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Blood pressure and hypertension in an American colony (Puerto Rico) and on the USA mainland compared, 1886–1930

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Abstract

We compare blood pressure and hypertension between adult men on the USA mainland and in Puerto Rico born during 1886–1930 to test hypotheses about the link between cardiovascular health and large socioeconomic and political changes in society: (a) 8853 men surveyed in Puerto Rico in 1965 and (b) 1449 non-Hispanic White men surveyed on the mainland during 1971–1975. Systolic and diastolic blood pressure and hypertension were regressed separately on demographic and socioeconomic variables and cardiovascular risk factors. Mainland men not taking anti-hypertensive medication showed statistically significant improvements in systolic blood pressure and hypertension at the beginning of the century and men in Puerto Rico showed improvements in diastolic blood pressure but only during the last two quinquenniums. An average man born on the mainland during the last birth quinquennium (1926–1930) had 7.4–8.7 mmHg lower systolic blood pressure and was 61% less likely to have systolic hypertension than one born before 1901. On average Puerto Rican men born during 1921–1925 had ~1.7 mmHg lower diastolic blood pressure than men born before 1901. Analyses of secular trends in cardiovascular health complements analyses of secular trends in anthropometric indicators and together provide a fuller view of the changing health status of a population.

JEL classification : I12; I32; N33

Keywords: Blood pressure; Hypertension; Puerto Rico; Secular trends; USA; Stress; Male living standards; Anthropometric history

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1. Introduction

Structural changes in an economy have been associated with a temporary decline in the biological standard of living (Bogin and Keep, 1999; Komlos, 1998; Komlos and Baur, 2004; Komlos and Lauderdale, 2007; Steckel and Rose, 2002). The record of industrial nations during the 19th century suggests that the decline of agriculture and the growth of employment in industries and services induced migration from the countryside to the city. Urbanization, in turn, produced changes in health risk factors, such as diet, physical activity, social capital, and pathogen exposure. The link between structural transformations in an economy and the biological standard of living has been well documented through analyses of secular changes in physical stature (Fogel et al., 1982). Economic historians have shown that onset of industrialization during the 19th century in Europe and the USA was associated with a short-term decline in adult physical stature (Arora, 2005; Fogel, 2005; Haines, 2004; Komlos, 1994).

We build on a growing body of research on the biological standard of living to explore the association between large socioeconomic and political changes in society and secular changes in a biological indicator of the standard of living that has received scant attention from economists or historians but that has received much attention from social epidemiologists and human biologists: adult blood pressure.

Blood pressure reflects the force of blood against artery walls (O'Rourke, 1990). Systolic blood pressure (SBP) measures the maximum force created as the heart contracts and blood expands in the arteries; diastolic blood pressure (DBP) measures the minimum force maintained when the ventricles of the heart relax. Risk factors for high blood pressure restrict blood flow and increase the pressure placed on artery walls. Different risk factors affect blood pressure in different ways. For example, elevated salt intake increases blood volume, making it harder for blood to flow through arteries. Obesity increases salt retention and promotes constriction of blood vessels (Montani et al., 2002).

Blood pressure is a complex phenotype influenced by multiple genetic and environmental factors over the life course. Growing evidence suggests that blood pressure reflects conditions during a person's early years and therefore provides a convenient biological barometer of past socioeconomic conditions. Adverse socioeconomic conditions during childhood increase the risk of coronary heart disease in adulthood (Blane et al., 1996). Huxley et al. (2000) reviewed over 80 studies and concluded that birth weight bore a negative association with adult systolic blood pressure (see also Cruickshank et al., 2005). Impaired fetal development, maternal smoking during pregnancy, absence of breast-feeding, and high salt consumption as an infant all bore a positive association with blood pressure as an adult (Lawlor and Smith, 2005; Barker, 1995, 2001; Barker et al., 2002). Juonala et al. (2005) found that childhood obesity bore a positive association with stiffness of arteries as an adult. Confounders, such as adult obesity and psychosocial stress, mediate the association between events during early life and adult cardiovascular health (Goya et al., 1996; Regidor et al., 2006; Hardy et al., 2003; Huxley et al., 2002).

The earliest measures of blood pressure date back to the turn of the 20th century (Evans, 2003). However, economists and historians have not used blood pressure to assess the biological costs of large socioeconomic and political changes in society. For example, a search for "hypertension/blood pressure" and "industrialization/modernization" in EconLit and in the economics and history journals of JSTOR, two main literature databases for economic historians and behavioral scientists, turned up just one article about industrialization's impact on blood

pressure (Possas and Bobadilla, 1992). The article mentioned modernization's adverse effect on blood pressure in Brazil, Colombia, and Mexico, but did not discuss or measure it. Analyses of secular trends in cardiovascular health complements analyses of secular trends in anthropometric indicators and together provide a more comprehensive view of the changing health status of a population.

To explore the association between large socioeconomic and political changes in society and secular trends in adult blood pressure we turn to the modern history of the Caribbean island of Puerto Rico. A colony of Spain from the late 15th century until the late 19th century, Puerto Rico became a territory of the USA after the Spanish-American War of 1898. The USA introduced many changes in Puerto Rico during the first three decades of the 20th century, including reforms of public health, schooling, taxes, trade, and land tenure, and promoted the development of commercial agriculture (Dietz, 1987; Perloff, 1950; Godoy et al., 2003, 2007). In 1917 Congress granted the people of Puerto Rico USA citizenship. Together, the takeover and the subsequent socioeconomic and political changes amounted to a significant structural transformation of Puerto Rican society and economy. In contrast, the mainland had transitioned out of agriculture into an industrial economy during the 19th century, so during the early 20th century the mainland economy was well on its way to industrialization.

For several reasons Puerto Rico provides a good case study to assess whether large socioeconomic and political changes bear an association with secular trends in adult blood pressure. First, because events early in the lifecycle affect adult blood pressure, one should be able to detect and compare the strength of the association between adult blood pressure and date of birth between people born during the late 19th and early 20th centuries in Puerto Rico and their peers on the mainland. Since Puerto Rico belongs to the USA, people on the mainland provide an appropriate contrast. Second, since Puerto Rico has been and remains much poorer than the mainland (Lefort, 1997), the comparison allows one to highlight differences in cardiovascular health between a developing and a developed area.

The literature yields three hypotheses that guide our analysis.

1. *Economic history.* As noted, economic historians have found evidence that physical stature in the USA and Europe declined during the onset of industrialization in the first half of the 19th century. If we assume that biological indicators of living standards are affected by large socioeconomic and political changes, then we would hypothesize that blood pressure and hypertension in Puerto Rico during the late 19th and early 20th centuries might increase because of the socioeconomic and political changes in Puerto Rico. Several strands of evidence support the hypothesis. Lipowicz (2007) describes a possible temporary increase in hypertension in Poland during the 1980s that followed the collapse of communism and the emergence of the market economy. Studies of contemporary populations in developing nations also find a positive association between blood pressure and economic modernization (Dressler, 1999; Grossman and Rosenthal, 1993; James, 1987; McGarvey, 1999; Sobngwi et al., 2004; Ulijaszek et al., 2005; Hajjar et al., 2006).
2. *Social epidemiology.* Research in social epidemiology of industrialized nations suggests that secular improvements in health have been generalized, though more marked among some groups than among others (McCarron et al., 2001; Sjøl et al., 1998). McCarron et al. (2002) documented a secular decline in blood pressure during 1948–1998 among people between 5 and 34 years of age in six high-income nations. McCarron et al. (2001) and Sjøl et al. (1998) used multiple cohorts and found a secular decline in systolic and diastolic blood pressure

among both women and men in Scotland (1948–1968) and Denmark (1964–1991).[1] Burt et al. (1995) drew on repeated cross-sectional surveys done during 1960–1991 on the USA mainland and found a decline in systolic blood pressure. The decline was most marked for Black women, followed by Black men, White women, and White men in that order. If secular improvements of health have been general in the USA, though more marked and more readily visible among people of lower socioeconomic status, then we would hypothesize that people in Puerto Rico would have experienced a higher rate of secular improvement in blood pressure than their peers on the mainland.

3. *Political economy.* Structural transformations create socioeconomic forces working in opposite directions that may produce ambiguous net effects on secular trends in blood pressure. For instance, Guarnaccia et al. (1996) describe how the structural transformation of the economy, society, and political system in Puerto Rico undermined the lives of the working class and poor, and link the transformations to increasing signs of stress, such as nervous breakdowns, anxiety, and hysteria. Nonetheless, the 20th century also witnessed increased investments in public schools and public health in Puerto Rico (Clark et al., 1930; Rigau-Pérez, 2000), which would have improved awareness and prevention of disease. This line of thinking would predict that the secular trend in blood pressure would be ambiguous owing to forces working in opposite directions.

2. Data and methods

We compare secular trends in cardiovascular health between two groups of USA citizens: (a) men born during 1886–1930 in Puerto Rico and surveyed as part of the Puerto Rico Heart Health Program (PRHHP) in 1965 and (b) non-Hispanic White men (hereafter Whites) born in the rest of the USA (hereafter mainland) during the same period and surveyed during 1971–1975 as part of the first National Health and Nutrition Examination Survey (NHANES-I).[2]

2.1. Study subjects: PRHHP and NHANES-I

Most of the large, representative databases on general health for the USA do not contain data on people in Puerto Rico. NHANES surveys, the best source of general health data for the USA, include few Hispanics, do not follow people over time, and exclude people in Puerto Rico. NHANES-I (1971–1975) included only 156 Puerto Ricans on the mainland. The Hispanic Health and Nutrition and Examination Survey (HHANES, 1984) increased the sample of Hispanics. It included 2606 people living in New York City, Connecticut, and New Jersey who self-identified as Puerto Ricans, but excluded people in Puerto Rico. The only representative sample of general health data for adults in Puerto Rico we identified is the Puerto Rico Heart Health Program panel study done during 1965–1980 in Puerto Rico by the National Heart, Lung, and Blood Institute of the USA Public Health Services (García-Palmieri et al., 2002). Researchers have used PRHHP to

[1] In Scotland, men experienced stronger improvements in diastolic blood pressure than women, but women and men experienced the same rate of improvement in systolic blood pressure. In Denmark women experienced stronger improvements in both systolic and diastolic blood pressure than men.

[2] As of February 2007, access to NHANES was available to the public at the following web address: http://www.cdc.gov/nchs/nhanes.htm. For PRHHP data contact Sean Coady (coadys@mail.nih.gov) or Paul Sorlie (sorliep@mail.nih.gov) at NHLBI/DECA/EBP, 6701 Rockledge Center MSC 7934, Bethesda, MD 20892, USA, Tel.: +1 301 435 0456.

study the association between blood pressure and cardiovascular risk factors (Benson et al., 1966; Costas et al., 1981; García-Palmieri et al., 1969, 1970, 1982, 1984; Gordon et al., 1974, 1981; Sorlie et al., 1982; Sorlie and García-Palmieri, 1990), but not to study secular trends in cardiovascular health.

PRHHP included only men born during 1886–1930 who were 35–79 years old at the time of the baseline survey in 1965. PRHHP included three follow-up surveys of the same people, each survey done 3–4 years apart. We use data only from the first survey.[3] The sample for PRHHP came from four rural areas of northeast Puerto Rico largely populated by farmers and from three urban areas (Crespo et al., 2002). Because PRHHP excluded women, we limit the comparison to men.

For comparative purposes we used NHANES-I because it took place during 1971–1975, at about the same time as the PRHHP survey in Puerto Rico. NHANES-I included people 1–74 years old. Had we used later waves of NHANES we would have introduced a selectivity bias because men on the mainland with low blood pressure live longer than men with high blood pressure (Borhani et al., 1963; Kannel, 1975; Paffenbarger et al., 1966). Eighty percent of the NHANES-I sample is White and 19% is Black. We do the main analysis with Whites because minorities accounted for a small share of the sample, but in the sensitivity analysis we do add Blacks to ensure that the main results of the analysis hold up.

Researchers doing analysis of blood pressure have followed two approaches when deciding whether to include people taking medications against hypertension. Some researchers include people taking medication in the analysis and add a dummy variable for whether the person took medication (Gravlee and Dressler, 2005). Others exclude people taking medication against hypertension (Lipowicz, 2007; McGrath et al., 2006). In the first set of regressions (Table 4A) we follow the latter approach and exclude 873 people or 8.9% of the sample from Puerto Rico and 118 people or 7.5% of the sample from the mainland because they were taking medication against hypertension at the time of the surveys. Since excluding such people would exclude people with high blood pressure, our results could be biased. For this reason, in Table 4B we present regression results with the sample that includes people taking medication against hypertension.

The sample for the main analysis includes 8853 men in Puerto Rico (rural = 2712, urban = 6141) and 1449 White men on the mainland (rural = 591, urban = 858) with data on blood pressure who were not taking medications against hypertension.

2.2. Methods to create variables

2.2.1. Outcome variables: Blood pressure and hypertension

As outcome variables we use systolic and diastolic blood pressure and categorical variables for two forms of hypertension. We use both systolic and diastolic blood pressure because they had relativity low correlation coefficients (0.72 in Puerto Rico and 0.62 on the mainland) and because they capture different dimensions of health. Systolic blood pressure predicts strokes and coronary heart disease better than does diastolic blood pressure (Black, 2004), but diastolic blood pressure

[3] Since PRHHP is a panel study, the decision of which year to use is partly arbitrary. We opted to use the first survey to ensure we had the largest sample size; the sample size of later surveys would be smaller from attrition. Also, since we want to estimate the association between cardiovascular health and the socioeconomic changes in Puerto Rico during the early 20th century, the earliest survey is more appropriate.

Table 1
Mean and standard deviation (S.D.) of male systolic and diastolic blood pressure (mmHg) by birth cohorts (1886–1930) in Puerto Rico and the mainland

Birth quinquennium	(I) Puerto Rico			(II) Mainland—Whites			(III) Difference: mainland–Puerto Rico		
	N	Mean	S.D.	*N*	Mean	S.D.	*N*	Mean	S.E.
(A) Systolic blood pressure (SBP)									
1886–1890	12	150.3	22.8	–	–	–	–	–	–
1891–1895	54	142.8	25.0	–	–	–	–	–	–
1896–1900	512	141.9	26.3	62	155.0	27.2	574	13.1	3.5**
1901–1905	1530	135.7	23.6	182	142.6	20.5	1712	6.8	1.8**
1906–1910	1889	133.1	21.6	217	143.9	22.3	2106	10.8	1.5**
1911–1915	2438	129.4	20.3	197	139.0	21.9	2635	9.5	1.5**
1916–1920	2091	126.2	18.0	277	136.5	19.0	2368	10.2	1.1**
1921–1925	277	122.3	15.0	279	133.5	19.1	556	11.2	1.4**
1926–1930	50	124.6	17.9	235	131.2	17.0	285	6.5	2.6
Total	8853	131.1	21.4	1449	138.1	21.0	10302	6.9	0.6**
(B) Diastolic blood pressure (DBP)									
1886–1890	12	82.8	12.0	–	–	–	–	–	–
1891–1895	54	79.7	12.9	–	–	–	–	–	–
1896–1900	512	81.2	11.9	62	85.4	13.9	574	4.1	1.6
1901–1905	1530	81.0	11.6	182	83.7	10.7	1712	2.7	0.9**
1906–1910	1889	82.1	11.6	217	85.1	12.0	2106	2.9	0.8**
1911–1915	2438	81.7	11.2	197	86.8	11.7	2635	5.0	0.8**
1916–1920	2091	81.5	10.7	277	87.0	11.7	2368	5.4	0.6**
1921–1925	277	78.7	10.3	279	88.1	12.2	556	9.3	0.9**
1926–1930	50	79.3	10.8	235	87.0	12.2	285	7.7	1.8**
Total	8853	81.5	11.3	1449	86.4	12.0	10302	4.9	0.3**

Information for Puerto Rico comes from the 1965 survey of the Puerto Rico Heart Health Program (PRHHP) and information for the mainland comes from NHANES-I (1971–1975). S.D.: standard deviation. S.E.: standard error. (**) Significant at $\leq 1\%$ in two-tailed *t*-test comparing difference in means. (–) No information available. Blood pressure reading excludes people taking anti-hypertensive medications.

provides a better measure of overall, chronic physical stress or force on the arterial walls. We created dummy variables for systolic and diastolic hypertension based on clinical cut-off points of, respectively, 140 and 90 mmHg (NLBHI, 2006).

Table 1 contains the sample sizes, means, and standard deviations of systolic and diastolic blood pressure for each birth cohort of 5 years (quinquennium). For each type of blood pressure and for each birth cohort we include the mean difference in blood pressure between the mainland and Puerto Rico. Figs. 1 and 2 show histograms with the distribution of systolic (Fig. 1) and diastolic (Fig. 2) blood pressure for people in Puerto Rico and the mainland who were not taking medications against hypertension.

Table 2 summarizes the methods used in Puerto Rico and on the mainland to measure blood pressure. On the mainland, researchers took all measures in mobile examination centers. In Puerto Rico, measures took place in clinics, but in some rural areas researchers had to move ''staff and equipment into the field to perform the examination in town halls, churches, restaurants and even cockfight rings'' (García-Palmieri et al., 1969, p. 63). We did not find documentation on the training of staff who took blood pressure in Puerto Rico or on the mainland.

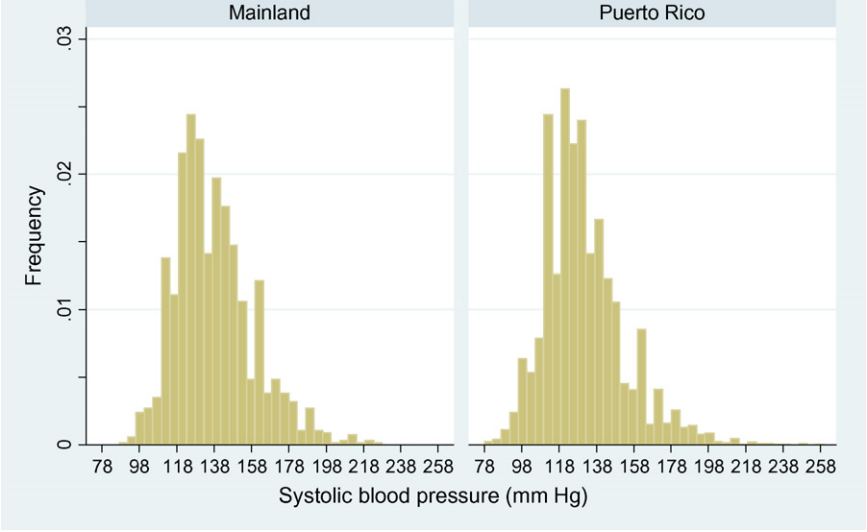

Fig. 1. Systolic blood pressure: men born 1886–1930 mainland USA and Puerto Rico.

Measures of blood pressure in Puerto Rico had greater rounding on the digit zero (Table 2) (De Lusignan et al., 2004; Shi et al., 1993). Since machines to measure blood pressure (sphygmomanometer) have ticks in the scale only around even digits, we tested whether there were rounding errors around preferred even digits. Forty-three percent of the measures of either systolic or diastolic blood pressure in Puerto Rico ended in the digit zero, whereas 35.7% of the measures of systolic blood pressure and 38.3% of the measures of diastolic blood pressure on the mainland ended in the digit zero. Chi square tests (χ^2) comparing the frequency of occurrence of the last even digit in measures of systolic or diastolic blood pressure between Puerto Rico and the mainland showed statistically significant differences (systolic: $\chi^2 = 49$, $p = 0.001$; diastolic: $\chi^2 = 26$, $p = 0.001$).

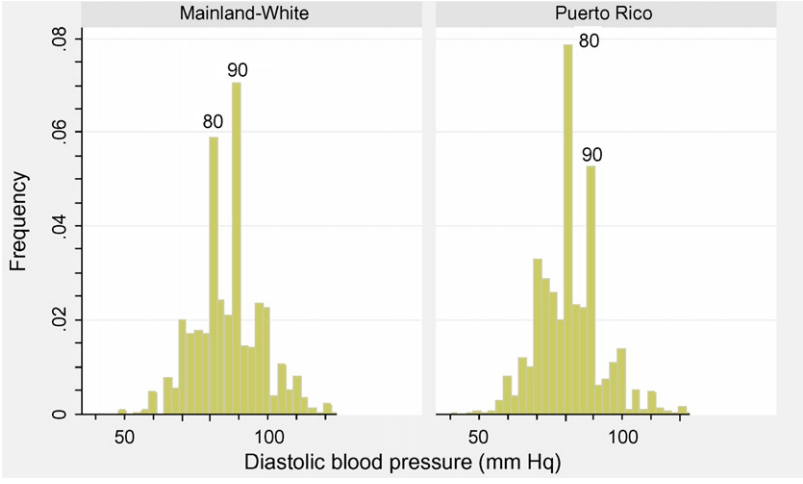

Fig. 2. Diastolic blood pressure: men born 1886–1930 mainland USA and Puerto Rico.

Table 2
Comparison of methods used to measure blood pressure in NHANES-I on the mainland and the first wave of the Puerto Rico Heart Health Program (PRHHP)

	Puerto Rico (PRHHP)	Mainland NHANES-I
Year of measurement	1965	1971–1975
Measurement site	Multiple	Mobile examination centers
Number of measures	2	1 (2/3 participants) or 3 (1/3 participants)
Observers	Physician	Physician
Posture	Sitting	Sitting, supine
Staff training	Unknown	Unknown
Share of measures ending in the digit zero		
Systolic	43.6	35.7
Diastolic	43.6	38.3
Cuffs available	Unknown	Child, adult
Equipment maintenance	Unknown	Weekly zero-level calibration
Published diastolic definition	Point of disappearance, K5	Point of complete cessation or muffling if heard to zero

Information for NHANES from Burt et al. (1995) and information for PRHHP from Benson et al. (1966), Costas et al. (1981), García-Palmieri et al. (1969), Gordon et al. (1974), and Sorlie et al. (1982). The shares of measures ending in the digit zero or five are our calculations. "Unknown" means we were unable to obtain the information.

2.2.2. *Explanatory variables: Socioeconomic and demographic (Table 3)*

2.2.2.1. Birth quinquennium. To protect the confidentiality of participants in the survey of Puerto Rico, the data made available to the public excludes the subject's birth date. As a result, we used the subject's age at the time of the survey and the year of the survey to create variables for birth quinquenniums. We did not find evidence that data collectors rounded measures of age around preferred last digits.[4]

2.2.2.2. Schooling. We created the following dummy variables for schooling: (a) no schooling, (b) primary school (grades 1–4), (c) middle school (grades 5–8), (d) attended but did not complete high school (grades 9–12), (e) graduated from high school, and (f) some university attendance.

2.2.2.3. Relative poverty and place of residence. We created a variable for relative poverty that took the value of one if the household income of the person fell in the bottom third of the income distribution of the sample, and zero otherwise. The variable was created by comparing household income with the income of the rest of the sample of either Puerto Rico or the mainland. We included a dummy variable for place of residence at the time of the survey (rural = 1, urban = 0). In the analysis of the mainland, we included dummy variables for three of the four geographical regions.

2.2.3. *Explanatory variables: Cardiovascular risk factors*

Cardiovascular risk factors include body mass index (BMI; body weight in kg/standing physical stature in m^2), albumin, serum cholesterol, physical activity, smoking, heart rate, and

[4] A χ^2-test comparing the frequency of occurrence of the last digit in measures of age between Puerto Rico and the mainland showed statistically insignificant results ($\chi^2 = 8.89$, $p = 0.44$). An editorial from the Puerto Rican Medical Association noted that there were no significant errors in the measure of age in PRHHP (Editorial, 2002).

Table 3
Definition and summary statistics of variables used in regressions

Variable		Place					
Name	Definition and units	(I) Puerto Rico			(II) Mainland—Whites		
		N	Mean	S.D.	*N*	Mean	S.D.
Outcome variable (blood pressure)							
Systolic	mmHg. Systolic = SBP; diastolic = DBP	8853	131.1	21.4	1449	138.1	21.0
Diastolic		8853	81.5	11.3	1449	86.4	12.0
Outcome variable (hypertension):							
Systolic-h	1 = ≥140 mmHg and 0 otherwise. Number is percent	8853	30.7	46.1	1449	43.7	49.6
Diastolic-h	≥90 mmHg and 0 otherwise. Number is percent	8853	23.8	42.6	1449	40.3	49.0
Explanatory variables (socioeconomic and demographic)							
Age	Age in years at interview	8853	54.2	6.5	1449	57.3	8.7
Schooling	% in each category:	8843			1438		
None	No schooling		10.3			0.6	
Primary	Grades 1–4		35.5			3.5	
Middle	Grades 5–8		28.4			28.3	
HS-A	Attended grades 9–12 but did not graduate from high school		8.2			18.3	
HS-G	Graduated from high school		9.1			27.0	
University	Attended or graduated from university		8.2			22.1	
Poverty	1 = bottom third of income distribution; 0 = top 2/3. Percent	8643	33.9		1449	30.2	
Rural	1 = rural place of residence; 0 = urban. Percent	8853	30.6		1449	40.7	
Regions					1449		
Midwest	% residing in region. 1 = if person resides in	NA				24.4	
South	region; 0 = person resides elsewhere					25.8	
West						28.2	
Northeast						21.3	

Table 3 (*Continued*)

Variable		Place					
Name	Definition and units	(I) Puerto Rico			(II) Mainland—Whites		
		N	Mean	S.D.	*N*	Mean	S.D.
Explanatory variables (risk factors)							
BMI	Body mass index: weight in kg/stature in mt^2	8845	24.9	3.9	1449	25.7	3.9
Albumin	Urine albumin; %; 1 = positive; 0 = negative	8808	10.9		1386	3.8	
Cholesterol	Serum cholesterol: mg/dl	8807	201.4	40.7	1438	226.3	43.9
Activity	1 = top 25% in index of physical activity; 0 = bottom 75%. See text	8826	0.2	0.4	1447	0.2	0.4
Smoke	% of people who smoke now: 1 = person smokes now; 0 = person does not smoke	8842	44.8		1133	48.4	
Heart rate	Heart beats/min	8852	71.3	11.7	1445	77.7	12.6
Salt	1 = person in top third of salt intake measure; 0 = bottom 2/3 of salt intake	8826	0.3	0.47	953	0.37	0.48

Standard deviation (S.D.) in parenthesis. NA: not applicable. Explanatory variables related to schooling, poverty, place of residence, salt intake, and region named after +1 category, with zero for reference group. For example, ''primary'' = +1 if person completed no more than the first four grades of school, and zero otherwise. White refers to non-Hispanic people who classified themselves as White. Summary statistics are only for people not taking anti-hypertensive medications. Variables in italic are the reference categories in the regressions. Under outcome variable (hypertension), ''h'' stands for hypertension.

salt intake. Albumin was measured from urine samples and took the value of one if the protein could be detected in the urine, and zero otherwise. Serum cholesterol was measured in milligram per deciliter. Since each of the two surveys had different measures of physical activity, we created a variable called ''activity'' that took the value of one if the person scored at the top 25% of the scale for physical activity in their site, and zero otherwise. The variable smoke took the value of one if the person self-classified himself as a current smoker, and zero otherwise. We included a measure of heart rate.

Last, we included salt intake. The variable was measured differently in Puerto Rico and on the mainland. In Puerto Rico, researchers measured salt intake in ''sodium units/week,'' whereas on the mainland researchers measured salt in at least three ways, none comparable to the way it was measured in Puerto Rico. For the mainland, we opted to equate salt intake with milligrams of salt consumed by a person as revealed through a 24-h dietary recall. Since the measure of salt intake differed between Puerto Rico and the mainland, we created a dummy variable that took the value of one if the person was in the top third of the salt intake distribution for their site, and zero otherwise. Because 36% of the mainland sample lacked information on salt consumption (irrespective of the way NHANES-I measured salt), we present separately the regression results with salt intake.

2.3. Statistical analysis

We used ordinary least squares regressions (OLS) to estimate the association between blood pressure and explanatory variables separately for Puerto Rico and for the mainland. We used robust standard errors when the probability of exceeding the χ^2-value in the Breusch–Pagan test for heteroskedasticity was $<5\%$. To avoid producing unreasonable values for constants, we transformed measures of blood pressure by subtracting 35 from age. This way the constant refers to a 35-year-old man. In addition, we subtracted 0.6 and 0.02 from the values of systolic and diastolic blood pressures for each year of age. The values 0.6 and 0.02 represent the yearly change in blood pressure from an additional year of age. We prefer this approach because we are unable to estimate age and birth of year effects otherwise. We used probit regressions when using hypertension as an outcome. STATA 9 for Windows was used for the statistical analysis.

Our analysis of secular trends relies on a one-time measure of blood pressure and focuses on the coefficients of birth quinquennium while controlling for relevant covariates. The approach would be more accurate if blood pressure did not change in adulthood. Ideally, the coefficients for the variables for birth quinquennium pick up cohort effects common to a group born during the same period (Borjas, 2005; Fienberg and Mason, 1979; Rodgers, 1982). Since blood pressure increases generally with age, our identification strategy is not ideal because it does not allow us to separate well the collinearity between age and cohorts. This is why studies of secular trends of blood pressure rely on measures of blood pressure taken from people of the same age bracket but at different times (Sjøl et al., 1998; McCarron et al., 2001; Burt et al., 1995). We could not use the preferred identification strategy because we did not find other representative surveys of blood pressure in Puerto Rico done after PRHHP.

We ran three different types of regression for each type of blood pressure. First, we only controlled for birth quinquennium to detect secular trends (columns 1 of Table 4A and 4B). Second, we added covariates (except salt) that might explain the secular trend (column 2). Third, we added salt as a covariate (column 3). We ran the three regressions for people not taking

Table 4A
Secular trends in blood pressure for men in Puerto Rico and White men on the USA mainland born during 1886–1930: Excludes subjects taking anti-hypertensive medicines

Explanatory variables	(I) Puerto Rico						(II) Mainland					
	(A) Systolic			(B) Diastolic			(A) Systolic			(B) Diastolic		
	[1]	[2]	[3]	[1]	[2]	[3]	[1]	[2]	[3]	[1]	[2]	[3]
Birth quinquennium (reference = people born before 1901)												
1901–1905	–3.4**	−3.0**	−3.1**	−0.03	−0.05	−0.1	−10**	−12**	−9.1*	−1.5	−3.4	−3.1
1906–1910	−3.0*	−3.1**	−3.2**	1.1*	0.8	0.8	−6.5	−8.2*	−4.7	−0.1	−2.7	−0.7
1911–1915	−3.7**	−4.5**	−4.6**	0.9	0.1	0.1	−8.2*	−9.7**	−5.2	1.6	0.1	0.9
1916–1920	−4.1**	−4.9**	−5.0**	0.8	−0.09	−0.1	−7.9*	−9.9**	−8.1*	1.9	−0.4	0.2
1921–1925	−5.3**	−4.8**	−4.9**	−1.8*	−1.7*	−1.8*	−7.9*	−9.3*	−5.5	3.2	0.9	1.6
1926–1930	0.04	−0.65	−0.7	−1.2	−2.5	−2.6	−7.4*	−8.7*	−5.4	2.1	0.07	0.8
Schooling (reference = attended university)												
None	^	0.06	0.05	^	0.1	0.1	^	−4.8	−11	^	−4.5	−8.3
Primary	^	−0.1	−0.2	^	0.002	−0.04	^	2.3	1.5	^	0.9	−0.3
Middle	^	−0.009	−0.001	^	−0.2	−0.2	^	−0.7	−0.2	^	−0.3	−0.9
HS-A	^	0.6	0.61	^	0.05	0.03	^	−1.4	0.8	^	−1.0	−0.4
HS-G	^	0.4	0.41	^	−0.003	0.003	^	1.3	1.7	^	0.2	−0.5
Poverty	^	0.6	0.6	^	0.2	0.2	^	3.9*	4.2*	^	2.3*	2.5*
Rural	^	−1.9**	−2.0**	^	0.3	0.3	^	−0.1	−0.4	^	0.5	0.5
Region (reference = northeast)												
Midwest			Not applicable				^	−5.1**	−3.5	^	−1.0	0.8
South							^	−4.4*	−3.5	^	−0.8	0.4
West							^	−4.3	−2.5	^	−0.5	0.3
BMI	^	1.0**	1.0**	^	0.8**	0.7**	^	0.9**	1.1**	^	0.7**	0.8**
Albumin	^	11.4**	11.4**	^	4.9**	4.8**	^	−1.8	−4.4	^	−1.7	−2.0
Cholesterol	^	0.03**	0.03**	^	0.01**	0.01**	^	0.01	0.01	^	0.01*	0.02*
Activity	^	0.7	0.6	^	−0.04	−0.08	^	−2.0	−3.4	^	−0.4	−1.3
Smoke	^	−0.9*	−1.0*	^	−1.2**	−1.3**	^	−0.4	−0.6	^	−2.0**	−1.7
Heart rate	^	0.2**	0.2**	^	0.1**	0.1**	^	0.2**	0.2	^	0.1**	0.2**
Salt	^	^	0.2	^	^	0.2	^	^	−2.8	^	^	−1.1
Constant	123**	72**	73**	80**	43**	43**	132**	92**	87**	84**	50**	43**
R^2	0.002	0.12	0.12	0.003	0.18	0.18	0.009	0.09	0.11	0.01	0.15	0.18
Joint	3.3**	4.9**	5.0**	4.6**	4.1**	4.2**	1.5	2.1*	1.1	3.9**	2.8**	1.9
N	8853	8532	8514	8853	8532	8514	1449	1060	682	1449	1060	682

Table 4B
Secular trends in blood pressure for men in Puerto Rico and White men on the USA mainland born during 1886–1930: Includes subjects taking anti-hypertensive medicines

Explanatory variables	(I) Puerto Rico						(II) Mainland					
	(A) Systolic			(B) Diastolic			(A) Systolic			(B) Diastolic		
	[1]	[2]	[3]	[1]	[2]	[3]	[1]	[2]	[3]	[1]	[2]	[3]
Birth quinquennium (reference = people born before 1901)												
1901–1905	−3.2**	−2.9*	−2.9*	−0.4	−0.3	−0.3	−10**	−12**	−9.1*	−1.1	−3.4	−3.1
1906–1910	−3.6**	−3.6**	−3.6**	0.4	0.2	0.2	−6.1	−8.1*	−4.7	0.2	−2.3	−0.7
1911–1915	−4.5*	−5.3**	−5.2**	0.2	−0.4	−0.3	−8.4*	−9.8**	−5.2	1.9	0.4	0.9
1916–1920	−5.8**	−6.6**	−6.5**	−0.2	−0.9	−0.9	−6.6	−8.6*	−8.1*	2.4	0.1	0.2
1921–1925	−7.4**	−6.4**	−6.3**	−3.0**	−2.6**	−2.5**	−7.3*	−9.1*	−5.5	3.6*	1.2	1.6
1926–1930	−3.4	−3.4	−3.2	−3.3*	−4.0**	−3.9**	−6.8	−8.1*	−5.4	3.0	0.7	0.8
Schooling (reference = attended university)												
None	^	−0.4	−0.3	^	−0.1	−0.1	^	−5.1	−11.0	^	−5.0	−8.3
Primary	^	−0.7	−0.6	^	−0.3	−0.3	^	1.7	1.5	^	−0.1	−0.3
Middle	^	0.3	0.3	^	−0.2	−0.2	^	−0.8	−0.2	^	−0.2	−0.9
HS–A	^	1.4	1.4	^	0.3	0.3	^	−1.2	0.8	^	−1.5	−0.4
HS–G	^	0.6	0.6	^	−0.2	−0.2	^	1.8	1.7	^	−0.06	−0.5
Poverty	^	0.5	0.5	^	0.2	0.2	^	4.2**	4.2*	^	2.3*	2.5*
Rural	^	−1.5**	−1.5**	^	0.4	0.4	^	−0.2	−0.4	^	0.5	0.5
Region (reference = northeast)												
Midwest			Not applicable				^	−6.0**	−3.5	^	−1.4	0.8
South							^	−4.9**	−3.5	^	−1.4	0.4
West							^	−4.8**	−2.5	^	−0.7	0.3
BMI	^	1.2**	1.2**	^	0.8**	0.8**	^	0.9**	1.1**	^	0.6**	0.8**
Albumin	^	13.9**	13.9**	^	6.2**	6.2**	^	−1.0	−4.4	^	−1.8	−2.0
Cholesterol	^	0.03**	0.03**	^	0.01**	0.01**	^	0.01	0.01	^	0.01*	0.02*
Activity	^	0.09	0.1	^	−0.3	−0.3	^	−1.3	−3.4	^	−0.3	−1.3

Table 4B (*Continued*)

Explanatory variables	(I) Puerto Rico						(II) Mainland					
	(A) Systolic			(B) Diastolic			(A) Systolic			(B) Diastolic		
	[1]	[2]	[3]	[1]	[2]	[3]	[1]	[2]	[3]	[1]	[2]	[3]
Smoke	^	−1.2**	−1.2**	^	−1.3**	−1.3**	^	−0.8	−0.6	^	−1.9**	−1.7
Heart rate	^	0.2**	0.2	^	0.2**	0.2**	^	0.2	0.2	^	0.1**	0.2**
Salt	^	^	−0.7	^	^	−0.2	^	^	−2.8	^	^	−1.1
Constant	126**	70**	70**	82**	42**	42**	132**	92**	87**	84**	51**	43**
R^2	0.004	0.15	0.15	0.002	0.20	0.20	0.008	0.09	0.11	0.01	0.14	0.18
Joint	7.4**	9.6**	9.9**	5.4**	5.7**	5.5**	1.5	2.2*	1.1	4.6**	3.5**	1.9
N	9811	9453	9431	9811	9453	9431	1567	1144	682	1567	1144	682

Regressions are ordinary least squares; robust standard errors used when $p > \chi^2$ in Breusch–Pagan test for heteroskedasticity <5%. Dependent variables = systolic or diastolic blood pressure adjusted for age-related change. Single (*) and double asterisks (**) denote significant at 5 and 1% levels, respectively. The constant reflects blood pressure at age 35. "Joint" is *F*-test of joint statistical significance for all variables of birth quinquennium. (^) Variable intentionally left out.

anti-hypertensive medications (Table 4A) and then repeated the regressions including people taking such medications (Table 4B).

3. Results

3.1. Description of socioeconomic and health status of the two samples

Table 3 suggests that the two samples had roughly similar mean body mass index (∼25) and share of smokers (45–48%), but the two samples also differed in socioeconomic and health status. People on the mainland had much higher levels of school achievement. For example, 27.0 and 22.1% of the sample from the mainland had graduated from high school or university respectively, whereas only 9.1 and 8.2% of the sample from Puerto Rico had done so. A larger share of the sample came from the countryside on the mainland (40.7%) than in Puerto Rico (30.6%). People on the mainland had higher levels of serum cholesterol (226.3 mg/dl) than in Puerto Rico (201.4 mg/dl), but a higher share of people in Puerto Rico tested positive for urine albumin (10.9%) than on the mainland (3.8%). Urine albumin is an indicator of renal disease, which can reflect hypertension, though hypertension can also result from renal disease. Microalbuminuria is associated with metabolic syndrome and increased risk for cardiovascular disease. The higher share of people in Puerto Rico who tested positive for urine albumin would suggest that renal damage may have been more common in Puerto Rico.

Table 3 suggests that both populations had roughly the same mean age (Puerto Rico = 54.2, mainland = 57.3), but Table 1 suggests that there were fewer young men in the sample from Puerto Rico (born after 1921).[5]

3.2. Descriptive, bivariate, and visual analysis

This section presents the raw data (without controlling for any of the covariates) to obtain a preliminary impression of the data. Table 1 (Sections I and II) suggests that the average subject in Puerto Rico born during 1886–1930 had 6.9 mmHg lower systolic blood pressure and 4.9 mmHg lower diastolic blood pressure than the average subject born on the mainland during the same period. Table 1 (Section III) suggests that the differences in both systolic and diastolic blood pressure between people on the mainland and in Puerto Rico increased, the former from an average of 8.5 mmHg among men born 1896–1905 to an average of 9.8 mmHg for those born 1921–1930. The mainland–Puerto Rico difference in diastolic blood pressure increased from an average of 3.1 mmHg among people born during 1896–1905 to an average of 8.7 mmHg for people born after 1921.

Among people who were not taking anti-hypertensive medication both systolic and diastolic blood pressures were always higher on the mainland than in Puerto Rico (Fig. 3). There was a secular parallel decline in systolic blood pressure in these groups while diastolic blood pressure rose on the mainland, but rose and fell in Puerto Rico. However, if one includes in the sample those who were taking anti-hypertensive medication the relationship is reversed and it is Puerto Ricans who have the greater systolic and diastolic blood pressures at the outset. The USA catches up and exceeds Puerto Rican levels at the end of the period.

[5] If the smaller sample of younger cohorts reflects a selectivity bias (e.g., migration to the mainland of younger adults), then this could bias parameter estimates.

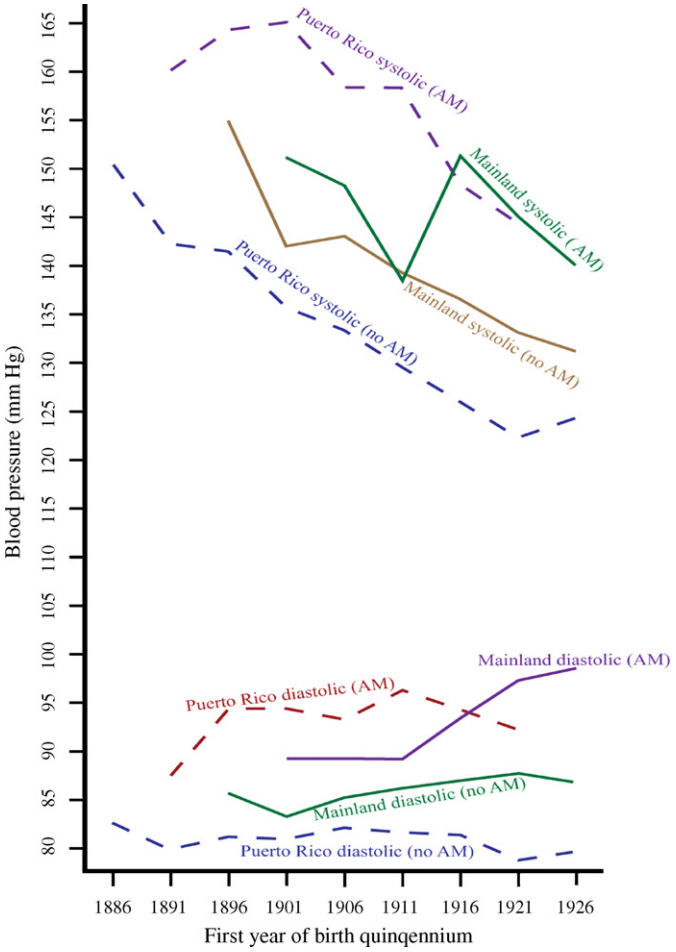

Fig. 3. Trends in male blood pressure for Puerto Rico and mainland: by birth quinquennium (1886–1930), with and without anti-hypertensive medications (AM).

3.3. Multivariate regression analysis

3.3.1. Puerto Rico

3.3.1.1. Systolic. The results of Tables 4A and 4B (Section IA) suggest a statistically significant decline in systolic blood pressure from 1901 until 1925 compared with people born before 1901. Only during the quinquennium 1926–1930 do we see no improvement. Most of the individual coefficients for birth quinquennium were slightly larger in the regressions with people taking anti-hypertensive medication (Table 4B), and so were the F-tests of joint statistical significance for all of the variables for birth quinquennium. The secular decline in systolic blood pressure held up even after controlling for risk factors, including salt intake (columns 2–3, Section I, Tables 4A and 4B).

In Fig. 4, we show the implied secular trend in systolic and diastolic blood pressure for an average man 35 years of age in Puerto Rico taking and not taking anti-hypertensive medications. Fig. 4 draws on the constant and coefficients of rows [1] in Tables 4A and 4B. The two lines for

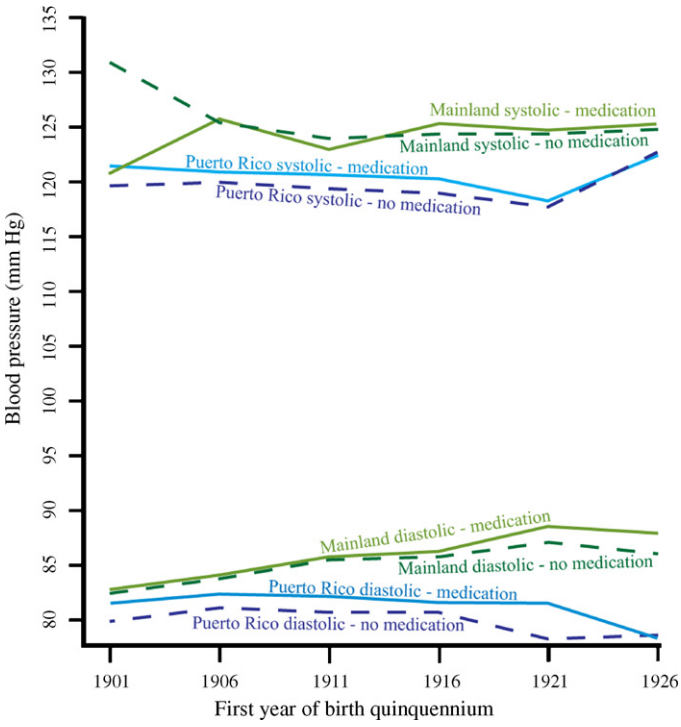

Fig. 4. Implied secular trend in blood pressure for men 35 years old born during 1901–1930 taking and not taking anti-hypertensive medicines: Puerto Rico and mainland compared.

systolic blood pressure for Puerto Rico (with and without anti-hypertensive medication) suggest a slight secular decline in systolic blood pressure until the cohort born in 1921. Fig. 4 suggests that levels of systolic blood pressure were almost always lower in Puerto Rico than on the mainland, but converged to some degree towards the end of the period under consideration.

3.3.1.2. Diastolic. In Puerto Rico, the secular decline in diastolic blood pressure is brief and occurs only toward the end of the period (Tables 4A and 4B, Section IB). In the sample of subjects not taking anti-hypertensive medication, the decline takes place only during one quinquennium (1921–1925), and in the sample taking anti-hypertensive medication the decline covers the last two quinquenniums (1921–1925, 1926–1930). As was the case with systolic blood pressure, the secular improvement was more marked in the sample that included men taking anti-hypertensive medication. The individual coefficients for quinquenniums 1921–1925 and 1926–1930 were much larger and always statistically significant in the sample that included people taking medication, and so were the F-statistics for the tests of joint significance of all the variables for birth quinquennium.

Fig. 4 shows that an average man in Puerto Rico 35 years of age always had lower diastolic blood pressure than a peer on the mainland and the difference diverged over time.

In sum, irrespective of whether they took anti-hypertensive medication, men in Puerto Rico experienced unambiguous improvement in systolic blood pressure during all but the last quinquennium (1926–1930). They generally saw no secular improvement in diastolic blood pressure, except for men born during the last two quinquenniums. The magnitude of the improvement was larger in the sample that included people taking anti-hypertensive medications.

3.3.2. Mainland

3.3.2.1. Systolic. The regression results for the mainland shown in Tables 4A and 4B (Section IIA) suggest small secular improvements in systolic blood pressure. In the sample that excludes people taking anti-hypertensive medications (Table 4A), the regression that includes only birth quinquenniums (column 1) and the regression that controls for risk factors (but not salt intake) (column 2) both suggest a secular decline in systolic blood pressure. If we compare the coefficients for birth quinquennium in columns 1–2 for the mainland with Puerto Rico we see that the magnitude of the improvement was larger on the mainland than in Puerto Rico but was confined to the early period. For instance, columns 1 of systolic pressure in Table 4A suggests that during 1916–1920, an average men born in Puerto Rico had 4.1 mmHg lower systolic blood pressure than a peer born before 1901; the comparable coefficient for the mainland was 7.9. The difference between the mainland and Puerto Rico widened by 1921, but then converged. By the end of the period the difference was miniscule.

The secular decline on the mainland becomes weaker once we control for salt intake. Columns 3 of Sections IIA of Tables 4A and 4B show the regression results that control for salt intake on the mainland. The coefficients retain their negative sign, but lose their statistical significance owing to the reduction in the sample size. After controlling for salt intake, the F-test for the joint significance of all variables related to birth quinquennium become statistically insignificant.

The results of the analysis of secular trends for systolic blood pressure on the mainland are roughly the same with the sample of people taking and not taking anti-hypertensive medications. If we compare the coefficients of Section IIA in Table 4A with the coefficients of the same section in Table 4B, we see that many of the coefficients become slightly smaller when we include the sample of people taking anti-hypertensive medications. Nevertheless, the trends are quite similar except at the beginning of the period.

3.3.2.2. Diastolic. The results of Sections IIB in Tables 4A and 4B suggest no evidence of a secular change in diastolic blood pressure on the mainland. In fact, most of the coefficients for birth quinquennium are positive (though statistically insignificant). The bottom of Fig. 4 shows the implied secular change in diastolic blood pressure for a man on the mainland 35 years of age; the secular trend for men taking and not taking anti-hypertensive medications are indistinguishable, and slope slightly upward.

In sum, the mainland experienced a sharper decline in systolic blood pressure than Puerto Rico if we consider those who were not taking medication, but experienced no secular change in diastolic blood pressure even if there is a hint of slight increase. Among those who were taking medication, systolic blood pressure remained constant throughout the period.

3.3.3. Robustness

To ensure the robustness of the main results, we introduced at the same time the following changes to the regressions of columns 3 of Table 4B: (a) redefined the reference category for birth quinquennium to include people born before 1906, (b) controlled for alcohol consumption, (c) controlled for the use of anti-hypertensive medications by adding a dummy variable for the use of such medication, and (d) we added Blacks to the mainland sample and included a dummy variable for Blacks. The main results for Puerto Rico remained essentially unchanged, though the coefficients became slightly smaller. The same was true for the secular trend in systolic blood pressure on the mainland. However, the secular trend in diastolic blood pressure for the mainland became positive; three of the five coefficients for birth quinquennium (1926–1930, 1921–1925, 1911–1915) became statistically significant and so was the test of joint

statistical significance for all the variables related to birth quinquennium. These results are not reported here.

3.3.4. Secular trends in hypertension

In Table 5, we show the results of probit regressions to estimate secular trends in hypertension. The evidence suggests that men in Puerto Rico experienced no statistically significant secular change in either systolic or diastolic hypertension, but men on the mainland experienced secular improvements in systolic hypertension. For example, men born on the mainland during 1921–1925 and 1926–1930 were 59 and 61% less likely to have systolic hypertension than men born

Table 5
Secular trends in hypertension for men in Puerto Rico and White men on the USA mainland born during 1886–1930, results of probit regressions

Explanatory variables	(A) Puerto Rico ($n = 8532$)		(B) Mainland Whites ($n = 1060$)	
	Systolic-h [1]	Diastolic-h [2]	Systolic-h [1]	Diastolic-h [2]
Birth quinquennium				
1901–1905	−0.02	−0.001	−0.23*	−0.15
1906–1910	0.001	0.02	−0.32**	−0.18
1911–1915	−0.01	0.01	−0.42**	−0.12
1916–1920	–0.006	0.01	−0.53**	−0.19
1921–1925	−0.05	−0.05	−0.59**	−0.18
1926–1930	0.09	0.04	−0.61**	−0.20
Age	0.01**	0.001	−0.02*	−0.007
Schooling				
None	0.006	−0.02	−0.15	−0.12
Primary	0.01	−0.01*	0.07	−0.03
Middle	0.02	−0.02*	0.01	−0.02
HS-A	0.05*	−0.03	−0.0	−0.05
HS-G	0.02	−0.02	0.008	0.006
Relative poverty	0.01	0.02*	0.04	0.08*
Rural	−0.03*	−0.001	−0.03	0.006
Regions				
Midwest	NA		−0.11*	−0.08
South			−0.07	−0.03
West			−0.10*	−0.02
BMI	0.01**	0.02**	0.01**	0.02**
Albumin	0.21**	0.16**	−0.001	−0.04
Cholesterol	0.0006**	0.0004**	0.0006	0.0009**
Activity	0.01	0.006	−0.04	0.007
Smoke	−0.02*	−0.03**	−0.02	0.009
Heart rate	0.004**	0.005**	0.005**	0.006**
R^2	0.09	0.09	0.09	0.07
Joint	5.71 (0.335)	10.47 (0.063)	20.55 (.002)	5.21 (0.517)

Same notes and covariates as column [2] Tables 4A and 4B, but age added. Regressions are probits with coefficients reported as marginal probabilities of having hypertension; probabilities estimated at mean values of *X*s. Dependent variables: (a) systolic hypertension (column 1) = 1 if men had ≥140 mmHg and 0 otherwise, (b) diastolic hypertension (column 2) = 1 if men had ≥90 mmHg and 0 otherwise. NA = not applicable.

before 1901. On the mainland, the variables for birth quinquennium were jointly statistically significantly associated with systolic hypertension at the 99% confidence level ($\chi^2 = 20.55$, $p = 0.002$).

3.3.5. Secular changes in cardiovascular risk factors and in the use of anti-hypertensive medications

We next estimate secular trends in cardiovascular risk factors and in the use of anti-hypertensive medications. We focus on risk factors that previous studies had identified as predictors of cardiovascular health (García-Palmieri et al., 1980; Gordon et al., 1974, 1981). The risk factors included (a) body mass index, (b) physical activity, (c) alcohol consumption, (d) smoking, (e) heart rate, and (f) cholesterol level. When estimating secular trends in risk factors or in the use of anti-hypertensive medications, we controlled for all the covariates of Table 4 and added age. We found a strong secular decline in physical activity among people in Puerto Rico (F-statistic for all birth quinquennium variables = 4.26, $p = 0.001$), but not among people on the mainland. In neither sample did we find significant secular changes in alcohol consumption, smoking, body mass index, heart rate, or cholesterol levels. These results are not reported here.

We used a probit regression with a dummy variable as an outcome for whether the person was taking anti-hypertensive medications and found no evidence of a secular change in the use of anti-hypertensive medication in Puerto Rico (F-statistics for test of all variables related to birth quinquennium = 1.12, $p = 0.89$), but we found a secular increase in the use of anti-hypertensive medication on the mainland ($F = 52.81$, $p = 0.001$). On the mainland subjects born starting with the quinquennium 1906–1910 were 34% (1906–1910), 76% (1911–1915), 90% (1916–1920), 97% (1921–1925), and 99% (1926–1930) more likely to use anti-hypertensive medications than people born before 1906.

The secular improvement in systolic blood pressure and in hypertension on the mainland and the more modest improvement in Puerto Rico might therefore reflect improved access to health care on the mainland, as shown by the increasing use of anti-hypertensive medication and by a stronger tendency toward a sedentary lifestyle in Puerto Rico. The use of anti-hypertensive medication is a proxy for greater access to health care, as discussed later.

We also analyzed secular trends in self-reported diabetes as a possible contributing factor to secular trends in blood pressure. We found no secular trend in the incidence of diabetes in Puerto Rico, but we found a small, but statistically significant secular decline on the mainland. On the mainland, each birth quinquennium was associated with a 1–2% lower probability of reporting diabetes, whereas in Puerto Rico each birth quinquennium was associated with about a 0.5% lower probability of reporting diabetes. The pattern could reflect a healthy survivor effect—that is, those with diabetes died at younger ages, so they are no longer in the sample. The frequency of Type 2 diabetes has been increasing on the mainland, lending credence to the healthy survivor interpretation.

4. Discussion and conclusions

4.1. Awareness and prevention

In this section, we discuss the role of awareness and prevention of cardiovascular health in explaining the more marked decline in systolic (but not diastolic) blood pressure and hypertension on the mainland. We lack data on awareness campaigns about cardiovascular health before the 1970s, but data after the 1970s suggests that campaigns to increase awareness about

cardiovascular health may have started earlier and may have been more intense on the mainland than in Puerto Rico. In 1972, the National Institutes of Health created the National High Blood Pressure Education Program to mobilize, educate, and coordinate resources for groups interested in the prevention and control of hypertension. During 1972–1976, clinics screened the blood pressure of 1 million people on the mainland as part of the Community Hypertension Evaluation Clinic Program (Stamler et al., 1976). Besides awareness and treatment programs, physicians on the mainland started to prescribe anti-hypertensive medication to more people. Prescriptions rose from 46 million in 1965 to 96 million in 1975, and the value of sales of anti-hypertensive medication climbed from US$ 118 million in 1965 to US$ 383 million in 1975 (Stamler et al., 1976). We too found evidence for a sharper secular increase in the use of hypertensive medication on the mainland than in Puerto Rico.

Several authors have suggested that programs of awareness and prevention of hypertension in Puerto Rico did not keep up with those of the mainland, that efforts started later (1980s) in Puerto Rico than on the mainland (1970s), and that the programs may have treated only a small share of the people in Puerto Rico with cardiovascular ailments (Cangiano, 1999; Crespo et al., 2002; Ramírez, 1980, 1994; Rigau-Pérez, 2000).

4.2. Evaluation of hypotheses

The comparative analysis of secular trends in blood pressure between Puerto Rico and the mainland yields mixed support for the hypotheses. People in Puerto Rico generally had lower blood pressure than people on the mainland, as seen in Figs. 3 and 4, and experienced a statistically significant decline in diastolic blood pressure toward the end of the period considered. However, people on the mainland experienced statistically significant secular declines in both systolic blood pressure and in hypertension (but not in diastolic blood pressure, particularly after we add Blacks). Mainland–Puerto Rico differences in both systolic and diastolic blood pressure increased modestly for the period under study. Neither group enjoyed unambiguous superiority in all dimensions of cardiovascular health.

Of the three hypotheses presented in Section 1, we find strongest—albeit partial—support for the hypothesis from social epidemiology that in industrial nations all groups experienced secular improvements in cardiovascular health, but that some groups did better than others. The transformations of the Puerto Rican economy and society attenuated the rate of secular improvement of two of the most important dimensions of cardiovascular health—systolic blood pressure and hypertension—in Puerto Rico compared with the mainland. However, support for the hypothesis is partial. Recall from Section 1 that among socioeconomic groups on the mainland secular improvements in blood pressure were more marked for people of the lowest socioeconomic status (Black women) and least marked for people of the highest socioeconomic status (White men). Full support for the hypothesis would have seen people in Puerto Rico experience larger secular improvements in cardiovascular health than people on the mainland across all dimensions of cardiovascular health.

4.3. Implications

Since we found some improvement in systolic blood pressure and hypertension on the mainland net of risk factors, the trend reflects variables we did not measure but that deserve attention in future research. One such variable might be awareness about cardiovascular health and access to health care. On the other hand, the absence of a secular increase in blood pressure in

Puerto Rico suggests that men in Puerto Rico must have benefited from compensatory mechanisms. It is possible that the socioeconomic and political changes in Puerto Rico during the late 19th and early 20th centuries had adverse effects on cardiovascular health, but that protective mechanisms in Puerto Rico—a strong sense of culture, community, language—protected people from harm.

We noted in Section 1 that an analysis of secular trends in cardiovascular health could complement analysis of secular trends of anthropometric indicators. In another study, we documented how despite the economic stagnation and the poor quality of the diet in Puerto Rico during the first half of the 20th century, the physical stature of adult men in Puerto Rico experienced a more modest rate of secular increase than on the mainland (Godoy et al., 2007). Seen this way, the results of the analysis of trends in cardiovascular health presented here carry the same general message that we found when examining secular trends in physical stature. With both outcomes—cardiovascular health and physical stature—we found that people in Puerto Rico experienced secular stability or improvement, but that the magnitude of the improvement (at least for some cardiovascular outcomes such as systolic blood pressure and hypertension) fell short of improvements on the mainland. The results are promising and suggest that development economists studying secular trends in the biological standard of living of people in modern periods should examine multiple indicators, including blood pressure, to obtain a more comprehensive picture of the changing health status of populations.

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References

Arora, S., 2005. On epidemiologic and economic transitions: a historical view. In: Lopez-Casanovas, G., Rivera, B., Currais, L. (Eds.), Health and Economic Growth. Findings and Policy Implications. MIT Press, Cambridge, pp. 199–238.

Barker, D.J.P., 1995. Fetal origins of coronary heart disease. Br. Med. J. 311, 171–174.

Barker, D.J.P., 2001. Fetal origins of cardiovascular and lung disease. Marcel Dekker, New York.

Barker, D.J.P., Eriksson, J.G., Forsen, T., Osmond, C., 2002. Fetal origins of adult disease: strength of effects and biological basis. Int. J. Epidemiol. 31, 1235–1239.

Benson, H., Costas Jr., R., García-Palmieri, M.R., Feliberti, M., Aixala, R., Blanton, J.H., Colón, A.A., 1966. Coronary heart disease risk factors: a comparison of two Puerto Rican populations. Am. J. Public Health 56, 1058–1060.

Black, H.R., 2004. The paradigm has shifted to systolic blood pressure. J. Hum. Hypertens. 18S, S3–S7.

Blane, D., Hart, C.L., Smith, G.D., Gillis, C.R., Hole, D.J., Hawthorne, V.M., 1996. Association of cardiovascular disease risk factors with socioeconomic position during childhood and during adulthood. Br. Med. J. 313, 1434–1438.

Bogin, B., Keep, R., 1999. Eight thousand years of economic and political history in Latin America revealed by anthropometry. Ann. Hum. Biol. 26, 333–351.

Borhani, N.O., Hechter, H.H., Breslow, L., 1963. Report of a ten-year follow-up study of the San Francisco longshoremen. J. Chronic Dis. 16, 1251–1266.

Borjas, G.J., 2005. Labor Economics, 3rd ed. McGraw Hill, New York.

Burt, V.L., Cutler, J.A., Higgins, M., Horan, M.J., Labarthe, D., Whelton, P., Brown, C., Roccella, E.J., 1995. Trends in the prevalence, awareness, treatment, and control of hypertension in the adult US population. Hypertension 26, 60–69.

Cangiano, J.L., 1999. Hypertension and renal disease in Puerto Ricans. Am. J. Med. Sci. 318, 369–373.

Clark, V., Dearing, C., Dickey, J., Newell, F., Reber, H., Seidemann, H., Tannenbaum, F., Zimmerman, E., 1930. Porto Rico and its Problems. The Brookings Institution, Washington, DC.

Costas Jr., R., García-Palmieri, M.R., Sorlie, P.D., Hertzmark, E., 1981. Coronary heart disease risk factors in men with light and dark skin in Puerto Rico. Am. J. Public Health 71, 614–619.

Crespo, C.J., García-Palmieri, M.R., Pérez Perdomo, R., McGee, D.L., Smit, E., Sempos, C.T., Min, I., Sorlie, P.D., 2002. The relationship of physical activity and body weight with all-cause mortality. Ann. Epidemiol. 12, 543–552.

Cruickshank, J.K., Mzayek, F., Liu, L., Kieltyka, L., Sherwin, R., Webber, L.S., Srinavasan, S.R., Berenson, G.S., 2005. Origins of the black/white difference in blood pressure: roles of birth weight, postnatal growth, early blood pressure and adolescent body size. Circulation 111, 1932–1937.

De Lusignan, B.J., Hague, N., Dzregah, B., 2004. End digit preference in blood pressure recordings of patients with ischaemic heart disease in primary care. J. Hum. Hypertens. 18, 261–265.

Dietz, J.L., 1987. Economic History of Puerto Rico: Institutional Change and Capitalist Development. Princeton University Press, Princeton.

Dressler, W.W., 1999. Modernization, stress, and blood pressure: new directions in research. Hum. Biol. 71, 583–605.

Editorial, 2002. El programa de salud del corazón Puerto Rico: 1961–1970. Boletín de la Asociación Médica de Puerto Rico, vol. 94, pp. 59–60.

Evans, H., 2003. Losing touch: the controversy over the introduction of blood pressure instruments into medicine. Technol. Cult. 34, 784–807.

Fienberg, S.E., Mason, W.M., 1979. Identification and estimation of age-period-cohort models in the analysis of discrete archival data. Sociol. Methodol. 10, 1–67.

Fogel, R.W., 2005. The Escape from Hunger and a Premature Death, 1700–2100. Cambridge University Press, New York.

Fogel, R.W., Engerman, S.L., Trussel, J., 1982. Exploring the uses of data on height. Soc. Sci. Hist. 6, 401–421.

García-Palmieri, M.R., Feliberti, M., Costas Jr., R., Colón, A.A., Cruz-Vidal, M., Cortés-Alicea, M., Ayala, A., Sobrino, R., Torres, R., 1969. An epidemiological study on coronary heart disease in Puerto Rico. Boletin Asociacion Medica de Puerto Rico 94, 61–67.

García-Palmieri, M.R., Costas Jr., R., Cruz-Vidal, M., Cortés-Alicea, M., Colón, A.A., Feliberti, M., Ayala, A.M., Patterne, D., Sobrino, R., Torres, R., Nazario, E., 1970. Risk factors and prevalence of coronary heart disease in Puerto Rico. Circulation 42, 541–549.

García-Palmieri, M.R., Sorlie, P.D., Tillotson, J., Costas Jr., R., Cordero, E., Rodríguez, M., 1980. Relationship of dietary intake to subsequent coronary heart disease incidence: The Puerto Rico Heart Health Program. Am. J. Clin. Nutr. 33, 1818–1827.

García-Palmieri, M.R., Costas Jr., R., Cruz-Vidal, M., Sorlie, P.D., Havlik, R., 1982. Increased physical activity: a protective factor against heart attacks in Puerto Rico. Am. J. Cardiol. 50, 749–755.

García-Palmieri, M.R., Costas Jr., R., Cruz-Vidal, M., Sorlie, P.D., Tillotson, J., Havlik, R.J., 1984. Milk consumption, calcium intake, and decreased hypertension in Puerto Rico: Puerto Rico Heart Health Program Study. Hypertension 6, 322–328.

García-Palmieri, M.R., Feliberti, M., Costas Jr., R., Colón, A.A., Cruz-Vidal, M., Cortés-Alicea, M., Ayala, A., Sobrino, R., Torres, R., 2002. An epidemiological study on coronary heart disease in Puerto Rico, 1969. Boletín de la Asociación Médica de Puerto Rico 94, 61–67.

Godoy, R.A., Jenkins, G.P., Patel, K., 2003. Review of quantitative studies of Puerto Rican migration. Journal of the Center for Puerto Rican Studies 15, 207–241.

Godoy, R.A., Goodman, E., Levins, R., Caram, M., Seyfried, C., 2007. A comparison of secular trends in height between men in Puerto Rico and the USA mainland, 1886–1930. Econ. Hum. Biol. 5 (1), 82–99.

Gordon, T., García-Palmieri, M.R., Kagan, A., Kannel, W.B., Schiffman, J., 1974. Differences in coronary heart disease in Framingham, Honolulu and Puerto Rico. J. Chronic Dis. 27, 329–344.

Gordon, T., Kagan, A., García-Palmieri, M.R., Kannel, W.B., Zukel, W.J., Tillotson, J., Sorlie, P.D., Hjortland, M., 1981. Diet and its relation to coronary heart disease and death in three populations. Circulation 63, 500–515.

Goya, W.S., Whincup, P.H., Shaper, G., Walker, M., 1996. Influence of father's social class on cardiovascular disease in middle-aged men. Lancet 348, 1259–1263.

Gravlee, C.C., Dressler, W.W., 2005. Skin pigmentation, self-perceived color, and arterial blood pressure in Puerto Rico. Am. J. Hum. Biol. 17, 195–206.

Grossman, E., Rosenthal, T., 1993. Effect of urbanization on blood pressure in Ethiopian immigrants. J. Hum. Hypertens. 7, 559–561.

Guarnaccia, P., Rivera, M., Franco, F., Neighbors, C., 1996. The experiences of ataques de nervios: towards an anthropology of emotions in Puerto Rico. Cult. Med. Psychiatry 20, 343–367.

Haines, M.R., 2004. Growing income, shrinking people—can economic development be hazardous to your health? Soc. Sci. Hist. 28, 249–270.

Hajjar, I., Kotchen, J.M., Kotchen, T.A., 2006. Hypertension: trends in prevalence, incidence, and control. Annu. Rev. Public Health 27, 465–490.

Hardy, R., Kuh, D., Langenberg, C., Wadsworth, M.E.J., 2003. Birth weight, childhood social class, and change in adult blood pressure in the 1946 British birth cohort. Lancet 362, 1178–1183.

Huxley, R.R., Shiell, A.W., Law, C.M., 2000. The role of size at birth and postnatal catch-up growth in determining systolic blood pressure: a systematic review of the literature. J. Hypertens. 18, 815–831.

Huxley, R.R., Neil, A., Collins, R., 2002. Unraveling the fetal origins hypothesis: is there really an inverse association between birth weight and subsequent blood pressure? Lancet 360, 659–665.

James, S.A., 1987. Psychosocial precursors of hypertension: a review of the epidemiologic evidence. Circulation 76, 60–66.

Juonala, M., Jarvisalo, M.J., Maki-Torkko, N., Kahonen, M., Viikari, J.S., Raitakari, O.T., 2005. Risk factors identified in childhood and decreased carotid artery elasticity in adulthood: the Cardiovascular Risk in Young Finns Study. Circulation 112, 1486–1493.

Kannel, W.B., 1975. Role of blood pressure in cardiovascular disease: the Framingham study. Angiology 26, 1–14.

Komlos, J. (Ed.), 1994. Stature, Living Standards, and Economic Development. University of Chicago Press, Chicago, IL.

Komlos, J., 1998. Shrinking in a growing economy? The mystery of physical stature during the Industrial Revolution. J. Econ. Hist. 58, 779–802.

Komlos, J., Baur, M., 2004. From the tallest to (one of) the fattest: the enigmatic fate of the size of the American population in the twentieth century. Econ. Hum. Biol. 2, 57–74.

Komlos, J., Lauderdale, B.E., 2007. Spatial correlates of U.S. heights and BMIs, 2002. J. Biosoc. Sci. 39, 59–78.

Lawlor, D.A., Smith, G.D., 2005. Early life determinants of adult blood pressure. Nephrol. Hypertens. 14, 259–264.

Lefort, F., 1997. Is Puerto Rico Converging to the United States? International Tax Program, Harvard Law School, Report number 1003, Cambridge, Massachusetts.

Lipowicz, A., 2007. Hypertension among Polish males during the economic transition. Econ. Hum. Biol. 5 (1), 61–73.

McCarron, P., Okasha, M., Mc Ewen, J., Smith, G.D., 2001. Changes in blood pressure among students attending Glasgow University between 1948 and 1968: analyses of cross sectional surveys. Br. Med. J. 322, 885–889.

McCarron, P., Smith, G.D., Okasha, M., 2002. Secular changes in blood pressure in childhood adolescence and young adulthood: systematic review of trends from 1948 to 1998. J. Hum. Hypertens. 16, 677–689.

McGarvey, S.T., 1999. Modernization, psychosocial factors, insulin, and cardiovascular health. In: Panter-Brick, C., Worthman, C. (Eds.), Hormones, Health and Behavior: A Socio-ecological and Lifespan Perspective. Cambridge University Press, Cambridge, pp. 244–280.

McGrath, J.J., Matthews, K.A., Brady, S.S., 2006. Individual versus neighborhood socioeconomic status and race as predictors of adolescent ambulatory blood pressure and heart rate. Soc. Sci. Med. 63, 1442–1453.

Montani, J., Antic, V., Yang, Z., Dulloo, A., 2002. Pathways from obesity to hypertension: from the perspective of a vicious triangle. Int. J. Obes. Relat. Metab. Disord. 26 (Supp. 2), S28–S38.

NLBHI, National Lung, Blood and Health Institute, 2006. What is high blood pressure? [Online] Available at http://www.nhlbi.nih.gov/health/dci/Diseases/Hbp/HBP_WhatIs.html. Accessed May 10, 2006.

O'Rourke, M.F., 1990. What is blood pressure? Am. J. Hypertens. 3, 803–810.

Paffenbarger, R.S., Notkin, J., Krueger, D.E., Wolf, P.A., Thorne, M.C., LeBauer, E.J., Williams, J.L., 1966. Chronic disease in former college students. II. Methods of study and observations of mortality from coronary heart disease. Am. J. Public Health 56, 962–971.

Perloff, H., 1950. Puerto Rico's Economic Future: A Study in Planned Development. University of Chicago Press, Chicago.

Possas, D.A., Bobadilla, J.L., 1992. How the epidemiological transition affects health policy issues in three Latin American countries. World Bank, Policy Research Working Paper Series No. 987.

Ramírez, E.A., 1980. Operation by allied health professional personnel of a long-term hypertension detection and treatment program. Boletín de la Asociación Médica de Puerto Rico 72, 298–304.

Ramírez, E.A., 1994. Cardiovascular health in Puerto Ricans compared to other population groups in the United States. Boletín de la Asociación Médica de Puerto Rico 86, 28–36.

Regidor, E., Banegas, J.R., Gutiérrez-Fisac, J.L., Domínguez, V., Rodríguez-Artalejos, F., 2006. Influence of childhood socioeconomic circumstances, height, and obesity on pulse pressure and systolic and diastolic blood pressure in older people. J. Hum. Hypertens. 20, 73–82.

Rigau-Pérez, J.G., 2000. Historia de la medicina. La salud en Puerto Rico en el siglo XX. P. R. Health Sci. J. 19, 357–368.

Rodgers, W.L., 1982. Estimable functions of age, period, and cohort effects. Am. Sociol. Rev. 47, 774–787.

Shi, W.W., Kramer, M.S., Hoey, J., Hanley, J.A., Usher, R.H., 1993. Terminal digit preference, random error, and bias in routine clinical measurement of blood pressure. J. Clin. Epidemiol. 46, 1187–1193.

Sjøl, A., Korsgård, T., Schroll, M., 1998. Secular trends in blood pressure levels in Denmark 1964–1991. Int. J. Epidemiol. 27, 614–622.

Sobngwi, E., Mbanya, J.C., Unwin, N.C., Porcher, R., Kengne, A.P., Fezeu, L., Minkoulou, E.M., Tournoux, C., Gautier, J.F., Aspray, T.J., Alberti, K., 2004. Exposure over the life course to an urban environment and its relation with obesity, diabetes, and hypertension in rural and urban Cameroon. Int. J. Epidemiol. 33, 769–776.

Sorlie, P.D., García-Palmieri, M.R., 1990. Educational status and coronary heart disease in Puerto Rico: the Puerto Rico Heart Health Program. Int. J. Epidemiol. 19, 59–65.

Sorlie, P.D., García-Palmieri, M.R., Costas Jr., R., Cruz-Vidal, M., Havlik, R., 1982. Cigarette smoking and coronary heart disease in Puerto Rico. Prev. Med. 11, 304–316.

Stamler, J., Stamler, R., Riedlinger, W., Algera, G., Roberts, R.H., 1976. Hypertension screening of 1 million Americans: community hypertension evaluation clinic (CHEC) program, 1973 through 1975. J. Am. M. Assoc. 235, 2299–2306.

Steckel, R.A., Rose, J.C. (Eds.), 2002. The Backbone of History: Health and Nutrition in the Western Hemisphere. Cambridge University Press, New York.

Ulijaszek, S.J., Koziel, S., Hermanussen, M., 2005. Village distance from urban centre as the prime modernization variable in differences in blood pressure and body-mass index of adults of the Purani delta of the Gulf Province, Papua New Guinea. Ann. Hum. Biol. 32, 326–338.