



# Fifty-year Time Trends in Blood Pressures, Body Mass Index and their Relations in a Japanese Community:

## The Circulatory Risk in Communities Study (CIRCS)

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**Aim:** Data for long-term trends in blood pressures, body mass index (BMI), and their relations are needed to set future intervention priorities for prevention of cardiovascular disease. The objective of this study was to investigate these trends revealed by repeated cross-sectional surveys conducted from 1963 to 2013 in a Japanese community.

**Methods:** Men and women aged 40–79 years who participated in annual cardiovascular checkups were enrolled, and the number of participants ranged between 1,776 and 2,366 with consistently high participation rates for both sexes aged 60–69 years. Sex- and age-specific mean systolic and diastolic blood pressures were calculated using mixed effects modeling for repeated measurement, and the prevalence of hypertension with and without obesity ( $BMI \geq 25 \text{ kg/m}^2$ ) were also calculated.

**Results:** Sex- and age-specific mean systolic and diastolic blood pressures declined irrespective of anti-hypertensive medication use in both men and women from 1963–1966 to 2009–2013, while mean BMI increased among men of all ages and women of ages 60–69 and 70–79 years. For both sexes aged 60–69 years, the prevalence of hypertension with obesity increased, but the prevalence of hypertension without obesity was still higher than that with obesity.

**Conclusions:** Despite the transition to increased BMI levels, targeting non to obese hypertension remains important in addition to targeting obese hypertension for cardiovascular disease prevention.

**Key words:** Blood pressure, Body mass index, Hypertension, Obesity, Long-term trends

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### Introduction

The overall worldwide prevalence of hyperten-

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sion in individuals aged  $\geq 25$  years was approximately 40% in 2008<sup>1</sup>). The number of hypertensive people in the growing and aging global population rose from 600 million in 1980 to nearly 1 billion in 2008<sup>2</sup>). Since elevated blood pressure, a major risk factor for stroke and coronary heart disease, is highly prevalent<sup>3-5</sup>), the population attributable fraction (PAF) of hypertension for cardiovascular disease is as high as 60% in Asian countries<sup>6</sup>). Similarly, body mass index

(BMI) levels have increased worldwide<sup>7</sup>. In 2008, the prevalence of obesity (BMI  $\geq 25$  kg/m<sup>2</sup>) was 34% for men and 35% for women aged  $>20$  years in the world<sup>7</sup>. Overweight or obesity is a major risk factor for hypertension and coronary heart disease<sup>8, 9</sup>. Increased BMI leads to increased cardiac output and peripheral vascular resistance, insulin resistance, substances released from adipocytes, increased sympathetic nervous system response, and obstructive type of sleep apnea<sup>10-14</sup>.

Worldwide, the increasing trend in BMI may have had an impact on trends in blood pressure levels and on the prevalence of hypertension. However, in Japan, where the prevalence of obesity has been low<sup>7</sup>, the impact has not been well elucidated. Data on long-term trends in blood pressures, BMI, and their relations are useful to build future intervention priorities for the prevention of cardiovascular disease in Japan and other countries where the prevalence of obesity is low.

### Aim

The objectives of this study were to investigate the longer-term trends for blood pressure, BMI, and their relations revealed by repeated cross-sectional surveys conducted from 1963 to 2013 in a Japanese community.

### Methods

#### Study Population

The Circulatory Risk in Community Study (CIRCS) is an ongoing dynamic cohort study that was started in Ikawa in 1963. Ikawa is a rural community of Akita prefecture, 550 km northeast of Tokyo. It covers an area of 48 km<sup>2</sup>, and its total census population was 7,030 in 1965 and 5,493 in 2010.

Non-institutionalized residents aged  $>40$  years in Ikawa were invited to undergo annual cardiovascular surveys and follow-up surveillance for the development of cardiovascular disease and stroke events. Details of the study methods have been previously reported<sup>15-17</sup>. Participation rates for the annual checkups are displayed in **Table 1**. Participants aged 40–79 years were enrolled to investigate the long-term trends for BMI and blood pressure levels.

Consent was implied by the participation in health checkups under a community-based program for stroke prevention and was approved by the municipal government and local physicians' association<sup>15</sup>. The study was also approved by the ethics committees of the Osaka Centre for Cancer and Cardiovascular Disease Prevention, the University of Tsukuba, and

Osaka University.

#### Bp Status at Baseline and at Follow-Up

Systolic and fifth-phase diastolic pressures in the right arm were measured by trained physicians using standard mercury sphygmomanometers with 14 × 51-cm cuffs according to the standard epidemiological method. Participants were seated and had rested for 5 min before the measurement. From 1963 to 1980, the blood pressure measurement was repeated after five deep breaths when systolic blood pressure  $\geq 160$  mmHg or diastolic blood pressure  $\geq 95$  mmHg; from 1981 to 2007, when systolic blood pressure  $\geq 140$  mmHg or diastolic blood pressure  $\geq 90$  mmHg; and from 2008 to 2013, when systolic blood pressure  $\geq 130$  mmHg or diastolic blood pressure  $\geq 85$  mmHg. To standardize the conditions, we used the first reading for the analyses. We defined hypertension as those with systolic blood pressure  $\geq 140$  mmHg and/or diastolic blood pressure  $\geq 90$  mmHg and/or taking antihypertensive medication. Controlled hypertension were persons under antihypertensive medication with systolic blood pressure  $<140$  mmHg and diastolic blood pressure  $<90$  mmHg. BMI was calculated by dividing weight in kilograms by height in meters squared, and BMI  $\geq 25$  kg/m<sup>2</sup> was considered obese.

The health checkups were performed every year and offered free of charge to all residents aged  $\geq 40$  years. From 1963, we conducted face-to-face interviews based on the CIRCS questionnaire related to participants' health conditions and dietary habits<sup>3</sup>. From 1975, we asked about smoking habits and usual daily alcohol intake (g/day).

#### Statistical Analysis

Sex-specific and age-adjusted mean systolic and diastolic blood pressure levels were calculated according to 11 periods (4–5 years for each period). We also calculated mean systolic and diastolic blood pressure levels according to antihypertensive medication use or not. When persons participated in annual cardiovascular risk surveys twice or more in each period, data in the earliest year were used. The significance of trends for blood pressure and BMI variables was examined using mixed effects modeling for repeated measurement adjusting for age, with the 11 periods represented as median year<sup>18</sup>. The repeated analysis was conducted because approximately 80% of the participants appeared in the next survey period.

All statistical analyses were performed using SAS for Windows version 9.4 (SAS Institute, Inc., Cary, NC, USA) for the analyses. All probability values for statistical tests were two-tailed, and values  $<0.05$  were regarded as statistically significant.

**Table 1.** Sex- and age-specific number of residents, participants and participation rates from 1963–66 to 2009–13

	1963-66	1972-75	1976-79	1980-83	1984-87	1988-91	1992-95	1996-99	2000-03	2004-08	2009-13
<b>Men</b>											
40-49											
Residents ( <i>n</i> ) *	362	479	461	443	403	467	496	458	420	331	304
Participants ( <i>n</i> )	286	356	334	283	299	255	208	192	135	97	89
Participation rates (%)	79.0	74.3	72.5	63.9	74.2	54.6	41.9	41.9	32.1	29.3	29.3
50-59											
Residents ( <i>n</i> ) *	335	314	356	398	456	440	406	432	458	501	425
Participants ( <i>n</i> )	279	249	265	324	361	321	265	202	221	225	167
Participation rates (%)	83.3	79.3	74.4	81.4	79.2	73.0	65.3	46.8	48.3	44.9	39.3
60-69											
Residents ( <i>n</i> ) *	215	270	265	259	278	361	423	420	416	359	421
Participants ( <i>n</i> )	199	222	199	216	240	257	278	326	294	264	295
Participation rates (%)	92.6	82.2	75.2	83.4	86.3	71.2	65.7	77.7	70.7	73.5	70.1
70-79											
Residents ( <i>n</i> ) *	80	144	150	155	185	204	219	244	268	332	330
Participants ( <i>n</i> )	53	91	82	107	126	137	135	150	189	201	199
Participation rates (%)	66.3	63.2	54.8	69.0	68.1	67.2	61.6	61.6	70.5	60.5	60.3
<b>Women</b>											
40-49											
Residents ( <i>n</i> ) *	456	497	487	477	453	483	494	459	423	352	298
Participants ( <i>n</i> )	399	471	381	365	395	309	272	272	210	152	128
Participation rates (%)	87.5	94.8	78.2	76.5	87.2	64.0	55.1	59.3	49.6	43.2	43.0
50-59											
Residents ( <i>n</i> ) *	354	419	446	472	484	483	445	460.5	476	485	410
Participants ( <i>n</i> )	325	363	345	404	451	403	363	342	345	314	264
Participation rates (%)	91.8	86.6	77.4	85.6	93.2	83.4	81.6	74.3	72.5	64.7	64.4
60-69											
Residents ( <i>n</i> ) *	244	312	330	348	378	442	476	476.5	477	434	465
Participants ( <i>n</i> )	229	260	261	302	336	367	382	416	383	355	357
Participation rates (%)	93.9	83.3	79.1	86.8	88.9	83.0	80.3	87.3	80.3	81.8	76.8
70-79											
Residents ( <i>n</i> ) *	101	188	191	193	247	293	347	389	431	466	448
Participants ( <i>n</i> )	76	89	109	143	158	145	180	223	259	281	277
Participation rates (%)	75.2	47.3	57.2	74.1	64.0	49.5	51.9	57.3	60.1	60.3	61.8

\*Census populations in 1965, 1975, 1980, 1985, 1990, 1995, 2000, 2005, and 2010, respectively.

## Results

The number of men and women aged 40–79 years who participated in health checkups were 1,846 in 1963–1966, 2,101 in 1972–1975, 1,976 in 1976–1979, 2,144 in 1980–1983, 2,366 in 1984–1987, 2,194 in 1988–1991, 2,083 in 1992–95, 2,123 in 1996–1999, 2,036 in 2000–2003, 1,889 in 2004–2008 and 1,776 in 2009–2013 (**Table 1**). Participation rates were consistently high ( $\geq 60\%$ ) for men aged 60–69 and 70–79 years and for women aged 50–59 and 60–69 years. Therefore, the results for men and women aged 60–69 years were regarded as the

primary finding for long-term trends.

Downward trends of mean systolic and diastolic blood pressure levels were observed for men and women of all age groups, except for men aged 70–79 years in diastolic blood pressure from 1963–1966 to 2009–2013 (**Table 2** and **Fig. 1**). These blood pressure declines were observed for persons without antihypertensive medication use as well as those with it (**Table 2**). The prevalence of antihypertensive medication use increased from 8.5% in 1963–1966 to 47.2% in 1976–1979 for men and from 8.7% to 42.2% for women, and thereafter along with downward trends for blood pressure levels, it declined to 38.0% for men

**Table 2.** Sex- and age-specific means and prevalence or proportions of cardiovascular risk characteristics from 1963-66 to 2009-13

	1963-66	1972-75	1976-79	1980-83	1984-87	1988-91	1992-95	1996-99	2000-03	2004-08	2009-13	p for trend
Men												
40-49												
Systolic blood pressure, mmHg	142	139***	134***	132***	133***	134***	133***	131***	132***	130***	126***	<0.001
With antihypertensive medication use	178	154***	149***	147***	150***	145***	148***	152***	146***	128***	130***	<0.001
Without antihypertensive medication use	140	138*	133***	131***	132***	133***	132***	130***	131***	129***	127***	<0.001
Diastolic blood pressure, mmHg	85	86	85	84	86	84	85	85	87*	85	85	0.65
With antihypertensive medication use	105	94**	92**	94**	95	92**	94*	96	94*	90**	90**	0.07
Without antihypertensive medication use	84	86*	84	83	85	84	85	85	87**	85	85	0.30
Antihypertensive medication use <sup>a</sup> , %	3.9	9.0	9.3	13.4***	9.0	9.0**	6.7	7.8	10.4	8.3	12.4*	0.05
Controlled hypertension under medication <sup>b,c</sup> , %	0.0	15.6	19.4	26.3*	25.9	30.4	7.1	20.0	28.6	62.5***	54.6***	0.002
Hypertension <sup>d</sup> , %	51.8	50.0	45.2	42.8**	42.5**	38.8**	35.6**	44.3	49.6	44.3	46.1	0.05
Body mass index, kg/m <sup>2</sup>	22.8	23.1	23.5***	23.4***	23.3**	23.6***	23.6***	23.9***	24.3***	24.6***	24.7***	<0.001
Obesity (BMI ≥ 25) <sup>a</sup> , %	12.5	18.5	21.3**	27.6***	28.4***	28.2***	32.2***	33.3***	28.9***	38.1***	42.7***	<0.001
50-59												
Systolic blood pressure, mmHg	150	145**	141***	138***	139***	138***	138***	135***	138***	130***	129***	<0.001
With antihypertensive medication use	168	157*	156**	145***	147***	146***	149***	148***	145***	138***	134***	<0.001
Without antihypertensive medication use	148	143**	137***	137***	138***	138***	136***	133***	138***	129***	128***	<0.001
Diastolic blood pressure, mmHg	88	87	87	85***	86**	85***	85***	87	89	83***	83***	<0.001
With antihypertensive medication use	100	90***	94*	89***	92**	89***	90***	92**	93*	87***	87***	<0.001
Without antihypertensive medication use	87	87	85*	84***	85*	84***	84***	86	88	82***	83***	<0.001
Antihypertensive medication use <sup>a</sup> , %	8.2	21.7***	25.3***	25.9***	18.3***	17.1***	18.9**	17.3**	16.3**	23.1***	28.1***	<0.001
Controlled hypertension under medication <sup>b,c</sup> , %	13.0	13.0	7.5	36.9*	36.4*	32.7	24.0	34.3	22.2	40.4**	51.1***	<0.001
Hypertension <sup>d</sup> , %	63.1	65.1	55.5*	56.8	51.3*	50.2*	50.6*	47.5**	57.0	48.9**	53.3	0.003
Body mass index, kg/m <sup>2</sup>	22.4	22.8*	23.1***	23.0***	23.1***	23.4***	23.4***	23.8***	24.0***	24.1***	24.2***	<0.001
Obesity (BMI ≥ 25) <sup>a</sup> , %	16.7	17.7	18.1	19.5	18.6*	27.1*	26.4***	38.6***	37.1***	36.9***	38.5***	<0.001
60-69												
Systolic blood pressure, mmHg	160	156*	149***	143***	141***	145***	140***	139***	139***	134***	132***	<0.001
With antihypertensive medication use	179	163**	157***	150***	146***	152***	144***	147***	145***	138***	136***	<0.001
Without antihypertensive medication use	158	153**	145***	141***	139***	143***	139***	137***	137***	133***	130***	<0.001
Diastolic blood pressure, mmHg	89	87	85***	84***	83***	84***	83***	84***	85***	80***	80***	<0.001
With antihypertensive medication use	97	90*	88**	87***	85***	87***	83***	87***	86***	80***	81***	<0.001
Without antihypertensive medication use	88	85**	83***	82***	82***	83***	84***	83***	85**	80***	80***	<0.001
Antihypertensive medication use <sup>a</sup> , %	8.5	36.0***	47.2***	41.2***	33.8***	36.6***	32.4***	32.8***	32.7***	35.2***	38.0***	<0.001
Controlled hypertension under medication <sup>b,c</sup> , %	5.9	8.8	17.0	27.0	34.6*	27.7	41.1**	34.6*	35.4*	55.9***	56.3***	<0.001
Hypertension <sup>d</sup> , %	76.9	79.3	76.9	67.6**	61.7***	66.9**	64.0***	58.6***	64.3**	58.0***	60.0***	<0.001
Body mass index, kg/m <sup>2</sup>	22.2	22.2	22.6*	22.4	22.4	22.8**	22.7***	23.3***	23.7***	23.7***	24.0***	<0.001
Obesity (BMI ≥ 25) <sup>a</sup> , %	10.6	12.2	20.2**	16.7	17.9*	22.2**	19.9**	24.2***	34.0***	29.6***	36.6***	<0.001
70-79												
Systolic blood pressure, mmHg	168	161***	156***	150***	146***	148***	143***	144***	142***	138***	133***	<0.001
With antihypertensive medication use	183	168	162	154*	149*	152*	149*	147*	146*	143**	137**	<0.001
Without antihypertensive medication use	167	152***	152***	145***	143***	145***	138***	140***	138***	134***	129***	<0.001
Diastolic blood pressure, mmHg	87	84	85	82**	80***	82**	81***	82**	81***	78***	77***	<0.001
With antihypertensive medication use	97	88	88	84	80*	82	82*	81*	82*	79*	77**	<0.001
Without antihypertensive medication use	87	80***	82*	80***	79***	81***	80***	82**	81***	77***	77***	<0.001
Antihypertensive medication use <sup>a</sup> , %	3.8	50.6***	56.1***	54.2***	50.0***	46.0***	48.9***	40.7***	45.0***	46.3***	51.3***	0.007
Controlled hypertension under medication <sup>b,c</sup> , %	0.0	6.5	17.4	22.4	33.3	30.2	39.4	31.2	34.1	37.6	52.9	<0.001
Hypertension <sup>d</sup> , %	88.7	86.8	87.8	81.3	77.0	75.2	66.7**	70.7**	64.6***	63.2***	65.8**	<0.001
Body mass index, kg/m <sup>2</sup>	21.8	22.0	22.4	21.8	21.9	22.2	22.3	22.9**	23.2***	23.1***	23.3***	<0.001
Obesity (BMI ≥ 25) <sup>a</sup> , %	13.3	13.3	17.3	16.0	13.5	20.4**	19.3*	24.0**	19.6**	26.4**	25.1*	0.02

(Cont Table 2)

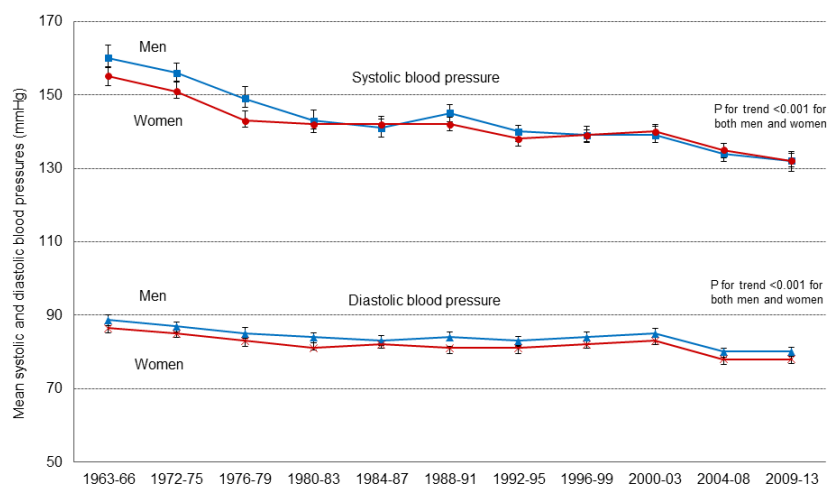
	1963-66	1972-75	1976-79	1980-83	1984-87	1988-91	1992-95	1996-99	2000-03	2004-08	2009-13	p for trend
Women												
40-49												
Systolic blood pressure, mmHg	133	131**	126***	126***	127***	129***	126***	126***	123***	121***	120***	<0.001
With antihypertensive medication use	172	160	145***	147***	149**	157*	150**	146***	142***	139***	133***	<0.001
Without antihypertensive medication use	132	129**	126***	125***	126***	128***	125***	125***	127***	121***	119***	<0.001
Diastolic blood pressure, mmHg	80	80	78**	77***	79	79	79	79	81	76***	76***	0.01
With antihypertensive medication use	95	94	86*	89	91	95	96	88	91	85*	87	0.23
Without antihypertensive medication use	79	79	77**	77***	79	78	79	79	80	76***	75***	0.02
Antihypertensive medication use <sup>a</sup> , %	2.8	5.3	7.6*	9.3***	5.6	5.8	4.8	6.3	4.3	5.9	6.3	0.17
Controlled hypertension under medication <sup>b,c</sup> , %	18.2	8.0	41.4	32.4	36.4	16.7	7.7	23.5	33.3	44.4	62.5*	0.127
Hypertension <sup>d</sup> , %	33.6	28.0*	26.0***	23.3***	25.6***	30.7	25.4*	25.4**	23.8*	21.1**	19.5***	0.001
Body mass index, kg/m <sup>2</sup>	23.1	23.5**	24.0***	23.6**	23.7***	23.5*	23.6**	23.5*	23.3	23.2	22.9	0.95
Obesity (BMI ≥ 25) <sup>a</sup> , %	19.8	30.8***	31.8***	28.2**	31.4***	27.8**	28.3*	26.5*	28.1	27.6*	24.2	0.52
50-59												
Systolic blood pressure, mmHg	143	140	134***	135***	135***	135***	133***	133***	135***	128***	125***	<0.001
With antihypertensive medication use	159	151	147**	145***	145***	146***	145***	147***	149**	139***	135***	<0.001
Without antihypertensive medication use	142	139*	132***	133***	134***	134***	131***	132***	133***	127***	124***	<0.001
Diastolic blood pressure, mmHg	84	84	81***	81***	82*	81**	82*	82	84	78***	77***	<0.001
With antihypertensive medication use	95	94	86*	89	91	95	96	88	91	85*	87	0.02
Without antihypertensive medication use	83	84	80***	80***	81*	81**	81*	82	83	78***	77***	<0.001
Antihypertensive medication use <sup>a</sup> , %	6.5	14.3*	22.6***	24.0***	17.3***	16.4***	14.6**	12.6*	15.4***	15.6***	13.3*	0.13
Controlled hypertension under medication <sup>b,c</sup> , %	23.8	19.2	29.5	38.1	39.7	36.4	24.5	23.3	17.0	44.9*	65.7***	0.01
Hypertension <sup>d</sup> , %	52.0	52.6	45.8**	47.0	47.0	45.2	39.9***	39.2***	42.6***	36.9***	29.2***	<.0001
Body mass index, kg/m <sup>2</sup>	23.0	23.7***	24.4***	24.1***	24.1***	24.4***	24.2***	24.3***	24.3***	24.1***	23.8**	0.005
Obesity (BMI ≥ 25) <sup>a</sup> , %	23.6	34.2***	37.7***	38.9***	38.8***	40.3***	34.4***	38.0***	32.5**	32.8**	31.4*	0.17
60-69												
Systolic blood pressure, mmHg	155	151*	143***	142***	142***	142***	138***	139***	140***	135***	132***	<0.001
With antihypertensive medication use	177	167*	154***	148***	147***	147***	145***	147***	147***	139***	135***	<0.001
Without antihypertensive medication use	153	145***	139***	139***	140***	140***	135***	136***	138***	133***	132***	<0.001
Diastolic blood pressure, mmHg	86	85	83***	81***	82***	81***	81***	82***	83***	78***	78***	<0.001
With antihypertensive medication use	93	89	86**	87***	87***	85***	87***	89***	92***	84***	82***	<0.001
Without antihypertensive medication use	86	83**	80***	80***	81***	79***	79***	81***	83***	77***	78***	<0.001
Antihypertensive medication use <sup>a</sup> , %	8.7	34.6***	42.2***	35.4***	29.8***	32.4***	35.1***	31.7***	32.9***	29.3***	31.7***	<0.001
Controlled hypertension under medication <sup>b,c</sup> , %	5.0	7.8	21.8	43.0***	35.0**	37.8**	38.8*	27.3*	34.1**	51.9***	60.2***	<0.001
Hypertension <sup>d</sup> , %	67.7	68.1	64.8	61.6*	61.3	60.0*	56.8***	57.0**	61.1*	52.7***	53.8***	<0.001
Body mass index, kg/m <sup>2</sup>	23.1	23.7**	24.1***	23.9***	24.0***	24.3***	24.1***	24.8***	25.0***	24.6***	24.5***	<0.001
Obesity (BMI ≥ 25) <sup>a</sup> , %	23.5	31.7	41.9***	37.9*	37.6**	40.9***	36.2**	46.9***	45.2***	35.8**	35.1**	0.001
70-79												
Systolic blood pressure, mmHg	165	157**	152***	148***	145***	148***	143***	141***	141***	141***	138***	<0.001
With antihypertensive medication use	176	161*	158**	155**	149***	149***	147***	145***	147***	143***	139***	<0.001
Without antihypertensive medication use	163	154*	145***	140***	141***	146***	140***	138***	137***	139***	137***	<0.001
Diastolic blood pressure, mmHg	88	83**	82***	80***	80***	78***	78***	78***	79***	75***	75***	<0.001
With antihypertensive medication use	86	87	84	82	81	78*	79	78*	80	76**	75**	<0.001
Without antihypertensive medication use	88	81**	79***	78***	78***	78***	77***	78***	79***	76***	75***	<0.001
Antihypertensive medication use <sup>a</sup> , %	11.8	49.4***	69.7***	55.9***	53.2***	43.5***	41.7***	47.1***	47.1***	55.5***	52.0***	0.003
Controlled hypertension under medication <sup>b,c</sup> , %	22.2	9.1	18.4	25.0	32.1	34.9	40.0***	41.0	34.4	39.7	51.4	<0.001
Hypertension <sup>d</sup> , %	80.3	88.8	86.2	75.5	76.0	78.6	65.6*	68.2*	67.2*	74.7	72.6	0.002
Body mass index, kg/m <sup>2</sup>	23.3	23.3	23.6	23.6	23.6	24.3*	23.9	24.4**	24.5**	24.4*	24.2	0.003
Obesity (BMI ≥ 25) <sup>a</sup> , %	22.0	34.8	33.3	33.8	33.5	42.1*	38.9	40.1*	40.9**	42.0**	38.8**	0.001

Test of differences from the 1963-66 values: \*p<0.05, \*\*p<0.01, \*\*\*p<0.001

<sup>a</sup>Prevalence: the denominator is the participants of each sex- and age-specific group, <sup>b</sup>Proportion: the denominator is the hypertensive persons of each sex- and age-specific group,

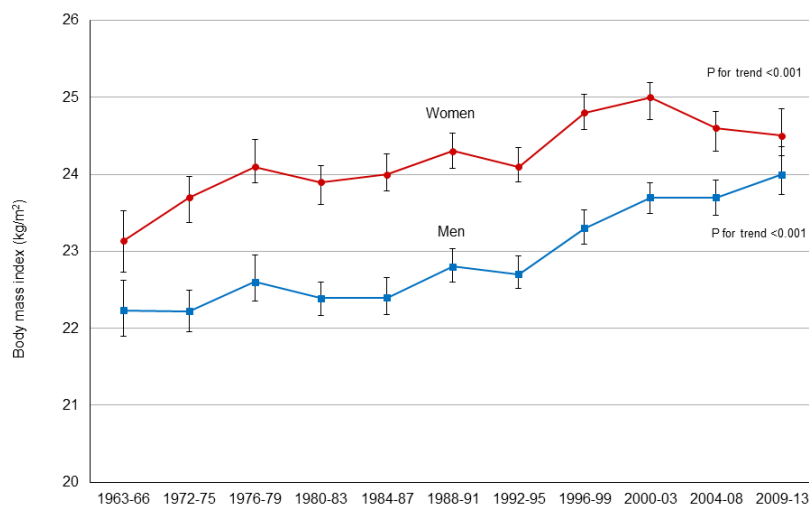
<sup>c</sup>The proportion of controlled hypertension under medication among hypertensive persons aged 40-49 and 50-59 years fluctuated because of the small number of persons who took antihypertensive medication, <sup>d</sup>Systolic blood pressure ≥ 140 mmHg and/or diastolic blood pressure ≥ 90 mmHg and/or antihypertensive medication use





**Fig. 1.** Mean systolic and diastolic blood pressure levels for men and women aged 60–69 years between 1963–1966 and 2009–2013

The I bars indicate 95% confidence intervals.



**Fig. 2.** Mean body mass index for men and women aged 60–69 years between 1963–1966 and 2009–2013

The I bars indicate 95% confidence intervals.

and to 31.7% for women in 2009–2013. The proportion of hypertension controlled under antihypertensive medication among hypertensive persons increased from 5.9% in 1963–1966 to 56.3% in 2009–2013 for men and from 5.0% to 60.2% for women. The prevalence of hypertension declined from 76.9% in 1963–1966 to 60.0% in 2009–2013 for men and from 67.7% to 53.8% for women.

Age-adjusted mean values of BMI and prevalence of obesity increased for men and women of all age groups, except for women aged 40–49 years (Table 2). Mean BMI increased from 22.2 kg/m<sup>2</sup> in 1963–1966 to 24.0 kg/m<sup>2</sup> in 2009–2013 for men aged 60–69 and

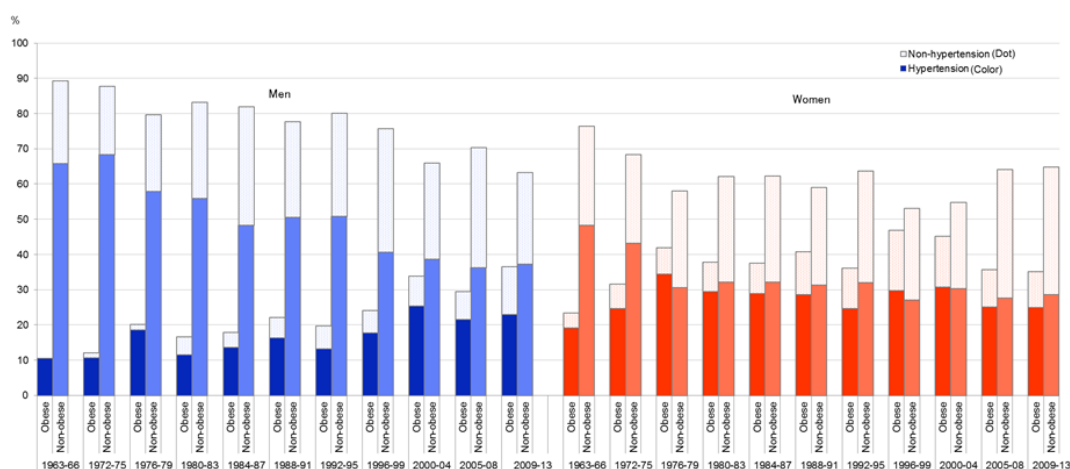
from 23.1 kg/m<sup>2</sup> in 1963–1966 to 25.0 kg/m<sup>2</sup> in 2000–2003 for women aged 60–69, and thereafter, declined to 24.5 kg/m<sup>2</sup> for women in 2009–2013 (Table 2 and Fig. 2). When adjusted for BMI as well as age, the declining trend for mean diastolic blood pressure was somewhat enhanced for men aged 40–49 years, but otherwise, no substantial changes were observed (data not shown).

Table 3 and Fig. 3 show the sex- and age-specific prevalence of hypertension with and without obesity for men and women from 1963–1966 to 2009–2013. The prevalence of hypertension with obesity increased from 10.5% in 1963–1966 to 23.1% in 2009–2013

**Table 3.** Sex and age-specific prevalence of hypertension with and without obesity from 1963-66 to 2009-13

	1963-66	1972-75	1976-79	1980-83	1984-87	1988-91	1992-95	1996-99	2000-03	2004-08	2009-13	P for trend
<b>Men</b>												
40-49												
Hypertension with obesity, %	5.3	11.0*	13.8***	14.8***	17.1***	12.9***	16.4***	19.8***	17.8***	17.5***	27.0	<0.001
Hypertension without obesity, %	42.9	39.0*	31.4***	27.9***	25.4***	25.9***	19.2***	24.5***	31.9***	26.8***	19.1***	<0.001
50-59												
Hypertension with obesity, %	12.3	12.5	11.7	13.3	13.3*	17.5***	15.5**	23.3***	26.2***	21.8***	24.6***	<0.001
Hypertension without obesity, %	49.3	52.6	43.6	43.5	38.0*	32.7***	35.1**	24.3***	30.8***	27.1***	28.7***	<0.001
60-69												
Hypertension with obesity, %	10.5	10.8	18.6*	11.6	13.8*	16.3*	13.3	17.8***	25.5***	21.6***	23.1***	<0.001
Hypertension without obesity, %	65.3	68.5	57.7*	56.0	48.3*	50.6*	50.7	40.8***	38.8***	36.4***	37.3***	<0.001
70-79												
Hypertension with obesity, %	8.7	13.3	13.3	14.2	11.9	17.5*	14.8*	18.7**	14.3***	19.9***	21.1***	<0.001
Hypertension without obesity, %	78.3	73.3	73.3	67.0	65.1	57.7*	51.9*	52.0**	50.3***	43.3***	44.7***	<0.001
<b>Women</b>												
40-49												
Hypertension with obesity, %	7.9	13.0***	11.8***	11.0**	11.7**	12.3	12.1*	12.5**	10.0*	10.5**	10.9*	0.02
Hypertension without obesity, %	22.8	15.1***	14.2***	12.3**	13.9**	18.5	13.2*	12.9**	13.8*	11.2**	8.6*	0.02
50-59												
Hypertension with obesity, %	14.2	24.8***	23.0***	23.5***	22.4***	20.9***	17.9**	23.1***	20.6***	19.4***	13.6***	0.001
Hypertension without obesity, %	36.4	27.8***	22.5***	23.5***	24.6***	24.1***	22.0**	16.1***	22.0***	17.5***	15.5***	0.001
60-69												
Hypertension with obesity, %	18.8	24.7	33.3***	29.5**	29.0**	28.6***	24.7**	29.8***	30.8***	25.1***	25.0**	<0.001
Hypertension without obesity, %	47.3	43.2	29.7***	32.1**	32.2**	31.3***	32.0**	27.2***	30.3***	27.6***	28.7**	<0.001
70-79												
Hypertension with obesity, %	15.6	32.6	31.9	26.8*	28.5	37.2***	29.4**	30.6**	31.7**	34.9**	32.3**	0.003
Hypertension without obesity, %	60.9	56.2	52.1	48.6*	47.5	41.4***	36.1**	37.4**	35.5**	39.9**	40.2**	0.003

\*Test of differences from the 1963-66 values: \* $p < 0.05$ , \*\* $p < 0.01$ , \*\*\* $p < 0.001$



**Fig. 3.** Trends in the prevalence of hypertension with and without obesity for men and women aged 60–69 years between 1963–1966 and 2009–2013

Hypertension is shown as colored, and non-hypertension is shown as dotted.

for men aged 60–69 years and from 18.8% to 25.0% for women aged 60–69 years. The corresponding prevalence of hypertension without obesity for ages 60–69 years decreased from 65.3% to 37.3% for men and from 47.3% to 28.7% for women, but it was mostly higher than that of hypertension with obesity over time.

## Discussion

The present study showed a substantial and consistent decline in systolic blood pressure levels, while BMI levels increased and correspondingly prevalence of hypertension with obesity increased over the past 50 years for both men and women in a Japanese rural community. The prevalence of hypertension with obesity increased for both sexes of all age groups, but the prevalence of hypertension without obesity still overwhelmed that with obesity for men and women aged 60–69 years and other age groups except for ages of 40–49 years in 2009–2013. The previous study using Japanese national data showed that the prevalence of obesity increased in men and remained stable in women, and the odd ratio of hypertension associated with obesity increased from 1.94 in 1980 to 2.82 in 2010 for men and from 2.37 to 3.48 for women<sup>19</sup>). In that study population aged 30–79 years, the PAF increased from 14.6% in 1980 to 39.3% in 2010 for men, and from 23.9% to 34.8% for women. The PAF estimated in the present study population aged 40–79 years was 12.6% in 1980–1983 and 24.4% in 2009–2013 for men, and 36.7% and 40.1% for women<sup>20</sup>). Although hypertension attributable to obesity increased overtime, there remained a large fraction of hypertension attributable to non-obesity.

Long-term blood pressure trends were reported from Japanese, Finnish, and US studies. According to the National Health and Nutrition Survey in Japan<sup>21, 22</sup>), mean systolic and diastolic blood pressures for men and women aged 60–69 years declined between 1961 and 2010. Mean BMI increased from 22.0 kg/m<sup>2</sup> in 1976–1980 to 23.7 kg/m<sup>2</sup> in 2011 for men aged 60–69 years, whereas for women, it did not change: 23.0 kg/m<sup>2</sup> and 22.9 kg/m<sup>2</sup> for 1976–1980 and 2011, respectively<sup>23</sup>). As shown in **Supplementary Fig. 1**, the prevalence of obesity increased from 16.0% in 1976–1980 to 31.0% in 2011 for men aged 60–69 years, but it decreased from 27.2% to 24.0% for women.

A 35-year population survey in the province of North Karelia in Finland showed that both mean systolic and diastolic blood pressure levels for men and women aged 30–59 years declined between 1972 and 2002, but plateaued between 2002 and 2007<sup>24</sup>). For

men, mean BMI continuously increased from 26.0 kg/m<sup>2</sup> in 1972 to 27.1 kg/m<sup>2</sup> in 2002 and to 27.4 kg/m<sup>2</sup> in 2007, whereas for women, it did not change: 26.8, 26.8, and 26.6 kg/m<sup>2</sup> for 1972, 2002, and 2007, respectively<sup>25</sup>). As shown in **Supplementary Fig. 1**, the corresponding prevalence of obesity was 57%, 68%, and 70% for men, and 61%, 54%, and 54% for women.

The National Health and Nutrition Examination Survey (NHANES) in the United States<sup>26, 27</sup>) indicated that mean systolic and diastolic blood pressure for individuals aged 18–74 years decreased between 1960–1962 and 2001–2008 (age  $\geq$  18 in 2001–2008) for men and women. As shown in **Supplementary Fig. 1**, the prevalence of obesity increased from 50% in 1960–1962 to 61% in 1988–1994 and to 73% in 2009–2012 for men, and from 40% to 51% and to 65%, respectively, for women<sup>28</sup>).

The declining trend in systolic blood pressure levels were commonly observed among men and women of Japanese, Finnish, and US samples. The improvement of hypertension treatment and the reduction of salt consumption may have favored the change in blood pressure in these countries. Other dietary factors which contributed to the systolic blood pressure decline<sup>29</sup>) for Japanese may include increased intakes of fresh fruits, vegetables, and dairy products<sup>30</sup>). The prevalence of obesity was much lower in Japanese than in Finnish and Americans (**Supplementary Fig. 1**). Globally, people in countries of east, southeast, and south Asia and central Africa are less obese<sup>31</sup>) and have high risk of mortality from stroke<sup>32</sup>). Lean hypertensives had the greater risk of mortality from cardiovascular disease than obese hypertensives<sup>33, 34</sup>). Therefore, the prevention and control for hypertension may be also important in countries with less obese populations.

The strengths of this study are its investigation of long-term time trends and the high response rates among men and women aged 60–69 years in addition to among men aged 70–79 years and women aged 50–59 years. To the best of our knowledge, no other population-based study has been conducted to investigate long-term trends for the relations between blood pressures and BMI.

The limitations of the study warrant discussion. First, we did not have individual information on salt intake, which is a major determinant of blood pressure levels. According to our nutrition survey of a subsample of the present study<sup>3</sup>), mean salt intake decreased from 20 g/day in the 1960s to 14 g/day in the 1980s for men aged 40–59 years. The large decline in the prevalence of hypertension without obesity may be partly explained by this reduction in salt intake,



although this was not directly shown here because of the subsample nutrition survey. Second, this study was performed in one rural community in Japan, and the participation rates were not high enough for men aged 40–59 years, nor for women aged 40–49 years in the 1990's and thereafter. Therefore, caution should be taken in applying our findings to other Japanese populations. However, comparing our results with Japanese national survey (National Health and Nutrition Survey), we found similar trends in blood pressure levels in the general Japanese population, although the prevalence of obesity among women was higher by 5 to 23 point in the present study than in the national sample<sup>21, 22</sup>. Third, because we used the first reading of blood pressure measurement to analyze the data consistently through 50 years, blood pressure levels may be overestimated compared with usual values. However, when we used the second reading, if the first reading was high, the prevalence of hypertension did not change materially: the difference = -0.3% to 0.0%. Lastly, hypertensive persons can move from non-obese in one survey to obese in another or vice versa. However, the percentage for the shift to the other category between one to the next periods was small (approximately 5%).

In conclusion, we found a substantial decline in blood pressure levels over the past 50 years for both men and women aged 40–79 years in a Japanese rural community. The prevalence of hypertension without obesity declined and that with obesity increased along with increased BMI levels. In spite of the transition for increased BMI levels, the targeting for non-obese hypertension remained important in addition to the targeting for obese hypertension in order to control of hypertension. Our findings may be applicable to other countries where the prevalence of hypertension is high and that of obesity is low.

### Acknowledgments

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### Conflict of Interest

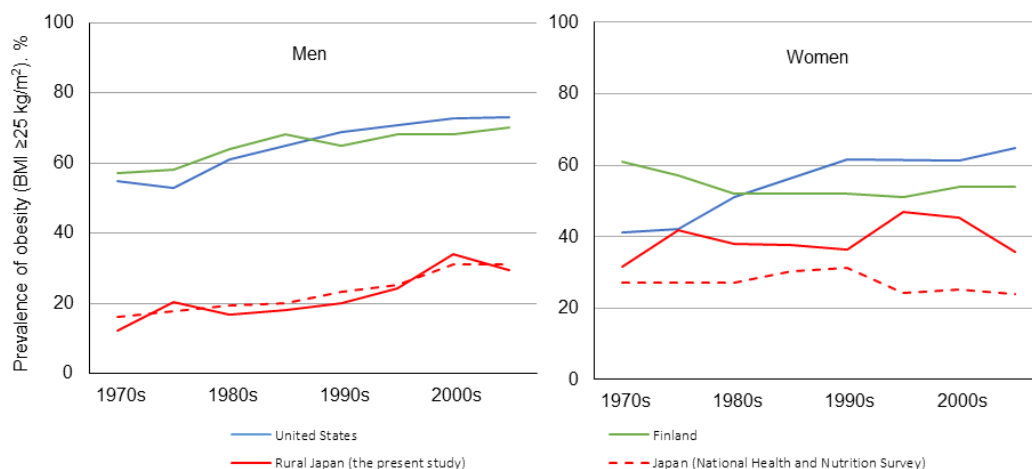
None declared.

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**Supplementary Fig. 1.** Trends in age-adjusted prevalence of obesity ( $\text{BMI} \geq 25 \text{ kg/m}^2$ ) among US, Finnish, and Japanese men and women

Finland: Data from the North Karelia province project for men and women aged 30–59 years in 1972, 1977, 1982, 1987, 1992, 1997, 2002, and 2007<sup>1</sup>.

United States: Data from NHANES I (1971-74), NHANES II (1976-80), NHANES III (1988-94), NHANES (1999-2002), NHANES (2003-06), and NHANES (2009-12) for men and women aged 20–74 years<sup>2</sup>.

Rural Japan: Data from the present study for men and women aged 60–69 years in 1972–1975, 1976–1979, 1980–1983, 1984–1987, 1992–1995, 1996–1999, 2000–2003, and 2004–2008.

Japan: Data from the National Health and Nutrition Survey in Japan in 1976–1980, 1981–1985, 1986–1990, 1991–1995, 1996, 2001, and 2011<sup>3</sup>.

### Supplementary References

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