Original Article

Recent blood pressure trends in adolescents from China, Korea, Seychelles and the United States of America, 1997–2012

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Objective: Although the prevalence of obesity is increasing worldwide, secular trends in elevated blood pressure (BP) differ across populations. We aimed to compare recent BP and obesity trends in adolescents aged 10–19 years in China, Korea, Seychelles and the United States of America.

Methods: Data in adolescents aged 10–19 years came from China (1997–2011, $n = 8025$), Korea (1998–2012, $n = 10\,119$), Seychelles (1998–2012, $n = 27\,569$) and the United States of America (1999–2012, $n = 14\,580$). Elevated BP was defined as SBP or DBP equal to or above the referent sex, age and height-specific 95th percentile of the US Fourth Report. Overweight and obesity were defined using criteria of the International Obesity Task Force.

Results: Between 1997–2000 and 2011–2012, the prevalence of elevated BP decreased in Korea and did not change substantially in China and in the United States of America. The prevalence of elevated BP increased in Seychelles. In 2011–2012, the prevalence of elevated BP was 1.7% in the United States of America, 3.8% in China, 3.7% in Korea and 14.3% in Seychelles. The prevalence of overweight and obesity increased over time and reached in 2011–2012 41.2% in the United States of America, 18.6% in China, 25.2% in Korea and 27.4% in Seychelles. Elevated BP was strongly associated with obesity in all countries.

Conclusion: Although the prevalence of obesity increased markedly in the four countries, secular BP trends in adolescents differed in countries of different regions.

Keywords: blood pressure, epidemiology, pediatrics, trends

Abbreviations: BP, blood pressure; CHNS, China Health and Nutrition Survey; CVD, cardiovascular disease; KNHANES, Korean National Health and Nutrition Examination Survey; NHANES, National Health and Nutrition Examination Survey; WHtR, waist-to-height ratio

INTRODUCTION

Elevated blood pressure (BP) in children and adolescents is positively associated with risk of target organ damage including carotid intima–media thickness and left ventricular hypertrophy [1]. Furthermore, elevated BP in childhood moderately tracks into adulthood [2] and increases cardiovascular disease (CVD) risk [3] as well as premature mortality in adulthood [4]. Trends in the level of BP during childhood and adolescence have therefore important public health and clinical implications [5].

Obesity, diet habits, physical activity and birth weight, which are importantly determined by national or local environments, are determinants of BP in children and adolescents [6]. Obesity in particular is strongly associated with elevated BP in childhood [7]. In recent years, overweight and obesity have increased markedly in all populations worldwide, including in Asian [8,9] and African [10] youths. In view of the strong association between obesity and elevated BP, it is useful to assess the combined trends in obesity and BP levels in children in different populations [7].

In adults, the Global Burden of Disease study reported different trends in BP between 1980 and 2008, with downward trends in several high-income countries and upward trends in a number of low-income and middle-income countries [11]. Mean BMI has increased in nearly all countries during the same time period [12]. In children and adolescents, previous epidemiologic studies have reported parallel upward secular increases in the prevalence of elevated BP and obesity in China [13,14] and United Kingdom [15]. However, downward BP trends have been

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reported in Japan [16], Korea [9], Iran [17], Northern Ireland [18] and Seychelles [10], despite increasing prevalence of obesity. BP trends in youths in China [14], Korea [9] and Seychelles [10] were last updated several years ago. An update of these trends in these countries is timely as the prevalence of obesity has continued to increase, contrasting with youths in the United States of America in which the increasing prevalence of obesity has recently leveled off [19,20].

Therefore, the aim of this study was to compare changes in prevalence of elevated BP and obesity in adolescents aged 10–19 years old among China, Korea, Seychelles and the United States of America using national data between 1997 and 2012.

METHODS

Study populations

Data came from several national cross-sectional surveys conducted in each of four countries, that is, China [China Health and Nutrition Survey (CHNS), 1997–2011] [21], Korea [Korean National Health and Nutrition Examination Survey (KNHANES), 1998–2012] [22], Seychelles (School-based National Surveillance Program, 1998–2012) [10] and the United States of America [National Health and Nutrition Examination Survey (NHANES), 1999–2012] [23]. Details of studies have been described elsewhere [10,21–23]. Based on available data, we considered the following time periods: '1997–2000', '2001–2002', '2003–2004', '2005–2006', '2007–2008', '2009–2010' and '2011–2012'. We limited our analyses to adolescents aged 10–19 years for which data were available for all countries.

Measurements included SBP, DBP, height, weight and waist circumference in the four countries. For China, Korea and the United States of America, SBP and DBP were measured using auscultatory mercury sphygmomanometers by trained examiners, following the standard protocol of the American Heart Association [21–23]. The onset of sound (Korotkoff phase I) was taken as SBP, and the disappearance of the sound (Korotkoff phase V) was measured as DBP. Up to three BP measurements were taken for each individual, and the mean of them was used in the analyses. Pulse pressure (PP) was calculated as mean SBP minus mean DBP. For Seychelles, BP was measured using an oscillometric automated device (Omron M5), which has been clinically validated [24]. Two readings were obtained and averaged. In all countries, BP was taken on the right arm with appropriate cuff sizes (pediatric, normal or large), and a study participant was asked to seat quietly for at least 5 min before measurement. BP measurement methods were kept identical over time.

Weight and height were recorded for each individual in light clothing without shoes. BMI was calculated as weight in kilograms divided by height in meters squared. For China, Korea and Seychelles, waist circumference was measured using a nonelastic tape at a point midway between the lowest rib margin and the iliac crest in a horizontal plane at the end of a normal expiration, as recommended by WHO [25]. For the United States of America, waist circumference was measured above the iliac crest [26]. Each survey received ethical approval from the appropriate institutional review boards and obtained informed consent from the study participants or parents/guardians.

Definitions of elevated blood pressure and obesity

Elevated BP was defined as SBP or DBP equal to or above the referent sex-specific, age-specific and height-specific 95th percentile according to the Fourth Report of the US National High Blood Pressure Education Program Working Group [27]. Overweight and obesity were defined according to the criteria of the International Obesity Task Force [28]. Central obesity was defined as a waist-to-height ratio (WHtR) equal to or above 0.5 [29], as there is no globally accepted sex and age-specific waist circumference percentile references for defining central obesity in children and adolescents.

Statistical analysis

All data analyses were performed using SAS 9.2 (SAS Institute, Cary, North Carolina, USA). For NHANES and KNHANES data, sampling weights were taken into account to account for complex survey design (primary sampling units and strata) at the country level. Time trends in mean height, weight, BMI, waist circumference, WHtR, SBP, and DBP levels across seven time periods (1997–2000 to 2011–2012) were examined using linear regression with adjustment for age and sex (and race for NHANES data) and height (for trends in SBP, DBP and PP). Time trends in prevalence of elevated BP, overweight and central obesity during the same period were tested using multiple logistical analyses with adjustment for age and sex (and race for NHANES data). To enable direct comparison for mean SBP, DBP and PP and for the prevalence of elevated BP, overweight and central obesity between the four countries, these variables were sex and age-standardized to the composition of the total population combined from the four countries. Subgroup analyses by BMI or WHtR categories were performed with adjustment for age and sex (and race for NHANES data). Such analyses allow assessing whether BP trends are independent of body weight trends. A two-sided value of P less than 0.05 was considered to be statistically significant.

RESULTS

Characteristics of the study populations

Complete data on sex, age, weight, height, SBP and DBP were available in 8025 adolescents (4269 boys and 3756 girls) from six survey cycles from China (1997–2011); 10 119 (5254 boys and 4865 girls) in Korea from six survey cycles (1998–2012); 27 569 (13 639 boys and 13 930 girls) in Seychelles from school based surveys every year between 1998 and 2006, and between 2011 and 2012; and 14 580 (7463 boys and 7117 girls) in the United States of America from seven survey cycles between 1999–2000 and 2011–2012 (Table 1). The mean BMI and waist circumference increased in all countries except for waist circumference (kept stable) and WHtR (slightly decrease) in Korea during the study period (Table 1).

TABLE 1. Characteristics of adolescents aged 10–19 years in four countries (China, Korea, Seychelles and the United States of America) from 1997–2000 to 2011–2012

	Variables	1997–2000	2001–2002	2003–2004	2005–2006	2007–2008	2009–2010	2011–2012	*P* for linear trends[a]
China	*n*	1905	2036	1221	963	–	840	1060	
	Sex (males, %)	52.5	53.7	53.8	53.1	–	55.0	51.4	0.859
	Age (%)								
	10–14 year	60.2	64.9	53.2	55.5	–	65.5	64.5	0.077
	15–19 year	39.8	35.1	46.8	44.5	–	34.5	35.5	
	Height (cm)	151.2 (0.2)	153.0 (0.2)	154.8 (0.3)	154.6 (0.3)	–	155.2 (0.3)	156.8 (0.3)	<0.001
	Weight (cm)	42.8 (0.2)	44.0 (0.2)	45.4 (0.2)	45.3 (0.3)	–	46.2 (0.3)	48.5 (0.3)	<0.001
	BMI (kg/m^2)	18.4 (0.1)	18.5 (0.1)	18.7 (0.1)	18.6 (0.1)	–	18.9 (0.1)	19.4 (0.1)	<0.001
	WC (cm)	64.8 (0.2)	65.4 (0.2)	66.4 (0.2)	66.2 (0.3)	–	67.2 (0.3)	69.2 (0.2)	<0.001
	WHtR	0.429 (0.001)	0.428 (0.001)	0.429 (0.001)	0.428 (0.002)	–	0.433 (0.002)	0.441 (0.001)	<0.001
Korea	*n*	1789	1302	–	993	1790	2433	1812	
	Sex (males, %)	51.8 (1.2)	52.1 (1.5)	–	52.4 (1.6)	53.1 (1.2)	52.7 (1.2)	52.8 (1.4)	0.470
	Age (%)								
	10–14 year	44.4 (1.4)	47.0 (1.7)	–	62.6 (2.0)	50.9 (1.4)	48.8 (1.3)	46.8 (1.5)	0.092
	15–19 year	55.6 (1.4)	53.0 (1.7)	–	37.4 (2.0)	49.1 (1.4)	51.2 (1.3)	53.2 (1.5)	
	Height (cm)	160.8 (0.4)	161.1 (0.4)	–	159.4 (0.4)	160.5 (0.3)	161.6 (0.3)	161.8 (0.3)	<0.001
	Weight (cm)	52.8 (0.4)	54.6 (0.5)	–	53.4 (0.5)	53.9 (0.4)	54.7 (0.4)	54.9 (0.4)	<0.001
	BMI (kg/m^2)	20.2 (0.1)	20.8 (0.1)	–	20.7 (0.1)	20.6 (0.1)	20.7 (0.1)	20.7 (0.1)	<0.001
	WC (cm)	69.5 (0.3)	71.2 (0.3)	–	69.6 (0.4)	70.2 (0.3)	69.6 (0.3)	69.6 (0.3)	0.126
	WHtR	0.433 (0.002)	0.442 (0.002)	–	0.436 (0.002)	0.437 (0.002)	0.431 (0.001)	0.430 (0.001)	0.002
Seychelles	*n*	6165	5677	5057	5955	–	–	4715	
	Sex (males, %)	49.7	49.4	48.9	50.2	–	–	49.0	0.708
	Age (%)								
	10–14 year	49.5	56.2	52.0	64.8	–	–	69.0	<0.001
	15–18 year	50.5	43.8	48.0	35.2	–	–	31.0	
	Height (cm)	157.2 (0.1)	158.1 (0.1)	158.7 (0.1)	159.1 (0.1)	–	–	160.0 (0.1)	<0.001
	Weight (cm)	48.4 (0.2)	49.4 (0.2)	50.2 (0.2)	50.7 (0.2)	–	–	52.5 (0.2)	<0.001
	BMI (kg/m^2)	19.3 (0.1)	19.6 (0.1)	19.7 (0.1)	19.9 (0.1)	–	–	20.4 (0.1)	<0.001
	WC (cm)	68.1 (0.1)	67.9 (0.2)	–	–	–	–	73.1 (0.2)	<0.001
	WHtR	0.433 (0.001)	0.430 (0.001)	–	–	–	–	0.458 (0.001)	<0.001
United States of America	*n*	2528	2583	2387	2404	1498	1632	1548	
	Sex (males, %)	51.0 (0.9)	52.2 (1.2)	51.0 (1.3)	52.4 (1.4)	52.4 (1.6)	50.9 (1.6)	49.6 (2.0)	0.491
	Age (%)								
	10–14 year	51.4 (1.0)	52.8 (1.6)	52.2 (2.0)	50.5 (2.0)	49.2 (1.8)	51.2 (1.7)	51.0 (1.7)	0.341
	15–19 year	48.6 (1.0)	47.2 (1.6)	47.8 (2.0)	49.5 (2.0)	50.8 (1.8)	48.8 (1.7)	49.0 (1.7)	
	Height (cm)	161.7 (0.3)	162.2 (0.2)	162.2 (0.3)	161.9 (0.3)	162.1 (0.4)	162.7 (0.3)	162.4 (0.3)	0.062
	Weight (cm)	59.6 (0.4)	60.0 (0.5)	61.2 (0.6)	60.4 (0.6)	60.9 (0.7)	62.1 (0.7)	61.8 (0.7)	0.001
	BMI (kg/m^2)	22.4 (0.2)	22.4 (0.2)	22.9 (0.2)	22.6 (0.2)	22.8 (0.2)	23.0 (0.2)	23.1 (0.3)	0.005
	WC (cm)	77.9 (0.5)	78.4 (0.5)	79.6 (0.7)	79.1 (0.5)	78.9 (0.6)	79.6 (0.5)	80.0 (0.7)	0.008
	WHtR	0.481 (0.003)	0.483 (0.003)	0.491 (0.004)	0.489 (0.003)	0.487 (0.004)	0.489 (0.002)	0.492 (0.004)	0.026
	Race (%)								
	Mexican American	10.3 (2.2)	10.8 (1.4)	11.5 (2.6)	11.6 (1.3)	12.2 (2.3)	14.4 (2.8)	14.0 (2.4)	0.928
	Other Hispanic	8.1 (2.3)	7.1 (2.2)	4.7 (1.1)	4.1 (0.8)	6.6 (2.0)	5.8 (1.4)	7.7 (1.7)	
	White	57.9 (2.9)	61.8 (2.8)	63.8 (4.5)	62.6 (3.6)	61.4 (3.6)	57.9 (3.6)	54.9 (4.2)	
	Black	14.2 (2.6)	13.9 (2.2)	14.8 (2.4)	14.4 (2.7)	14.6 (2.1)	14.3 (1.2)	15.3 (3.3)	
	Others	9.5 (2.4)	6.4 (0.8)	5.2 (1.1)	7.3 (1.6)	5.2 (1.2)	7.5 (1.1)	8.1 (1.1)	

Continuous variables are expressed as mean (SE); category variables are expressed as percentage (SE). –, Indicates the data are not available. SE, standard error; WC, waist circumference; WHtR, waist-to-height ratio.
[a]Adjusted for sex and age (additionally adjusted for race for the United States of America).

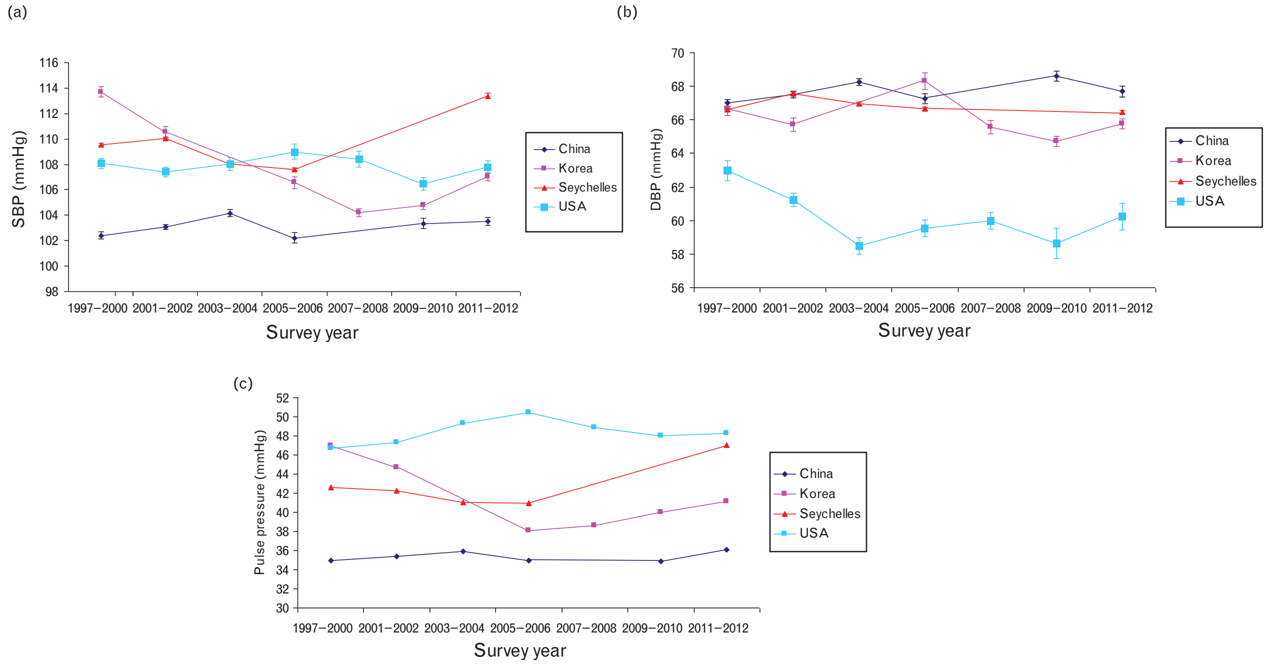

FIGURE 1 Trends in (a) SBP, (b) DBP and (c) PP in adolescents aged 10–19 years among China, Korea, Seychelles and the United States of America from 1997–2000 to 2011–2012. Data are expressed as mean (standard error) and were sex and age-standardized to the composition of the total population combined from the four countries.

Trends in mean blood pressure and pulse pressure values from 1997–2000 to 2011–2012

Mean SBP values increased over time in the total population, and in subgroups by sex and age in China and Seychelles except in girls and in 15–19 years old adolescents in China. Mean SBP values decreased over time in all groups in Korea. There was no change in mean SBP in all groups in the United States of America, expected for a slight decrease in 10–14 years old adolescents (Supplemental Table 1, http://links.lww.com/HJH/A653).

Mean DBP increased over time in the total population, in boys and in younger adolescents in China. Mean DBP decreased in most groups in Korea and in Seychelles, and in all groups in the United States of America (Supplemental Table 1, http://links.lww.com/HJH/A653).

Mean PP did not increase over time in most categories of Chinese participants, but a slight increase was noted in girls and younger adolescents. Mean PP decreased over time in Korea but increased in Seychelles and the United States of America (Supplemental Table 1, http://links.lww.com/HJH/A653).

In 1997–2000, Korean adolescents had the highest mean SBP value (113.7 mmHg), followed by Seychelles (109.6 mmHg), the United States of America (108.1 mmHg) and China (102.4 mmHg) (Fig. 1a). In 2011–2012, adolescents in Seychelles had the highest mean SBP value (113.4 mmHg) compared with other countries (the United States of America: 107.8 mmHg, Korea: 107.0 mmHg, China: 103.5 mmHg) (Fig. 1a). Adolescents in China, Korea and Seychelles had similar mean DBP values in 1997–2000 and 2011–2012, respectively, whereas adolescents in the United States of America had the lowest DBP values compared with the other countries (Fig. 1b). In 1997–2000, PP values were highest in adolescents in the United States of America and Korea (~47 mmHg in both countries), followed by Seychelles (~42 mmHg) and China (~35 mmHg). In 2011–2012, PP values were highest in adolescents in the United States of America and Seychelles (~48 mmHg), followed by Korea (~41 mmHg) and China (~36 mmHg) (Fig. 1c).

Supplemental Fig. 1, http://links.lww.com/HJH/A653 presents the trends in mean PP in adolescents aged 10–19 years in four countries between 1997–2000 and 2011–2012, according to BMI categories. In China, mean PP did not change over time in normal weight adolescents but increased in overweight study participants. In Korea, mean PP decreased in both normal weight and overweight adolescents although a slightly increase since 2005–2006. In Seychelles, mean PP increased in both groups of adolescents. In the United States of America, mean PP increased between 1999–2000 and 2005–2006 in both groups of adolescents but did not change since 2007–2008. In all four countries, mean PP was much higher in overweight than normal weight adolescents in nearly all survey years.

Trends in prevalence of elevated blood pressure from 1997–2000 to 2011–2012

In China, there was no apparent change in the prevalence of elevated BP over time in boys but a decrease in girls. In Korea, the prevalence of elevated BP decreased dramatically over time in all groups. In Seychelles, the prevalence of elevated BP decreased during the period 1998–2006 and increased thereafter in 2011–2012. In the United States of America, a slight decrease (but not reach statistical significance) in the prevalence of elevated BP was observed in all groups (Table 2).

In 1997–2000, Korean adolescents had the highest prevalence of elevated BP (12.6%), followed by Seychelles

TABLE 2. Trends in prevalence of elevated blood pressure among adolescents aged 10–19 years in four countries (China, Korea, Seychelles and the United States of America) from 1997–2000 to 2011–2012

	Variables	1997–2000	2001–2002	2003–2004	2005–2006	2007–2008	2009–2010	2011–2012	Δ	*P* for linear trends[a]
China	All	4.9 (0.5)	5.0 (0.5)	4.3 (0.6)	3.3 (0.6)	–	5.1 (0.8)	3.9 (0.6)	−1.0	0.211
	Sex									
	Males	3.9 (0.6)	5.2 (0.7)	4.6 (0.8)	4.5 (0.9)	–	4.5 (1.0)	5.0 (0.9)	1.1	0.590
	Females	6.0 (0.8)	4.8 (0.7)	4.1 (0.8)	2.0 (0.7)	–	5.8 (1.2)	2.7 (0.7)	−3.3	0.019
	Age									
	10–14 year	4.2 (0.6)	5.7 (0.6)	3.8 (0.8)	2.6 (0.7)	–	5.8 (1.0)	4.2 (0.8)	0.1	0.888
	15–19 year	5.9 (0.9)	3.8 (0.7)	4.9 (0.9)	4.2 (1.0)	–	3.8 (1.1)	3.2 (0.9)	−2.7	0.063
Korea	All	12.2 (0.9)	7.5 (0.9)	–	5.8 (0.9)	3.3 (0.4)	2.7 (0.3)	3.7 (0.5)	−8.5	<0.001
	Sex									
	Males	12.6 (1.1)	9.6 (1.4)	–	6.9 (1.4)	4.2 (0.7)	3.1 (0.5)	4.2 (0.8)	−8.4	<0.001
	Females	11.6 (1.3)	5.3 (1.0)	–	4.5 (0.9)	2.4 (0.5)	2.1 (0.4)	3.1 (0.6)	−8.5	<0.001
	Age									
	10–14 year	14.1 (1.4)	7.8 (1.0)	–	5.6 (1.1)	3.2 (0.5)	2.7 (0.4)	3.5 (0.5)	−10.6	<0.001
	15–19 year	10.6 (1.1)	7.3 (1.4)	–	6.0 (1.5)	3.5 (0.7)	2.6 (0.5)	4.0 (0.8)	−6.6	<0.001
Seychelles	All	8.7 (0.4)	9.4 (0.4)	7.7 (0.4)	6.7 (0.3)	–	–	14.5 (0.5)	5.8	<0.001
	Sex									
	Males	8.7 (0.5)	9.5 (0.6)	7.7 (0.5)	6.6 (0.5)	–	–	16.0 (0.8)	7.3	<0.001
	Females	8.7 (0.5)	9.4 (0.5)	7.6 (0.5)	6.8 (0.5)	–	–	13.1 (0.7)	4.4	<0.001
	Age									
	10–14 year	7.1 (0.5)	6.9 (0.4)	6.0 (0.5)	6.7 (0.4)	–	–	15.1 (0.6)	8.0	<0.001
	15–18 year	10.2 (0.5)	12.7 (0.7)	9.5 (0.6)	6.6 (0.5)	–	–	13.2 (0.9)	2.9	<0.001
United States of America	All	2.9 (0.6)	2.4 (0.5)	2.2 (0.6)	3.2 (0.6)	2.3 (0.4)	1.6 (0.2)	1.7 (0.4)	−1.2	0.058
	Sex									
	Males	3.7 (0.7)	2.7 (0.7)	2.3 (0.7)	2.5 (0.5)	3.0 (0.6)	1.7 (0.4)	2.2 (0.9)	−1.5	0.174
	Females	2.1 (0.8)	2.1 (0.5)	2.1 (0.8)	3.8 (1.0)	1.6 (0.6)	1.5 (0.2)	1.3 (0.3)	−0.8	0.130
	Age									
	10–14 year	3.2 (0.9)	2.8 (0.7)	2.8 (0.9)	3.6 (1.1)	2.9 (0.6)	1.6 (0.3)	1.3 (0.5)	−1.9	0.017
	15–19 year	2.6 (0.6)	1.9 (0.5)	1.5 (0.5)	2.7 (0.6)	1.8 (0.7)	1.7 (0.5)	2.2 (1.0)	−0.4	0.771

Data are expressed as percentage (SE) and are crude results without age and sex-standardization. –, Indicates the data are not available; Δ, indicates value in 2011–2012 minus that in 1997–2000. SE, standard error.
[a]Adjusted for sex and age (additionally adjusted for race for the United States of America).

(8.5%), China (5.0%) and the United States of America (2.9%). In 2011–2012, adolescents in Seychelles had the highest prevalence of elevated BP (14.3%), followed by China (3.8%), Korea (3.7%) and the United States of America (1.7%) (Fig. 2a).

Trends in prevalence of overweight (including obesity) and central obesity from 1997–2000 to 2011–2012

The prevalence of overweight increased greatly over time in all four countries while the prevalence leveled off in Korea in recent years. The prevalence of central obesity increased in China and Seychelles, but it was stable over time in Korea and the United States of America (Table 3).

In 1997–2000, US adolescents had the highest prevalence of overweight (35.3%) and central obesity (30.9%), followed by Korea (18.3 and 10.9%), Seychelles (16.5 and 10.7%) and China (5.6 and 5.6%) (Fig. 2b and c). In 2011–2012, US adolescents still had the highest prevalence of overweight (41.2%) and central obesity (37.0%) compared with the other three countries (Seychelles: 27.4 and 21.6%; Korea: 25.2 and 11.2%; China: 18.6 and 16.6%) (Fig. 2b and c).

Trends in prevalence of elevated blood pressure by BMI or waist-to-height ratio categories from 1997–2000 to 2011–2012

Figure 3 shows the secular trends in the prevalence of elevated BP by BMI or WHtR categories. Adolescents with overweight or central obesity had much higher prevalence of elevated BP than those with normal BMI or normal waist circumference in each country. In China, the prevalence of elevated BP in adolescents with normal BMI, normal WHtR or central obesity group remained stable over time, whereas it decreased in overweight adolescents. In Korea, the prevalence of elevated BP decreased in all groups over time. In Seychelles, the prevalence of elevated BP increased between 1998–2000 and 2011–2012 in all groups, although the prevalence slightly decreased between 1998–2000 and 2005–2006. In the United States of America, the prevalence of elevated BP decreased over time in overweight and central obesity groups although the prevalence remained stable in youths with normal BMI or normal WHtR.

DISCUSSION

To our knowledge, this is the first study that compared trends in the prevalence of elevated BP, general obesity and central obesity among adolescents using national data from several middle income countries (China and Seychelles) and high-income countries (Korea and the United States of America). We found that between 1997–2000 and 2011–2012, the prevalence of elevated BP was stable in adolescents in China and the United States of America, whereas it decreased in Korean adolescents and increased in Seychelles adolescents. In addition, we observed a large increase in the prevalence of overweight and obesity in

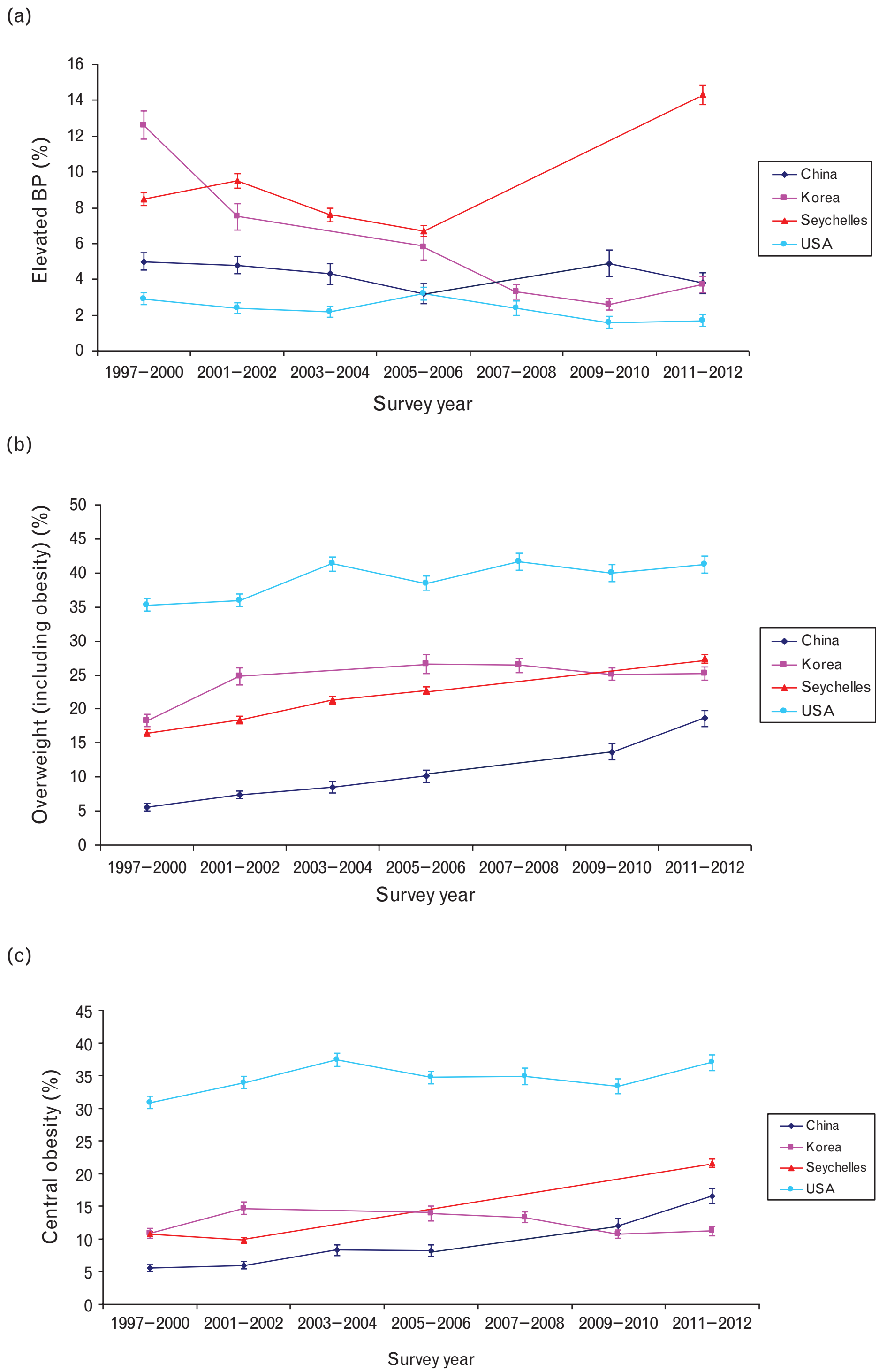

FIGURE 2 Trends in prevalence of (a) elevated blood pressure, (b) overweight (including obesity) and (c) central obesity in adolescents aged 10–19 years among China, Korea, Seychelles and the United States of America from 1997–2000 to 2011–2012. Data are expressed as percentage (standard error) and are standardized by sex and age to the composition of the total population combined from the four countries.

the four countries (although with a leveling off in Korea in recent years) and in central obesity in China and Seychelles.

Consistent with a previous publication using KNHANES data from 1998 to 2008 [9], our updated results (KNHANES 2008–2012) show that the prevalence of elevated BP continued to decrease over time in Korea in recent years, despite continued high prevalence of obesity in the interval. However, although there was a slight decrease in the prevalence of elevated BP in Seychelles from 1998–2000 (8.7%) to 2005–2006 (6.7%), the prevalence substantially increased and reached to 14.5% in 2011–2012. The continued secular increase in obesity since 1998 in Seychelles

TABLE 3. Trends in general and central obesity among adolescents aged 10–19 years in four countries (China, Korea, Seychelles and the United States of America) from 1997–2000 to 2011–2012

	Variables	1997–2000	2001–2002	2003–2004	2005–2006	2007–2008	2009–2010	2011–2012	Δ	*P* for linear trends[a]
China	BMI categories									
	Overweight	4.0 (0.5)	5.4 (0.5)	6.3 (0.7)	7.3 (0.8)	–	10.5 (1.1)	11.7 (1.0)	7.7	<0.001
	Obesity	0.4 (0.1)	0.8 (0.2)	0.6 (0.2)	0.7 (0.3)	–	1.2 (0.4)	3.9 (0.6)	3.4	<0.001
	WHtR categories									
	Central obesity	5.6 (0.5)	6.0 (0.5)	8.4 (0.8)	8.3 (0.9)	–	12.0 (1.1)	16.4 (1.1)	10.8	<0.001
Korea	BMI categories									
	Overweight	13.9 (1.0)	16.7 (1.1)	–	20.4 (1.5)	19.8 (1.2)	18.1 (0.8)	19.0 (1.0)	5.1	0.001
	Obesity	2.2 (0.3)	5.3 (0.7)	–	5.5 (1.0)	4.2 (0.5)	4.5 (0.5)	3.7 (0.5)	1.5	0.054
	WHtR categories									
	Central obesity	11.0 (1.0)	14.6 (1.2)	–	14.3 (1.2)	13.3 (0.9)	10.5 (0.7)	11.4 (0.9)	0.4	0.226
Seychelles	BMI categories									
	Overweight	9.9 (0.4)	11.1 (0.4)	12.4 (0.5)	13.4 (0.4)	–	–	13.1 (0.5)	3.2	<0.001
	Obesity	3.8 (0.2)	4.5 (0.3)	5.3 (0.3)	5.8 (0.3)	–	–	9.6 (0.4)	5.8	<0.001
	WHtR categories									
	Central obesity	10.8 (0.4)	9.9 (0.6)	–	–	–	–	21.9 (0.6)	11.1	<0.001
United States of America	BMI categories									
	Overweight	20.4 (1.5)	19.6 (0.8)	22.9 (1.3)	20.3 (1.1)	23.1 (1.1)	22.5 (1.4)	21.9 (1.3)	1.5	0.049
	Obesity	13.1 (1.1)	13.9 (1.1)	16.5 (1.4)	15.6 (1.6)	15.8 (1.5)	15.7 (0.9)	16.9 (1.8)	3.8	0.032
	WHtR categories									
	Central obesity	31.1 (1.6)	33.8 (1.7)	37.4 (2.5)	34.8 (1.2)	34.8 (1.6)	33.6 (1.2)	37.3 (1.6)	6.2	0.138

Data are expressed as percentage (SE) and are crude results without age and sex-standardization. –, Indicates the data are not available; Δ, indicates value in 2011–2012 minus that in 1997–2000. SE, standard error; WHtR, waist-to-height ratio.
[a]Adjusted for sex and age (additionally adjusted for race for the United States of America).

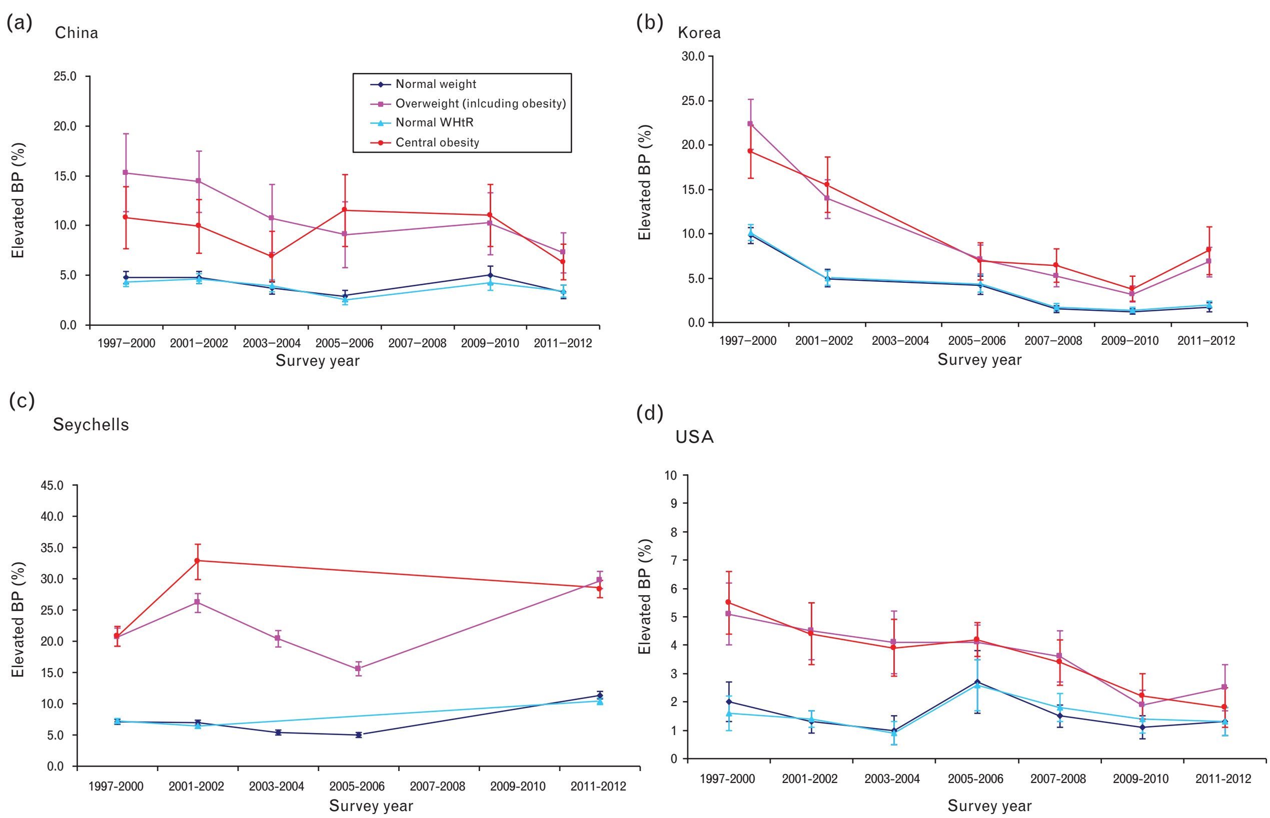

FIGURE 3 Trends in prevalence of elevated blood pressure in adolescents aged 10–19 years among (a) China, (b) Korea, (c) Seychelles and (d) the United States of America by BMI and waist-to-height ratio categories from 1997–2000 to 2011–2012. Data are expressed as percentage and standard error. *P* values for linear trends are statistically significant in all groups ($P < 0.05$) except for in normal weight and normal WHtR groups of China and the United States of America, and in central obesity group of China.

may partly explain the important increase in the prevalence of elevated BP from 2005–2006 to 2011–2012. Actually, a previous study in the United States of America showed that the BP rise lagged about 10 years behind the increase in obesity [30]. Such a lag time effect could partly explain upward trends in the prevalence of elevated BP in recent years in the Seychelles. More generally, our results may suggest that downward BP trends, when paralleling upward trends in the prevalence of obesity might still reverse in the future. As mentioned above, however, DBP seemed to decrease in all countries in this study, and further studies should examine the significance of these trends, which occurred along trends in SBP that were increasing in some countries and deceasing in others. In addition, a recent study by Kit *et al.* [31] reported that either high or borderline high BP remained stable in children aged 8–17 years between 1999–2000 and 2011–2012, 2012 in the United State of America, which was consistent with our findings although the age range were different between two studies. In addition, the study by Kit *et al.* [31] did not address whether or not BP trends were in parallel with obesity trends but we did.

Obesity is one of the main established risk factors for essential hypertension. In the present study, we also found that elevated BP was much more frequent among adolescents with overweight or central obesity than in adolescents with normal weight or no central obesity, underlining the importance of overweight as a main risk factor of hypertension in children and adolescents, and the need for effective weight control interventions starting in youths. Similar decreasing trends in CVD risk factors in overweight and obese US adults have also been reported in previous studies [32]. Studies in youths are informative as nearly no children are taking BP lowering treatment and therefore an increasing uptakes of BP lowering treatment over time (as observed in adults in many countries) cannot be a potential explanation for downward BP trends in these young populations. Identifying preventive factors that may offset or compensate for the effect of obesity on elevated BP is a research priority as this may underlie new strategies to reduce BP in populations. Significantly, recent studies suggest that daily intakes of total energy, carbohydrates, total saturated fatty acids (FAs), caffeine and sweets, as well as time of television viewing, have decreased in US children and adolescents during the past decade, whereas daily intake of total polyunsaturated FAs, dietary fiber, fruit and vegetables and physical activity increased [33,34]. Similar trends in some of these factors may have occurred in the countries in our study and could partly explain the favorable downward trends in elevated BP in some of them despite the upward trends of obesity over time.

In the present study, we used the US Fourth Report criteria to define elevated BP in all four countries. Trends in prevalence of elevated BP seemed stable in each group in Chinese adolescents except a decrease in girls. However, when Chinese sex and age-specific BP references [35] were used in the same population (Supplemental Table 3, http://links.lww.com/HJH/A653), we found a significant increase in the prevalence of elevated BP over time, with the prevalence of 10.5% in 1997 and 13.5% in 2011, which is consistent with our previous findings in Chinese children aged 6–17 years between 1991 and 2009 [8,14]. Our findings raise the issue of whether the US Fourth Report criteria are suitable for Chinese children, or for children in other countries. Recent data from CHNS indicate that the Chinese BP reference values for SBP are 9–10 mmHg lower than those reported in the Fourth Report [36]. It may follow that the cutoff values of the Fourth Report are too high to be used in some other countries, possibly because of some limitations of US BP references, such as inclusion of overweight children, and use of the first reading only.

In 2011–2012, Korean and Chinese children had similar higher prevalence of elevated BP (about 3.8%) than US adolescents (1.7%), but the prevalence of overweight and central obesity prevalence was much lower than in the United States of America. The reason for this paradox is unclear and a comparison between countries of factors that can potentially influence BP (dietary, physical activity, etc.) would be useful to highlight possible explanations, including ethnic or genetic differences [37]. However, recent studies suggest that Asian populations have a higher CVD risk at a given BMI compared with Western populations [38]. Thus, WHO recommends using lower BMI cutoffs to define overweight and obesity in Asian population [39]. This evidence may partly explain our findings of a discrepancy between lower prevalence of obesity but higher prevalence of elevated BP in adolescents in China and Korea compared with the United States of America.

PP has been considered as a marker of CVD risk, especially in elderly people [40,41]. However, recent studies did not show the superiority of PP over SBP or DBP in predicting long-term risk of CVD mortality [42–44]. In the present study, PP was highest in the US and Korean adolescents as compared with adolescents in China and Seychelles in 1997–2000. In 2011–2012, PP was highest in the United States of America and Seychelles as compared with Korea and China. Further studies are necessary to both assess the predictive value of PP childhood and assess differences in diverse populations.

Male adolescents generally had higher mean BP and higher prevalence of elevated BP than female adolescents in all four countries, consistent with findings in other studies [27,45,46]. However, the trends in mean BP and PP and in the prevalence of elevated BP over time were similar in both sexes in Korea, Seychelles or the United States of America. In contrast, mean SBP and DBP increased over time in boys but did not increase in girls in China. Overall, the prevalence of elevated BP did not increase over time in boys but decreased in girls, based on the Fourth Report criteria for elevated BP. In contrast, the prevalence of elevated BP significantly increased over time in boys but did not change in girls based on the Chinese references for elevated BP. These contrasting secular trends in elevated BP using two different methods to assess elevated BP in children and adolescents raise the issue of validity of the underlying references and stress the need to further assess why trends differ in different populations based on different methods.

Our study has several strengths. First, we used recent national data with large sample sizes from China, Korea, Seychelles and the United States of America. Second, data from all four countries shared similar characteristics: same age ranges, same calendar years and same cutoffs used to define elevated BP, general obesity and central obesity, which makes the results directly comparable between countries. Third, all studies used standardized protocols for BP, height, weight and waist circumference measurements. However, several limitations should also be noted. First, other factors associated with BP were not available in our data, including nutrition factors (e.g. intakes of sodium, potassium and other food items), physical activity, environment and birth weight. It would be useful that further studies include these covariates at the individual level to help analyze the paradox of upward trends in obesity and downward trends in BP seen in some populations [7]. Second, hypertension in adolescents should be defined on the basis of measurements taken on at least three different occasions. However, although this may overestimate the true prevalence of hypertension in all four countries in our study, this is unlikely to result in a bias when considering differences in prevalence between countries. Third, BP was measured with a mercury sphygmomanometer in China, Korea and the United States of America but with a validated oscillometric device in Seychelles, which makes limits the comparison of absolute BP levels between Seychelles and the other three countries. However, a validation study shows only a small difference in mean BP between the oscillometric device used in Seychelles compared with a mercury sphygmomanometer (−0.9/−0.8 mmHg; SD 5.8/4.8 mmHg) [24]. Of note, the use of different devices does not bias the comparison of secular trends since a same type of device was used in each country over time.

In conclusion, our study shows that the prevalence of elevated BP in adolescents aged 10–19 years seemed to level off in China and the United States of America and decrease in Korea, despite upward obesity trends in the interval. In Seychelles although BP seemed to slightly decrease between 1998 and 2006, a marked increase was observed in recent years. An association between obesity and BP was observed in all countries, as expected, and this underlies the need to strengthen interventions to reduce overweight in youths in all countries. Further studies should aim at identifying factors associated with downward trends in BP in some countries, despite upward trends in obesity: this might uncover important new areas for prevention of high BP in populations.

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Authorship statement: Each author takes responsibility for all aspects of the reliability and freedom from bias of the data presented and their discussed interpretation.

Author contributions: B.X., P.B. and Y.M.H conceptualized and designed the study, drafted the initial manuscript and approved the final manuscript as submitted. X.Z. and T.Z. carried out the initial analyses, reviewed and revised the manuscript, and approved the final manuscript as submitted. A.C., H.S.K. and M.Z. coordinated and supervised data collation, critically reviewed the manuscript and approved the final manuscript as submitted.

Conflicts of interest

There are no conflicts of interest.

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Reviewers’ Summary Evaluations

Reviewer 1

This manuscript examines secular trends in blood pressure and body mass index in four nationally representative contemporary cohorts from four different countries (each examined from 1997-1999 to 2011-2012). While the prevalence of obesity increased markedly in all countries, blood pressure trends differed by country. The study findings are partly in agreement with the hypothesis of a time lag of a few years between the trend in body mass index and subsequent BP trend. Although a same type of device was used in each country, one limitation of the study is that oscillometric devices were used in Seychelles and mercury devices in the other countries, thus limiting the between-country comparison of absolute blood pressure levels.

Reviewer 2

Strengths

This is a straightforward study. The major strength relates to the large number of subjects studied.

Analysis of data from adolescents is a strength

Weaknesses

1. Blood pressures were measured using different techniques between Seychelles and the other countries. Since only Seychelles demonstrated an increased prevalence in increased blood pressure in the four countries, one cannot

dismiss the possibility that differences in measurement techniques contributed to variability in prevalence.

2. Since there were differences in diastolic blood pressure trends between groups, it would be important to present data as the pulse pressure, especially since cardiovascular risk may relate to increased pulse pressure.

3. What was the association between body weight and pulse pressure?

4. There is no discussion relating to gender effects. Please provide more details about the trends in males and females.