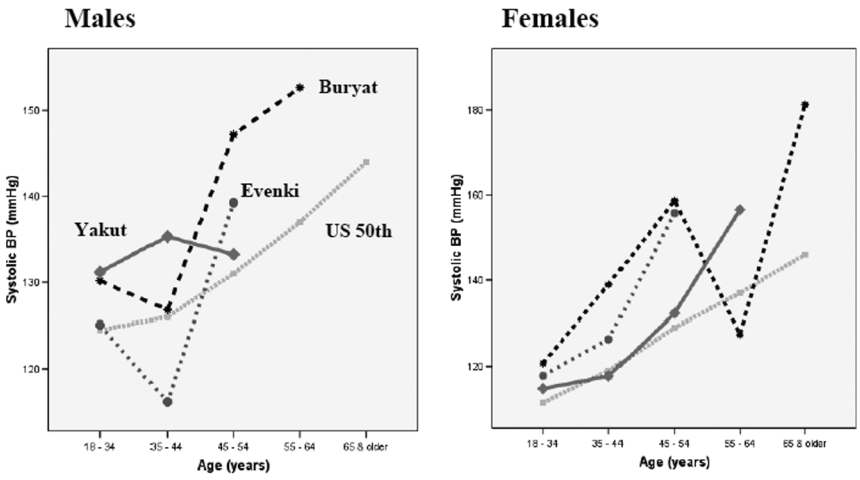

Figure 1.7. Systolic blood levels (mmHg) by age group for men and women of three indigenous Siberian populations (Buryat, Evenki, and Yakut) compared to the US 50th centile.

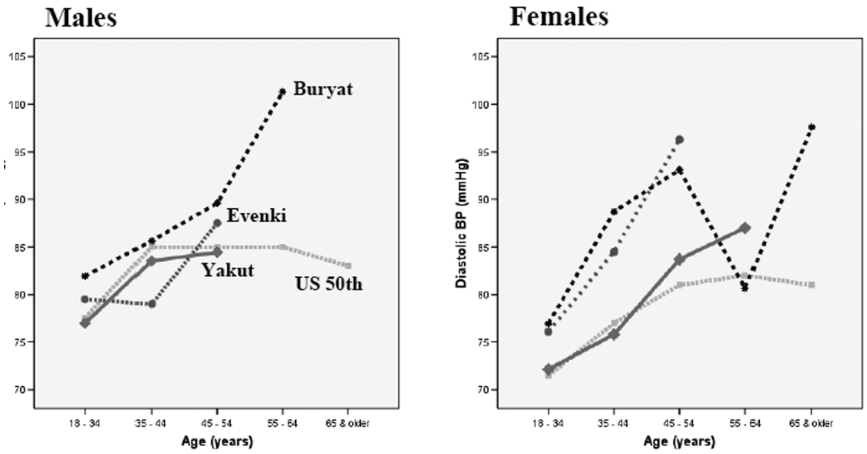

Figure 1.8. Diastolic blood levels (mmHg) by age group for men and women of three indigenous Siberian populations (Buryat, Evenki, and Yakut) compared to the US 50th centile.

observed in post-Soviet Russia are different from those typically seen among other acculturating groups. In addition, the differences also raise the question of whether key physiological or genetic adaptations among native Siberians may be structuring the health consequences associated with lifestyle change. Recent work with US and

Nigerian populations has shown that BMR exerts a positive influence on blood pressure after controlling for the influence of age, sex, and body composition (Luke et al. 2004). These findings suggest that the elevated BMRs of native Siberian groups may partly contribute to their high blood pressure (Snodgrass 2004).

To examine these issues, we used multiple regression analyses to explore the joint influence of anthropometric, lifestyle, and metabolic correlates of blood pressure and cholesterol levels. Table 1.5 shows the multiple regression model for systolic blood pressure (n=289 individuals). Note that neither residence location (urbanization) nor smoking status exerts a significant influence on blood pressure, whereas BMI and age are both positively associated with blood pressure levels. In addition, BMR exerts a significant positive influence on systolic blood pressure, even after controlling for the other covariates. We find that of all the variables entered into the model, BMR is the strongest predictor of blood pressure. The results are similar for diastolic blood pressure, with BMR exerting a positive effect after controlling for the same covariates. However, the magnitude of the effect is smaller (regression coefficient = 0.004; P = 0.11).

Table 1.6 presents the results of a multiple regression analysis of the correlates of LDL cholesterol variation. In this model (n = 175 individuals), residence location has a significant negative influence, suggesting the more urbanized Siberians have lower LDL-C levels. As expected BMI is positively associated with LDL-C. After controlling for the lifestyle and age covariates, BMR shows a significant negative association with LDL-C. This implies that the high metabolic turnover in native Siberians have a protective effect with regard to plasma lipid levels. In the total cholesterol model, the coefficient for BMR is also negative, but the effect does not reach statistical significance.

For a subsample of 154 individuals, food consumption data were also available, allowing us to explore the influence the following dietary correlates of blood pressure

Table 1.5. Multiple regression analysis of the correlates of systolic blood pressure in native Siberians.

Variable	Coefficient (SE)	P
Constant	73.84 (7.62)	< 0.001
Sex (0=female; 1=male)	4.00 (2.87)	0.165
Age (years)	0.31 (0.11)	0.006
Smoking (0=no; 1=yes)	1.34 (2.18)	0.537
Urbanization (0=village; 1=town)	–4.29 (2.82)	0.129
BMI (kg/m2)	0.83 (0.32)	0.010
BMR (kcal/day)	***0.016(0.005)***	***0.003***

Model R2 = 0.19; P < 0.001; n = 289

Table 1.6. Multiple regression analysis of the correlates of LDL cholesterol in native Siberians.

Variable	Coefficient (SE)	P
Constant	81.38 (16.27)	< 0.001
Sex (0=female; 1=male)	8.37(6.45)	0.196
Age (years)	0.32 (0.25)	0.216
Smoking (0=no; 1=yes)	–0.96 (5.04)	0.850
Urbanization (0=village; 1=town)	–15.06 (5.59)	0.008
BMI (kg/m2)	1.83 (0.65)	0.006
BMR (kcal/day)	***–0.03 (0.01)***	***0.013***

R2 = 0.15; P < 0.001; n = 175

and lipid levels: total energy intake (kcal/day), protein intake (g/day), fat intake (g/day), and alcohol intake (g/day). Of these dietary parameters, only energy intake was a significant predictor of systolic BP (regression coefficient = 0.003; P = 0.04) when included with the other independent variables from the model in Table 1.5. Dietary fat intake approached statistical significance (coefficient = 0.072; P = 0.069). With the inclusion of either total energy intake or fat intake into the model, age, BMI and BMR all remain significant predictors of BP (energy model $R^2 = 0.24$; P < 0.0001; fat model: $R^2 = 0.23$; P < 0.0001). For LDL-C, none of the dietary parameters were significant correlates when entered with the other independent variables from the model presented in Table 1.6.

We have also explored the lifestyle correlates of cardiovascular risk factors in greater detail among the Yakut. Sorensen et al. (2005) found lower total cholesterol and LDL-C levels among Yakut living in more urbanized settings and consuming a more market-oriented diet. The poorer lipid profile of the more rural Yakut reflects the conditions of marginalization that have occurred in smaller, more isolated communities following the collapse of the Soviet Union and the breakup of the collective farm system. These conditions contributed to more limited food choices, poorer dietary quality, and higher fat consumption among the rural Yakut (Sorensen 2003; Sorensen et al. 2005). In addition, Snodgrass and colleagues (2005b) found that higher blood pressure was associated with lower income levels in both Yakut men and women after controlling for age and body composition. Together, these findings suggest that conditions of social and economic marginalization in post-Soviet Siberia had significant effects on the cardiovascular health of indigenous groups. Thus, the distinctive clustering of cardiovascular risks in native Siberians appears to reflect the interaction of unique socioeconomic changes with underlying metabolic adaptations.

Discussion

Native Siberians face the challenge of adjusting to the interacting risks posed by both their marginal physical environment and ongoing socioeconomic and lifestyle changes. The economic collapse in post-Soviet Russia that occurred during the mid-1990s had profound health consequences for native Siberian groups. This transition was associated with marked declines in the nutritional status of young children, while adults showed largely the opposite effects—low rates of undernutrition and increased levels of body fatness. These divergent trends have produced a phenomenon that is now increasingly common among urbanizing populations in the developing world—the co-occurrence of adult overweight and obesity with high levels of childhood undernutrition (Caballero 2001; Popkin 2001, 2002; Cameron et al. 2006).

The dramatic declines in growth status witnessed among the Evenki children underscore how sensitive children's growth is to "environmental quality" (Stinson 1985). Such examples of "negative secular trends" (i.e., declines in childhood growth and reduced adult stature) are relatively uncommon in recent human history and tend to be associated with conditions of socioeconomic hardship and impoverishment similar to those recently observed in Russia. Tobias (1985, 1986), for example, demonstrated negative secular trends in stature among South African blacks during the Apartheid era. Similarly, Ellison and Kelly (2005) have recently documented substantial declines in the growth rates of British children living on the Channel Islands under German occupation during World War II.

Among adults, the growing rates of overweight and obesity in the Evenki and other Siberian groups are partly attributable to the shift away from traditional, subsistence activities to a more settled, urbanized way of life. In their traditional subsistence lifestyle, indigenous Siberians and other arctic populations were relatively protected from obesity and associated metabolic diseases by virtue of their elevated BMRs and their high levels of physical activity combining to produce high levels of daily energy expenditure (Godin and Shephard 1973; Heinbecker 1931; Milan and Evanuk 1967; Rodahl 1952; Rode and Shephard 1971). However, with the transition from a "traditional" to a more "modern" lifestyle, substantial and rapid changes in health are evident, including increases in levels of body fatness, declines in aerobic capacity, and increased rates of cardiovascular diseases (Naya et al. 2002; Rode and Shephard 1984, 1994; Shephard and Rode 1996; Young et al. 1995).

Our research indicates that important gender and lifestyle differences in energy expenditure and activity levels strongly contribute to the patterns of obesity and cardiovascular disease risks seen among native Siberians. Men have significantly higher levels of energy expenditure (both basal and total) than women. This difference appears to underlie the marked differences in obesity rates between men and women. Based on the data compiled in Table 1.3, rates of overweight and obesity are 44 percent higher in Siberian women than in men.

The lower daily energy expenditure and physical activity levels seen in women partly reflect the marked gender division of labor that is seen in native Siberian

groups. Physically demanding subsistence activities such as herding animals (Evenki and Buryat) and hay cutting (Yakut) are performed mostly by men, whereas women are generally responsible for cooking, child care, and other domestic activities. This sharp differentiation between male and female roles has its origins in the restructuring of subsistence activities that occurred with Soviet collectivization (Forsyth 1992; Fondahl 1998). These differences have become exaggerated with urbanization and the adoption of more sedentarily lifestyles. Indeed, as noted in Figure 1.4, gender differences in physical activity levels are most dramatic among native Siberians living in the most urbanized settings (towns).

Although lifestyle modernization contributes to declines in total energy expenditure and physical activity, basal metabolism in native Siberians remains elevated compared to both reference values and nonnative populations living in the same communities (Leonard et al. 2002c, 2005). We have also found that contrary to earlier work on native circumpolar populations (e.g., Rodhal 1952) these elevations cannot be attributed to high dietary protein consumption (see Snodgrass et al. 2005a; Leonard et al. 2005). Rather, they appear to reflect adaptations to severe climatic stress.

As for other measures of CV health, plasma lipid levels of native Siberians remain low, whereas blood pressure is quite elevated. Variation in lipid levels and blood pressure among native Siberians is explained, in part, by increased levels of adiposity and by the conditions of socioeconomic marginalization that have emerged since the collapse of the Soviet Union. Elevated blood pressure is also associated with increased energy and fat consumption. However, none of the dietary parameters were associated with variation in lipid levels.

Our recent work among the Yakut has provided some additional insights into the social and lifestyle correlates of CV risks. Sorensen et al. (2005) found that poorer dietary quality contributes to higher lipid levels in the more marginal, rural Yakut communities. For blood pressure, our data from the Yakut suggest that conditions of poverty (lower household income) are associated with higher blood pressure, even after adjusting for the effects of age and body composition (Snodgrass 2004; Snodgrass et al. 2005b). It is possible that the pervasive psychosocial stress resulting from the collapse of the Soviet system and the dismantling of farming and herding collectives has contributed to the elevations in blood pressure now observed throughout native Siberian groups. Such effects are consistent with a growing body of literature on how chronic stress represents an important axis through which lifestyle change and social marginalization influence blood pressure (Dressler 1999; Dressler and Bindon 2000; Dressler et al. 2005; Madrigal et al., this volume). Additional work is needed to examine the influence of psychosocial stress on changing in cardiovascular health of native Siberians.

In addition to body composition, dietary and lifestyle factors, elevations in BMR also have important implications for cardiovascular health in acculturating Siberian groups. After controlling for the effects of body composition and selected lifestyle

factors, we find that BMR is positively associated with blood pressure and negatively associated with lipid levels. Thus, it appears that increased BMR may protect against elevated plasma lipid levels while increasing the risks of hypertension.

A number of recent population studies have identified potential pathways linking metabolic rates and cardiovascular risk factors. In particular, alterations in the activity of the sympathetic nervous system (SNS) are now thought to play an important role in the regulation of cardiovascular homeostasis and energy balance. The SNS helps to regulate arterial pressure by altering the degree of vasoconstriction in the blood vessels (Malpas et al. 2001). Increased SNS activity in humans has been shown to be associated with elevations in blood pressure (Huggert et al. 2004; Masuo et al. 1997; Saad et al, 1991; Ward et al. 1996). In addition, it also appears that elevated sympathetic activity contributes to increased energy expenditure (both BMR and TEE) in humans (Spraul et al. 1993; Tataranni et al. 1998). Luke and colleagues (2004) have argued that increased SNS activity is a likely mechanism for explaining the associations they have found between blood pressure and BMR reported in both US and Nigerian populations. Our findings are consistent with this interpretation and suggest that heightened SNS activity may be responsible for contributing to both the high BMRs and elevated blood pressures in native Siberian groups.

In this context, the recent findings on cardiovascular health of the Pima Indians of Central Arizona provide an intriguing counterpoint to our Siberian example. As summarized in Table 1.7, research on Pima has shown that they have low BMRs, very high rates of obesity, very high rates of adult-onset (type 2) diabetes, and moderate to high plasma lipid levels, and yet they have relatively low rates of hypertension (Ravussin 1995; Spraul et al. 1993; Weyer et al. 2000). This clustering of metabolic and cardiovascular risk factors is, in many respects, the mirror image of what we see among indigenous Siberians and appears to be linked, in part, to reduced SNS activity. Indeed, the low SNS activity of the Pima is thought to be an important con-

Table 1.7. Comparison of metabolic and cardiovascular health parameters for indigenous Siberians and Pima Indians.

Parameter	Siberians	Pima
Metabolic Rate	Elevated	Depressed
Obesity levels	Moderate	High
Blood pressure	Higher	Lower
Lipids	Low	Moderate
NIDDM	Low?	Very High
SNS activity	???	Low

Pima data derived from: Ravussin (1995); Spraul et al. (1993); Tataranni et al. (1998) Weyer et al. (2000).

tributor to their sluggish basal metabolism and their high rates of obesity (Ravussin 1995). Reduced SNS activity is also thought to contribute to the low prevalence of hypertension in the Pima (Tataranni et al. 1998; Weyer et al. 2000).

The differences between the Siberians and the Pima underscore the point that lifestyle modernization can produce markedly different health outcomes. These differences appear to stem partly from the unique historical changes in lifestyle of the two groups and partly from underlying differences in metabolism that may have been shaped by distinct selective forces in the evolutionary pasts of both populations. Further work is necessary to understand how the different dimensions of lifestyle change are contributing to variation in cardiovascular health. In addition, more research is needed to determine whether there is a genetic basis for these differences in metabolic rate and, if so, what the central pathways might be for regulating metabolism and cardiovascular risk factors. We are currently beginning to explore the nature of the metabolic adaptations in native Siberians by examining how BMR varies in association with major genetic markers in the mitochondrial genome that have been identified by Wallace and colleagues (Mishmar et al. 2003; Ruiz-Pesini et al. 2004; Wallace 2005). If the model by Wallace and colleagues is correct, we should find that individuals with the key mutations for greater heat production should have increased BMRs over those who lack the mutations.

Conclusions

The biology and health of indigenous Siberian populations have been strongly shaped by both environmental and social stressors. Through their evolutionary history, native Siberians have adapted to their cold, marginal climate, in part, through increased metabolic heat production. They have BMRs that are 15 to 20 percent higher than expected for their size. Until recently, these elevated metabolic rates, coupled with high levels of physical activity, protected native Siberians against obesity and associated cardiovascular risk factors.

Recent social, economic, and political changes in Russia have had dramatic, yet variable influences on the health of indigenous Siberians. The collapse of the Soviet Union in the early 1990s had divergent effects on Siberian children and adults. While children's nutritional status sharply declined during this period, overweight and obesity became growing problems for adults. The increasing levels of obesity among Siberian adults appear to be linked to reductions in energy expenditure and activity levels associated with the transition from more "traditional" subsistence lifeways to a more sedentary "modern" lifestyle. In addition, the rates of overweight and obesity are significantly higher in Siberian women than men. This gender disparity is partly attributable to lower levels of activity and energy expenditure in women.

Although obesity and increased body fatness are growing problems, adult Siberians continue to have low plasma lipid levels. In contrast, the major cardiovascular risk for Siberian adults is elevated blood pressure, particularly among men. This "cluster-

ing" of cardiovascular risks is markedly different from that seen in other modernizing groups, such as the Pima Indians. This patterning of risks appears to be linked to the joint influences of body composition, lifestyle change, and elevated metabolism. Conditions of marginalization and impoverishment have significant influences on lipid and blood pressure levels. Additionally, increased BMR is associated with reduced plasma lipid levels and increased blood pressure even after adjusting for the influence of body composition. Further work is needed to better elucidate the mechanisms through which the social and metabolic parameters are shaping cardiovascular health. Nonetheless, these results underscore the importance of linking biocultural and evolutionary perspectives in understanding the health consequences of lifestyle change.

Appendix 1
Summary Points

1. The initial post-Soviet transition had divergent effects on Siberian children and adults. While children's nutritional status sharply declined during this period, overweight and obesity persisted as growing problems among adults.
2. Among adults, increasing levels of obesity appear to be linked to reductions in energy expenditure and activity levels associated with the transition from more "traditional" subsistence lifeways to a more sedentary "modern" lifestyle. The higher rates of overweight and obesity in women are attributable to their lower levels of activity and energy expenditure.
3. Basal metabolic rates of native Siberians remain elevated in comparison to reference values. This increased metabolic turnover appears to reflect an adaptation to their cold, marginal environment.
4. Despite increased levels of adiposity, plasma lipid levels of native Siberians remain low, whereas blood pressure is quite elevated. Variation in lipid levels and blood pressure reflects the interaction of body composition, lifestyle change, and metabolism. Conditions of marginalization and impoverishment in post-Soviet Russia contribute to elevations in both lipid levels and blood pressure. Additionally, after controlling for the effects of body composition and selected lifestyle factors, we find that BMR is positively associated with blood pressure and negatively associated with lipid levels.
5. The clustering of metabolic and cardiovascular risk factors in native Siberians is, in many respects, the mirror image of what we see in modernizing groups such as the Pima Indians. The differences between the Pima and indigenous Siberians appear to be the product of the unique historical changes in lifestyle and socioeconomic status of the two groups and underlying differences in metabolism shaped by adaptation to different environmental stressors.
6. By linking biocultural and adaptive perspectives, we are able to gain fresh insights into the origin and nature of variation in human health. The integrative perspec-

tive of biological anthropology is particularly powerful for addressing many of today's growing global health problems.

Appendix 2
Unresolved Issues/Future Research Directions

1. Additional research is needed to explore the mechanisms through which lifestyle change and marginalization in post-Soviet Russia may be influencing cardiovascular health outcomes. Future work should explicitly examine the role of psychosocial stress in promoting hypertension among indigenous Siberians.
2. Although it is clear that native Siberians display systematically elevated BMRs, the nature of those elevations has not yet been determined. Further work is necessary to identify the genetic and/or developmental factors responsible promoting metabolic adaptation in these groups. It is likely that different populations exploit different genetic and physiological pathways to increase metabolic rates.
3. The influence of metabolic rates on cardiovascular risk factors needs to be explored in a broader range of human populations. Additional research is also needed to elucidate the mechanisms responsible for linking variation in metabolic turnover with variation in blood pressure and lipid levels.
4. Follow-up research is needed to determine the trajectory of health changes in native Siberians in the face ongoing political and economic changes in Russia. It is currently unclear whether the increased levels of childhood undernutrition and growth stunting of the mid 1990s continue to persist. In addition, the long-term health consequences of the initial post-Soviet transition need to be examined in the cohort of children studied during the early-mid 1990s.

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