Human biology of indigenous populations in Oaxaca: 1898 to the present

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Resumen

Características de la genética de poblaciones de los grupos indígenas y los estudios históricos de la biología humana y el estado nutricional se consideraron brevemente, seguido de una evaluación detallada de un cambio secular en una sola comunidad zapoteca rural y en una amplia muestra de niños de las escuelas indígenas de cuatro regiones del estado. Las observaciones de la comunidad zapoteca indicaron aumentos seculares en la altura de adultos que no fueron lineales en el tiempo, las ganancias seculares correspondientes a las edades de 6-17 años fueron considerablemente mayores. Se encontraron ganancias seculares en las estaturas de los niños indígenas de cuatro regiones de Oaxaca entre los años 1970 y 2007; sin embargo, fueron inferiores a las estimaciones para los niños zapotecas rurales. Aunque las condiciones en las comunidades indígenas han mejorado, el estado de crecimiento de los niños de la escuela era marginal en comparación con los datos de referencia para los rangos de relativos a pobreza en el estado de Oaxaca, para los índices específicos de la situación nutricional, la marginación y el desarrollo humano de México. Las comunidades indígenas están aparentemente experimentando una transición nutricional, siendo hasta el momento mayor el aumento en sobrepeso que en obesidad.

Palabras clave: biología humana, Oaxaca, crecimiento, transición nutricional, enfermedades.

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Abstract

The "Oaxaca Project" analyzed growth of children and heights of adults across three major transitions (demographic, epidemiologic, nutritional) in a rural Zapotec community. It also documented the natural history of growth across intervals spanning high chronic undernutrition to the emergence of childhood overweight/obesity. The prevalence of childhood overweight and obesity has increased in the community, a signal of the nutritional transition. Diabetes is also increasing as is the frequency of other non-communicable, degenerative diseases.

KEYWORDS: human biology, Oaxaca, growth, nutritional transition, diseases.

Human biology in Oaxaca

The tradition of archeology and ethnography in Oaxaca is rich. Physical anthropology of living populations or human biology has been less extensively studied. After a brief overview of the archeological background and genetic studies of indigenous populations in Oaxaca, historical studies of human biology, early surveys of nutritional status and growth, and more recent studies of secular change in the growth of children, adolescents and of body size in adults with a focus on our field studies are reviewed.

Archeological background

The original inhabitants of the Valley of Oaxaca were nomadic hunters and gatherers present in the Valley by 8500 BC. They were sparse in number, and lived in small groups of 25 to 30 people when food sources were sufficiently abundant; during seasons when food stuffs were scarcer, they dispersed into small family bands of four to six people (Flannery and Marcus 2003). Although maize was domesticated in the Valley by 3470 BC, Zapotecs continued a nomadic lifestyle residing in temporary encampments until at least 2500 BC. The first signs of sedentary village life appeared with certainty by 2100 BC and possibly somewhat earlier (Marcus and Flannery 1996). By 2000 BC, there were at least 19 Zapotec settlements in the Valley (Kowaleski *et al.* 1989) with evidence of social segmentation (hierarchy) by 1540 BC (Marcus and Flannery 1996). About 75 to 85 settled villages were present in the Valley of Oaxaca in 1150 BC. At the founding of Monte Alban (500 BC), Zapotec hieroglyphic writing was established, and the number of settled villages in the Valley reached 261.

Of relevance to our research in Oaxaca, a prehistorically settled village was located < 5 km from the primary site of our field studies (a rural Zapotec community studied in 1968, 1970s and 2000). It was estimated to have had a population of several hundred people as early as 1500 BC. Signs of regional conflict, as evident in palisade fortifications and burned structures, were present by 1310 BC at an archeological site < 10 km from the community (Flannery and Marcus 2003). The study community may have emerged during the Classic period as archeological ruins apparently from that era are associated with the village. The community was also mentioned by name as an already established village in a census commissioned by Marquesado de Cortés in 1536 (Iturribarria 2005) and had an estimated population of about 400 in June 1546.

Indigenous populations of Oaxaca

Oaxaca is home to the largest indigenous population in Mexico, including at least 15 linguistically defined groups (Barabás and Bartolomé 1999). Zapotec (400 000 speakers) and Mixtec (> 200 000 speakers) are the two largest and have roots in the region that extend several thousand years (Marcus and Flannery, 1996). Mixe are the next largest (70 000 speakers).

Early genetic studies of indigenous populations in Mexico included several groups from Oaxaca (Matson 1970; Lisker 1971). Zapotec, Mixtec, Mixe, Mazatec and Chinantec samples were included in comparisons of hematological traits and genetic diversity among indigenous populations (Cordova *et al.* 1966; Lisker *et al.* 1971; Roychoudhury 1975). More recently, data for 15 short tandem repeat loci among 11 indigenous groups indicated they were quite similar genetically, although the groups were linguistically distinct and to some extent culturally isolated (Quinto-Cortés *et al.* 2010). Studies of variation in mitochondrial DNA and autosomal satellite markers indicated Zapotec, Mixtec and Mixe as more closely related (as a cluster) compared to other populations in Mexico and Central America (other indigenous groups from Oaxaca were not included, Torroni *et al.* 1994; Wang *et al.* 2007; Hunley and Healy 2011). Admixture estimates based on HLA haplotyping were 10 % for Zapotecs and Mixtecs but < 1 % for Mixe (Hollenbach *et al.* 2001); estimates for autosomal satellite markers were about 15 %, 9 % and 6 %, respectively (Hunley and Healy 2011). Study of the susceptibility of indigenous Oaxaca populations to diabetes and other metabolic complications will likely add to the understanding of health-related genetic polymorphisms (Flores-Martínez *et al.* 2004; Escobedo *et al.* 2010).

Earlier studies: adults

Frederick Starr of the University of Chicago undertook an anthropometric survey of indigenous populations of southern Mexico in 1898-1899, including 11 groups in the state of Oaxaca. The battery included 14 dimensions measured on approximately 100 males and 25 females in each of the groups; 8 indices were derived for (Starr 1902a). He also compiled an extensive photographic atlas (1899) and detailed ethnographic notes (Starr 1900, 1902b).

A generation or more passed before further surveys of indigenous groups in Oaxaca were undertaken (Comas 1943, 1974; Faulhaber 1970). The studies focused on the anthropometry of adults from several indigenous groups, although other variables were considered: 1) 1933, Mixtec and Zapotec males (Leche 1936), also dermatoglyphics and measures of laterality; 2) 1940-41, Trique males (Comas and Faulhaber 1944, 1965), also grip strength; 3) 1941, Chinantec males and females (D'Aloja 1941 in Comas 1943); 4) 1941, Zapotec males (Gómez Robleda *et al.* 1949), also functional and behavioral variables; 5) 1943, Mixtec males (Romero 1952), also grip strength; 6) 1950s, Zapotec males (Martínez Ríos and Luna Méndez 1960), also grip strength and psychological variables; and 7) 1954, Zapotec males (D'Aloja 1988), also physiological variables and grip strength. Adult heights from the earlier surveys are summarized later in the report with more recent studies of indigenous populations of Oaxaca.

Early studies were largely descriptive and comparative, and set in the context of typology which was a general theme of physical anthropology worldwide, long before the era of the "new physical anthropology." Focus was on males, consistent with a notion that characteristics were more stable on females: "Characters of race are better marked in men than in women; … women… are more alike than men" (Starr 1902a: 53), and "el tipo femenino es más estable y menos variable que el masculino" (Gómez Robleda *et al.* 1949: 268).

A collaborative project, the Italian-Mexican Mission, surveyed several indigenous Mexican populations in the early 1930s, including medical, anthropological, blood groups, anthropometric and dermatoglyphic variables, among others (Genna 1935; Gini 1934-1935). The mission included anthropometry of 230 Zapotec, 145 Mixe and 220 Chinantec adult males, but the data have apparently not been published; dermatoglyphic observations for the Oaxaca samples, however, were described (Alciati 1963). Anthropometric data for several other indigenous groups have also been published (Genna 1943, 1944; Jaen *et al.* 1976).

Earlier studies: children

Growth status of children was not a focus in earlier studies among indigenous groups in Oaxaca. The view of growth status of children as a reflection of health, nutritional and societal conditions is a relatively recent perspective. One exception was a medical thesis completed at Universidad Nacional Autónoma de México (Campos 1940). Mean heights and weights (no variance statistics) of combined samples of boys and girls age 2 to 16 from a Chinantec community in Papaloapam were reported. Age-specific mean heights of the combined samples 6-15 years were consistently shorter than school youth in Mexico City in the mid 1920s, but mean weights were not markedly different (Priani 1929). Mean height and weight of 12 year old Chinantec boys and girls were 110 cm and 33 kg, respectively; height was shorter but weight was not very different from rural 12 year old youth living within the Federal District at about 1920: boys 125 cm and 26 kg, girls 118 cm and 31 kg (Cabrera 1921).

The growth status of urban (public and private schools in Oaxaca de Juarez) and rural (Zapotec and Mixtec near Mitla; Tzotzil, Tzeltal and Chol in Chiapas) children 6-15 years old was also compared (Pryor and Thelander 1972). Data for the rural children were combined. Height (not weight), sitting height, biliac and chest breadths, and six craniofacial dimensions were measured. The report included only graphs with no tabular information. Heights of rural and urban boys did not differ consistently, on average, across the age range. Heights of urban and rural girls did not differ between 6 and 10 years old; subsequently, urban girls were taller.

Nutritional surveys provide information on conditions in indigenous communities which obviously have implications for the health and growth of children. Nutritional deficiencies and overall marginal conditions in the south region of Mexico, including the state of Oaxaca, were highlighted in national surveys in 1958 and 1968 (Pérez Hidalgo *et al.* 1970, 1973). A study of patterns of food consumption in 55 families in the Mixteca Alta over one year indicated a very limited diet and suggested chronic energy (calorie) deficiency. Only 12 foods and seasonings were consumed more than once per week, although 96 other foods were used though not on a regular basis (Martínez *et al.* 1976). Surveys of six indigenous communities highlighted protein, energy, vitamin and mineral deficiencies in preschool children, especially in the Central Valley and Mixteca (Muños de Chávez *et al.* 1976). The growth status (length/height and weight) of preschool children, specifically stunting (height *Z*-score of -2.00 and less), is an indicator of nutritional conditions and is often included in surveys. Among rural preschool children in three regions of Oaxaca (Mixteca, Canada, Pacífico Sur), the prevalence of stunting was about 60 % and did not change appreciably between 1974 and 1989 (Saucedo Arteaga *et al.* 2001).

The "Oaxaca project"

Our studies in Oaxaca began with a survey of the growth status of school children in a rural Zapotec community in the Central Valley in 1968 (Malina *et al.* 1972), with follow-up surveys in 1978 and 2000-2002. The latter also included adolescents and adults. An extensive anthropometric battery (height, weight, sitting height, skeletal breadths, limb circumferences, skinfolds, craniofacial dimensions, grip strength) was taken on primary school youth. The 1978 survey included three tests of motor fitness (standing long jump, dash, ball throw for distance), while the 2002 survey included tests of health-related (distance run, sit-ups, sit and reach) and motor (standing long jump, dash) fitness in the primary school children. A survey in 1979 focused exclusively on school children for the purpose of estimating growth velocities. A limited anthropometric battery, including grip strength, was collected in adolescents and adults in 1978 and 2000. Household information was also collected (see Appendix for specific studies). The ongoing study, which has been referred to as the "Oaxaca project", spans more than three decades,[1] has been cited among major research contributions to the human biology and genetics of Latin American populations (Salzano and Bortolini 2002).

The project expanded to other communities in the Central Valley and adjacent regions in the 1970s. Growth status of primary school children was assessed in nine communities in the Central Valley in 1971 and 1972 (plus the 1978 follow-up), and nine communities outside the Valley in 1977. Seven Central Valley communities were rural: five Zapotec-speaking, one historically Mixtec-speaking and one mixed Mestizo-Zapotec, and two were colonias located at the time on the fringes of Oaxaca de Juarez. Many colonia residents spoke Zapotec or Mixtec. The non-valley surveys were conducted at the request of and with the cooperation of the Instituto Nacional para el Desarrollo de la Comunidad y de la Vivienda Popular (INDECO), and included nine rural communities: a Zapotec-speaking municipio just beyond the limits of Oaxaca de Juarez, five Zapotec-speaking and two Mixe-speaking municipios in the Sierra South and Sierra Northeast, respectively, and a Zapotec-speaking municipio in the Isthmus of Tehuantepec. A basic set of dimensions was taken in all communities: weight, height, sitting height, relaxed mid-arm circumference and triceps skinfold. The sitting height ratio, body mass index (BMI, kg/m^2) and mid-arm muscle circumference were calculated. Ages were extracted from school records. Permission for all surveys was granted by community and school officials. Children were free to choose to or not to participate. Individual identities were blinded in all analyses.

The total sample of school children 6-14 years in the 1970s included 1 419 boys and 1 478 girls from 18 communities: Valley of Oaxaca (8 rural and 2 colonias, $n = 1\,941$), Sierra Northeast (2 rural, $n = 326$), Sierra South (5 rural, $n = 483$), and Isthmus of Tehuantepec (one rural, $n = 147$). Characterizing communities as indigenous was based on field observations, ethnography and historical information (Instituto Nacional para el Federalismo y el Desarrollo Municipal, 2005). The sample included

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children of Zapotec (1 724, 59 %), Mixtec (327, 11 %), Mixe (326, 11 %), and mixed (520, 18 %, one rural community, two colonias) ancestry. It was reasonable to describe colonia children as indigenous as most residents migrated from rural areas of the state. Moreover, children born in the colonias and those born elsewhere in Oaxaca did not differ in height and weight. General health and nutritional conditions, general subsistence, and tabular summaries of anthropometric data for each community are reported (Malina and Peña Reyes, in press). A follow-up study of school children in one of the colonias surveyed in 1972 was conducted in 2000 and included the same anthropometric and fitness variables as in the rural Zapotec community in 2000 (above). The 1970s data for school children were complemented by ages, heights and weights for a statewide sample of indigenous children attending *albergues escolares* in Oaxaca in 2007 (Peña Reyes *et al.* 2010).

Secular trends: adult height

Studies of secular trends are valuable for linking the past and present. Attained height reflects to a large health, nutritional and overall living conditions in a community or population (Tanner 1992; Bielicki 1999). The generalization does not apply to individuals as factors which affect the height of individuals are multiple and complex (Tanner 1992), and probably involve environmental and genetic factors and their interactions (Malina 1979).

Heights of adults from indigenous populations in Oaxaca between the 1890s and 2005 are shown in figures 1 and 2. The early data were complemented with surveys of several Zapotec communities in the 1970s and one community in 2000 (Malina *et al.* 1983, 2010a, 2010b) and a survey of Trique adults in 2002 (Ramos Rodríguez and Sandoval Mendoza 2007). Heights of Mixtec males and females (Schulz and Weidensee 1995) and males from historically Zapotec communities (Ramírez-Vargas *et al.* 2007) from surveys of metabolic risk are also included.

Variation among mean heights of adults from the 11 indigenous groups surveyed by Starr (1902a) in 1898-1899 should be noted. Mean heights of the small samples of females (about 25 per group) were more variable than those of males (100 per group in all except two). Although

Figure 1. Heights (means, standard deviations if available) of indigenous adult males in Oaxaca by year of survey between 1898 and 2005.

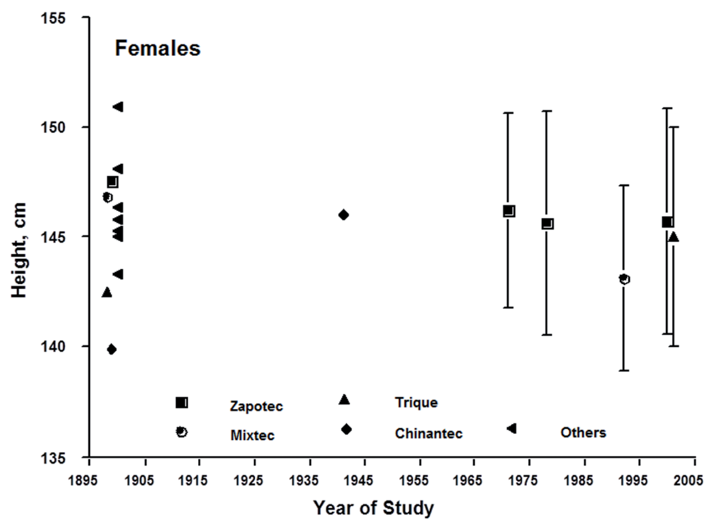

Figure 2. Heights (means, standard deviations if available) of indigenous adult females in Oaxaca by year of survey between 1898 and 2005.

sampling may be a factor, the observations contrasted the common notion that characteristics of females were more stable and less variable than those of males (Starr 1902a; Gómez Robleda *et al.* 1949). Other than Starr's early survey, subsequent data were more available for males than females and for Zapotecs than other indigenous groups. Nevertheless, mean heights showed relatively little variation across time (figures 1 and 2), consistent with Faulhaber's (1970) observation of negligible secular change among indigenous adults in Oaxaca.

Limitations of adult height data should be noted. Variance statistics were not consistently reported and age-associated variation in height was not considered. Among rural Zapotec adults surveyed in the 1970s and 2000, mean heights were reasonably stable into the 40s, but then declined with increasing age (Malina *et al.* 2010a). Loss of height with age is thus a confounder in studies of secular change. Longitudinal studies of aging in populations of European ancestry, 13 of men and 11 of women, indicated relatively little variation among samples (Sorkin *et al.* 1999). Height increased in both sexes to about 30 years, was stable to about 35 years, and subsequently declined with increasing age. Estimated decline with age was similar in both sexes until about 55 years when women began to lose height more rapidly than men. Nevertheless, the decline in height with age may vary among populations (Malina *et al.* 1983, 2010a).

Lack of consideration of age is a major limitation in making inferences about secular change on the basis of adult heights *per se*. More recent samples were more likely older than historical samples given improved living conditions and life expectancy. Heights of Trique males and females surveyed by Starr (1902a, ages not reported) were compared, for example, with Trique males 20-45 years in 1940-41 (Comas and Faulhaber 1944, 1965) and males and females 15-79 years in 2000-2002 (Ramos Rodríguez and Sandoval Mendoza 2007). Lack of ages for the early sample, the limited age range of males surveyed in 1940-41, and the broad age range of the more recent sample, limit the utility of secular comparisons of mean heights.

Secular trends in a rural Zapotec community

To evaluate age and secular factors on heights of adults measured in 1971, 1978 and 2000 (332 males, 405 females), linear regression of height and estimated maximum height (measured height adjusted for estimated stature loss with age) on year of birth (1896 to 1981) was used. Sex-specific equations of Sorkin *et al.* (1999) were used to estimate maximum height. The regression coefficient for measured heights provides an estimate of average change in height per year due to age and secular factors combined, while the coefficient for estimated maximum heights provides an estimate of change in height per year due to secular factors along.

It is often assumed that secular trends in height are linear, but they may in fact be non-linear over long periods. To address potential non-linear changes, segmented linear regression was used. The protocol partitions the regression problem into groups, usually in a consecutive series based on the independent variable (year of birth). Sex-specific regressions were done to evaluate secular change in heights of rural adults born in three periods of Mexican history (Malina *et al.* 2010a): 1) before 1930 a small number during the dictatorship of Porfirio Díaz, 1876-1910 and the majority during and immediately after the Mexican Revolution, 1910-1920; 2) in 1930 through 1959 changes associated with the Revolution were put into effect, i.e., land reform and associated economic growth; and 3) between1960 and 1981 during the economic boom which collapsed in the 1980s.

Secular increases in predicted maximum adult heights were noted, but estimated rates varied over time. In the relatively small samples born before 1930, males showed a secular increase but females did not. Among those born 1930-1959, gains occurred and estimated rates were similar in males and females. Secular gains continued among those born in 1960 and later and rates were also similar in both sexes (Malina 2010a). The segmented regression analyses thus showed trends different from comparisons of sample means (figures 1 and 2).

Broad historical periods, although of interest, may not be directly relevant to individual communities; locally specific factors may be more relevant. Secular change was thus considered in the context of demographic and epidemiologic transitions in the rural Zapotec community. The demographic transition is defined by a shift from relatively little population growth and small differences between births and deaths, to rapid population growth and divergence of births (continued increase) and deaths (decrease). The two phases are labeled "pre-modern" and "modernizing", respectively (Keyfitz and Flieger 1971). The demographic transition occurred in the community during the 1950s (Little *et al.* 2008). The epidemiologic transition is defined by a shift from high infectious disease mortality in the young (birth to 5 years) to increased mortality from degenerative disease in the aged (Gage 2005; Omran 1971). It occurred in the community in the mid-1980s, about one generation after the demographic transition (Malina *et al.* 2008). Birth years of adults spanned the demographic transition (1896 to 1981), while those for youth 6-17 years spanned the years immediately after the demographic (1978 survey, birth years 1961-1972) and epidemiologic (2000 survey, birth years 1985-1994) transitions.

Adult heights (adjusted for age-associated stature loss) were reanalyzed using two birth year cohorts: before 1955 (1896-1954) and 1955 and later (1955-1981). Data for adults were complemented with heights of indigenous youth 6-17 years studied in 1978 and 2000 (Malina *et al.* 2004a), which were also re-analyzed (the earlier report focused on height, sitting height and leg length; some individuals had only a height measurement and were excluded).

The results indicated several phases of secular change. An early weak signal for an incipient secular increase in heights of adult men and women born before 1955 (males 0.34 cm/decade, females 0.39 cm/decade) was followed by a "take-off" phase among those born between 1955 and 1981 in whom slightly greater secular gains were apparent (males 0.59 cm/decade, females 0.56 cm/decade). Secular change accelerated in adolescents 13-17 years and gains were greater in boys (3.17 cm/decade) than girls (1.52 cm/decade). Among primary school children 10-13 years, secular gains were similar in boys and girls (3.15 and 3.02 cm/decade) and slightly less in children 6-9 years (boys 2.65 and girls 2.99 cm/decade). The estimates for youth were likely related to the secular decline in age at menarche and sex differences in the timing of the growth spurt.

Recalled ages at menarche of adult women in the two birth year cohorts were also re-analyzed; probit estimates for girls in 1978 and 2000 have been reported (Malina *et al.* 2004b). Age at menarche in women born before 1955 was 15.1 ± 1.2 years and the regression on year of birth indicated no secular change, 0.00 years/decade. Among women born 1955-1981, recalled age at menarche was 14.2 ± 1.3 years; the regression indicated a secular decline of 0.51 years/decade. A further decline occurred between surveys of girls 9-17 years in 1978 (14.8 ± 1.2 years) and 2000 (13.0 ± 1.0 years), about 0.78 years/decade. Consistent with the preceding, estimated ages at peak height velocity declined by 0.61 and 0.15 years/decade in boys and girls, respectively, between 1978 and 2000 (Malina *et al.*, 2004a). Estimates were based on the Preece-Baines Model I fit to cross-sectional mean heights, but the model has limitations with cross-sectional data for girls (Zemel and Johnston 1994).

It is difficult to identify specific factors associated with the demographic transition that may have influenced the growth and in turn adult heights of those born before and after the transition. The most obvious may be beneficial changes associated with the fruits of land reform and economic growth, resulting in improved nutritional conditions (although they were still quite marginal in the state of Oaxaca). The improvement in growth status of children and adolescents in 1978 and 2000 was likely due to improved health and by inference nutritional conditions, i.e., reduced infant and preschool mortality associated with the epidemiologic transition (Malina *et al.* 2004a, 2008). Mortality among children 1-4 years is an accepted indicator of chronic nutritional stress in a community (Wills and Waterlow 1958) so that reduction of mortality in this age group probably reflected improved nutritional conditions. The results, though interesting, utilized a different approach to analyzing secular change which needs replication in other indigenous communities.

The preceding observations were limited to a single rural Zapotec community. Comparisons of heights of indigenous school children 6-14 years from four regions of Oaxaca (Central Valley, Sierra Northeast, Sierra South, Isthmus) measured in the 1970s and in 2007 provide further insights (Malina *et al.* 2011a); corresponding date indigenous adults are not available. Samples were from the same four regions of Oaxaca in the 1970s (18 communities, 1 419 boys, 1 478 girls) and in 2007 (58 communities, 2 628 boys, 1 937 girls). Secular gains over 3.2 decades (assuming 1975 as the mid-point for the 1970s) were similar in boys and girls 6-9 years, 1.10 and 1.05 cm/decade, and slightly greater in boys and girls 10-14 years, 1.35 and 1.15 cm/decade. The secular gains in indigenous children from four regions of Oaxaca between the 1970s and 2007 were less than estimates for rural Zapotec children between 1978 and 2000 and colonia children between 1972 and 2000 (Malina *et al.* 2004a, 2008b, 2011a). The secular increase between the 1970s and 2007 was reflected in a reduction in stunting, but its prevalence in rural indigenous Oaxaca school children in 2007 was still quite high at 6-9 years: 36 % in boys and 41 % in girls, and 10-14 years: 40 % in boys and 46 % in girls (Malina *et al.* 2011a), and higher than estimates for Oaxaca in the 2006 National Nutrition Survey: 5-11 years: 24 % in boys and 21 % in girls, and 12-17 years: 17 % in boys and 25 % in girls (Cuevas Nasu *et al.* 2007).

Improved growth status between the 1970s and 2007 presumably reflected better health and nutritional conditions in indigenous communities of Oaxaca. However, heights of indigenous school youth in 2007 approximated the 5th percentiles of United States reference data (Malina *et al.* 2011a). The marginal growth status was consistent with rankings of the state of Oaxaca compared to other states of Mexico on community-specific indices of nutritional status, marginalization and human development (Malina 2009; Malina *et al.* 2011a; Peña Reyes *et al.* 2010).

Secular trends in weight status

Communities worldwide are experiencing further transitions, and the transition in nutrition is especially relevant. Accordingly, modernization is followed by the epidemiologic transition and subsequently a behavioral transition characterized by changing patterns of nutrition and physical activity (Popkin 2002). This implies a transition from high chronic undernutrition and associated mortality from infectious and diarrheal diseases to a high prevalence of morbidity and mortality from non-communicable, degenerative diseases associated with dietary change and reduced habitual physical activity, and increased prevalence of overweight and obesity. The nutritional transition is occurring in Mexico as evident in increased mortality from myocardial infarct, hypertension and diabetes in parallel with an increased prevalence of obesity (Rivera *et al.* 2002). Given the history of poor/marginal nutritional conditions in Oaxaca historically and to some extent at present (Barquera *et al.* 2003) and increased opportunities for physical inactivity (Ávila Curiel *et al.* 2006), one can inquire if rural indigenous communities are experiencing the nutritional transition.

As noted, the rural Zapotec community has gone through the epidemiological transition. Preschool mortality (infectious and diarrheal diseases) has declined, and mortality from degenerative diseases in adults has increased. Among adults 45+ years, deaths attributed to cardiovascular disease increased: 1 % (*n* = 3) in the 1970s, 15 % (*n* = 23) in the 1980s, 29 % (n = 30) in the 1990s. Statistics from the community clinic in 2000 indicated diabetes (4 new cases, 12 under control, 13 under treatment) and hypertension (9, 13 and 15 cases, respectively) as significant health problems among individuals 65+ years (Reyes-Castellanos *et al.*, 2000).

Dietary surveys in the community indicated little variety, limited sources of animal protein and dependence upon corn (tortillas), beans and salsa in 1968 and 1978. Although corn (tortillas), beans and salsa persisted as the main staples in 2000, the diet showed greater variety and increased consumption of animal protein in the form of meat, cheese and eggs. On the other hand, tortilla consumption decline while consumption of bread increased (Peña Reyes *et al.* 2005; Malina *et al.* 2008a). Lifestyle changes suggested a decline in physical activity, especially among adults. This can be inferred from the decline in full-time farming. About 90 % heads of households were full-time farmers in 1978 compared to about 30 % in 2000. Many heads of households were now part-time farmers. Access to technology has facilitated agriculture, specifically tractors and irrigation projects. Other occupations of adult men included vendors, artisans, construction and industry, specifically in the city of Oaxaca (daily commuting). An additional factor was out-migration of young adult males which may have influenced the work force for agriculture; the burden of agriculture-related work may have shifted to youth and adult women. Nevertheless, productivity, household and community income (earned income and remittances from emigrants, see Malina *et al.* 2004a), and nutritional status have improved. Reduction in full-time agriculture probably contributed to a reduction in habitual physical activity in adults, especially moderate-to-vigorous activity. The estimated intensity of work activities in school youth 9-17 years of age (daily household chores) was about 5 METS per hour in boys and about 4 METS per hour in girls (Malina *et al.* 2008c). Estimated intensity of work activities of adult men declined slightly with age but varied between 3 and 4 METS per hour, while corresponding activities of adult women were relatively stable across adulthood at about 3 METS per hour (Malina in press).

Changes in morbidity and mortality and in lifestyle, specifically diet and physical activity, suggest the nutritional transition is under way. Secular change in weight status in the Zapotec community was thus addressed using BMI criteria of the World Health Organization (1998) for adults and International Obesity Task Force (Cole *et al.* 2000) for youth.

No primary school children 6-13 years were obese in 1968 ($n = 308$) and 1978 ($n = 369$); two boys were overweight in 1978 and one girl overweight in each survey. Obesity was also not a problem in 2000 ($n = 361$); two boys and two girls were classified obese. However, 9 boys (5 %) and 14 girls (8 %) were overweight. Among smaller numbers of youth 13-17 years, no boys and girls were obese in 1978 ($n = 104$) and 2000 ($n = 101$). In 2000, one boy was overweight, but 4 (7 %) and 9 (15 %) girls 13-17 years were overweight (Malina *et al.* 2007).

Corresponding data for Zapotec adults presented a different picture (Malina *et al.* 2007). Among 176 men in the 1970s (1971+1978), 7 % were overweight and 2% were obese, while among 147 women, 19 % were overweight and 4 % were obese. Overweight was equally prevalent in 155 men (46 %) and 255 women (47 %) in 2000, but obesity was less common in men (6 %) than in women (14 %). Among adult Mixtec in the 1990s, 15 % of men and 20 % of women were overweight, and 4 % and 2 %, respectively, were obese (calculated from data provided by Schulz and Weidensee 1995). No overweight or obesity was evident among 101 Trique men in 1940, but 35 % and 51 % of Trique men and women in 2000 were overweight or obese, respectively (Ramos Rodríguez and Sandoval 2007). Estimates for recent samples of Zapotec and Mixtec adults in Oaxaca were variable for overweight and lower for obesity compared to estimates for the state of Oaxaca in the 2006 National Nutrition Survey: men, 40 % overweight, 19 % obese; women, 35 % overweight, 27 % obese (Cueva Nasu *et al.* 2007).

Comparison of the weight status of indigenous Oaxaca school children between the 1970s and 2007 indicated an increase in overweight. In the 1970s, < 2 % of children of both sexes were overweight, but in 2007, 13 % of boys and girls 6-9 years and girls 10-14 years and 8 % in boys 10-14 years were overweight. Obesity was not a significant problem among indigenous children: < 1 % in both sexes 6-9 and 10-14 years in the 1970s and ≤ 1 % in youth 10-14 years in 2007, but 4 % in boys and girls 6-9 years in 2007 (Malina *et al.* in press). Estimates for Oaxaca in the 2006 National Nutrition Survey were as follows for children 5-11 years: overweight, 10 % boys, 19 % girls; obesity, 7 % boys, 4 % girls; and for youth 12-19 years: overweight, 17 % boys, 19 % girls; obesity, 5 % boys, 6 % girls (Shamah Levy *et al.* 2006).

The apparently high prevalence of overweight plus obesity in indigenous adults and in the national nutrition survey should be interpreted with caution. The BMI has limitations. It is legitimate to inquire whether the BMI has the same meaning in different populations, including indigenous populations in southern Mexico. Nevertheless, overweight and to a lesser extent obesity have apparently increased in indigenous adults.

Overweight more so than obesity has increased among indigenous youth in Oaxaca. The data for youth Oaxaca suggest that the imbalance between available dietary caloric energy (intake) and physical activity (expenditure) is apparently not yet sufficient to trigger a major increase in obesity. However, small percentages of younger children (indigenous 6-9 years, national survey 5-11 years) are obese, which suggests that the signal for obesity may be incipient in younger children, i.e., an increase in obesity may be on the way.

Genetic and social processes in the community

The preceding has focused on traditional approaches to growth and secular change which do not allow for genetic and social processes which may be relevant. The rural community had approximately 1 700 residents in 1978 and > 85 % of adults spoke Zapotec. The population was also almost closed genetically with estimated gene flow of 3.5 and 4.7 % in 1978 and 2000, respectively (Little and Malina 1989, 2006). The estimates were about one-third to one-half of average admixture among Zapotecs in Oaxaca (Hollenbach *et al.* 2001). The population was also relatively young (mean 23.1 years). Estimated potential for natural selection was moderately intense in 1978, comparable to other traditional subsistence agricultural groups. Selection for body size, however, was not detected (Little *et al.* 1989), and what may be selected for remains unknown. Mortality due to infectious disease primarily in early childhood was the primary component of selection (Little and Malina 1989, 2006). When the demographic transition began in the 1950s, differential fertility increasingly accounted for more of the variation in selection potential as the transition progressed. The epidemiologic transition occurred in the mid-1980s and was followed by major secular changes in height among children and adolescents. The population also experienced changes in genetic structure associated with relaxed selection and attendant changes, specifically more children surviving to reproductive age (population growth) and a shift in mortality due to degenerative, non-communicable diseases at older ages.

Direct environmental effects *per se* and genetic-environment interactions are pathways through which the influence of social processes on growth may be channeled. Although the community was largely homogenous biologically and culturally, and seemingly classless, variation among households in socioeconomic status was sufficient to significantly influence growth status (Malina *et al.* 1985), sibling similarities (Little *et al.* 1986, 1987), and annual increments in growth (Little *et al.* 1990), familial similarity (Little and Malina 2005a), and adult body size (Little and Malina 2010). The evidence thus indicated strong genetic-environmental interactions affecting the heights and weights of children and adults. Potential heterozygosity effects were addressed in a comparison of children with one parent who was from outside the community (immigrant) and children born of parents native to the community (sedentes). Children with an immigrant parent were taller and heavier than offspring of sedentes; similar trends were also apparent in craniofacial dimensions (Little *et al.* 1988, 1991).

Social processes within the Zapotec community and within families were strongly linked to household economic status and inheritance practices. In Mesoamerican subsistence agriculture peasant communities, mate choice is driven by a socially enforced economic strategy-patrilocal vs matrilocal postnuptial labor contracts (Selby 1966, 1974; Nutini 1967). Patrilocal marriages are the norm while matrilocal marriages are viewed as "socially deviant". Families thus tried to negotiate the best arrangement for the future economic status of their offspring. Adherence versus non-adherence to the norm reduced inbreeding in the community to a level below that expected to occur at random (Little and Malina 2005b).

The social influence of mate choice on growth status was analyzed by comparing *Z*-scores for heights of children and heights of adults by postnuptial (matrilocal, patrilocal, neolocal) and current (matrilocal, patrilocal, nuclear) residence (Little and Malina 2010). Household economic status was estimated from household resources related to production and demography. Mate choice, associated labor contract (economic strategy) and the inheritance cycle driven by social processes had a significant effect on child growth status, adult height and genetic variance (significantly decreased inbreeding) in the community. A matrilocal strategy was used by males from poorer households (shorter stature) for the purpose of socioeconomic mobility, which resulted in improved growth status of their offspring (taller). Of economic relevance, irrigated land was inherited differentially based on marriage decision and was also a significant factor affecting child growth status. Socially prescribed mating (marriage) and residence patterns thus positively and significantly influenced biological and genetic variation in the population. It was evident in the growth status of children and in lower inbreeding levels than would be expected at random given the small and closed nature of the indigenous population.

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APPENDIX: PAPERS FROM THE OAXACA PROJECT IN CHRONOLOGICAL ORDER

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