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ARTICLE

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Obesity and hypertension from a public health perspective in a small remote island of Okinawa, Japan

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Abstract

This study investigated the relationship between obesity and hypertension from a public health perspective in a small remote island of Okinawa where obesity is prevalent. A cross-sectional study was conducted in 456 residents aged ≥18 years in Yonaguni island who underwent an annual health check-up and the Yonaguni dietary survey in 2022. Each participant responded to our original questionnaire and provided further dietary survey data via the Yonaguni municipal government. The odds ratio for hypertension was calculated in the obese group, using a logistic regression model with the non-obese group serving as the reference. Hypertension was defined as a systolic blood pressure ≥140 mmHg, a diastolic blood pressure ≥90 mmHg measured on an automated sphygmomanometer, and/or taking anti-hypertensive agents, while obesity was defined as a body mass index ≥25 kg/m^2. The proportion of hypertension associated with obesity among all hypertensive subjects was calculated. The prevalence of obesity and hypertension was 54.3% and 49.0% in the 208 male subjects and 32.3% and 43.6% in the 248 female subjects, respectively. The odds ratio for hypertension in the obese group was 3.73 (95% confidence interval, 1.93–7.20) for men and 4.13 (2.06-8.29) for women after adjusting for age, alcohol drinking habit, behavior for lowering salt intake, and smoking habit. Hypertension in 49.5% (95% confidence interval, 29.4%-63.9%) of males and 37.9% (22.6%–50.2%) of females was associated with obesity in this island. Some areas of Japan could be urgently required to address obesity for preventing cardiovascular disease.

Keywords obesity · hypertension · public health · remote island · Japan

Introduction

Hypertension is a major risk factor for cardiovascular disease, especially coronary heart disease and stroke [1, 2]. Due to its high prevalence, hypertension is the main contributor to cardiovascular disease in the Japanese population [3–5], and the second leading contributor to all-cause mortality in this population [3, 6]. The major lifestyle factors for the development of hypertension are excessive salt and alcohol intake, obesity resulting from overeating and/or lack of physical activity, and a lack of vegetable intake [7]. In Japan, hypertension, especially that caused by excessive salt intake, has been the main target used in the past for preventing cardiovascular disease, especially stroke [8, 9].

While the Japanese population has decreased salt intake, this population has become obese due to the spread of the Westernized diet with a high energy intake [8, 9]. The mechanism by which obesity induces hypertension is overactivation of the renin-angiotensin-aldosterone and sympathetic nervous systems and also hyperinsulinemia compensating for insulin resistance, which together result in vasoconstriction and increased renal reabsorption of urinary sodium [10]. Because of this background, there is concern that hypertension in the Japanese population is attributable mainly to obesity [11]. To understand this possibility in Japan at present and in the future, it is necessary to quantify the relationship between obesity and hypertension from a public health perspective in an area of Japan with a high prevalence of obesity.

Okinawa prefecture consists of 160 islands (47 islands with residents and 113 islands without residents) and is located in the southwestern part of Japan with a sea area of approximately 1000 km in an east-west direction and approximately 400 km in a north-south direction. Okinawa

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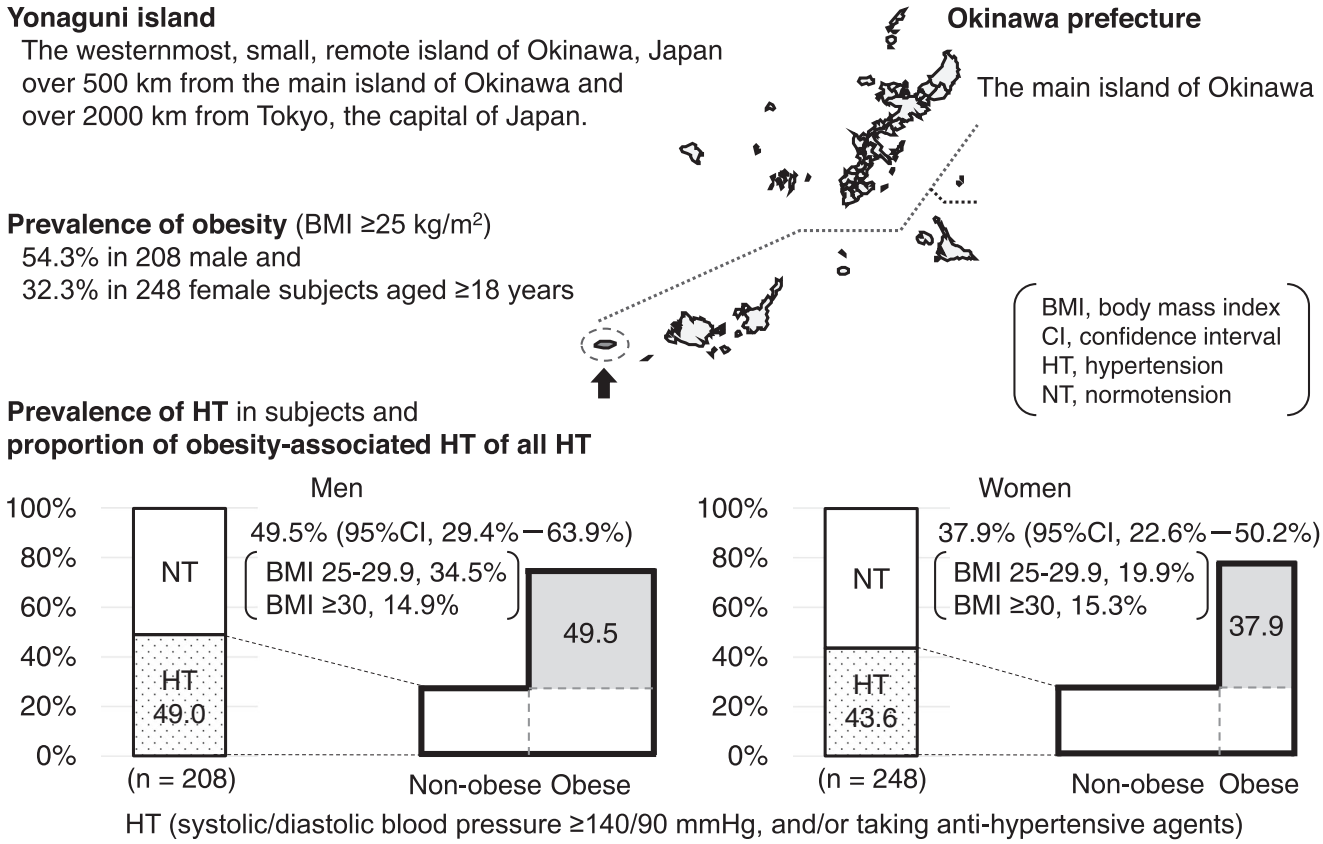
Graphical Abstract

A community-based, cross-sectional study in 456 residents aged ≥18 years in Yonaguni island, Okinawa prefecture, Japan



Approximately one-half of male and over one-third of female hypertensive subjects were associated with obesity ( ) in Yonaguni island (i.e., similar to the population attributable risk fraction).

Point of view

- Clinical relevance
  There was an area of Japan with an obesity epidemic, where approximately one-half of male and over one-third of female hypertensive subjects were associated with obesity defined as a body mass index ≥25 kg/m^2 (i.e., similar to the population attributable risk fraction).
- Future direction
  The obesity epidemic and relevant public health concern warrant further investigation from the viewpoints of social environments that lead to difficulties in having appropriate lifestyles for the prevention and improvement of obesity.
- Consideration for the Asian population
  The Asian population is in general thought to have a lower prevalence of obesity, compared with the Western population. However, the results of this study offer a caution that there could be areas of Asia with a considerably high prevalence of obesity, where the public health strategy should be revised by putting emphasis on obesity for the prevention and management of hypertension and the prevention of cardiovascular disease.

prefecture, especially some small remote islands, has a higher prevalence of obesity than the rest of Japan [12]. The primary aim of the present study was to investigate the prevalence of obesity and hypertension among adult residents and to estimate the proportion of hypertension associated with obesity among all hypertensive individuals in Yonaguni island, the westernmost small remote island of Okinawa prefecture in Japan. Among the 41 municipalities in Okinawa prefecture, Yonaguni island (Yonaguni town) is ranked as the fifth for men and as the sixth for women for the prevalence of obesity, defined as a body mass index (BMI) ≥ 25 kg/m^2 [12–14]. Small remote islands may have

social issues that have led to the obesity epidemic; for example, possible difficulties in food choices, especially fresh food, due to limited imports and distribution of food from outside of the island [15]. The secondary aim of the current study was to investigate the background of the obesity epidemic in this island.

Methods

Study design and population

The Yonaguni island study was a community-based, cross-sectional study in an adult population of Yonaguni island (Yonaguni town), Okinawa prefecture, Japan. The target island is the westernmost, small, remote island of Okinawa prefecture, Japan, with an area of 29 km^2, that is over 500 km from the main island of Okinawa and over 2000 km from Tokyo, the capital of Japan. The major industries are fishing, farming, and tourism. Approximately 1600 individuals register their residency as Yonaguni town; however, the residence registration system also includes those not living there to some extent because of personal issues.

The Yonaguni municipal government organizes an annual health check-up for all residents aged ≥18 years other than those working for one special institution. At the annual health check-up in June 2022, the Yonaguni municipal government conducted a dietary survey involving a self-administered questionnaire for examinees. We asked people who underwent both the health check-up and the Yonaguni dietary survey in June 2022 to participate in the Yonaguni island study. Each participant responded to our original self-administered questionnaire in addition to providing the Yonaguni dietary survey data via the Yonaguni municipal government. Of the 1328 residents aged ≥18 years based on the residence registration system, 585 underwent the health check-up, with 522 (241 men and 281 women) also participating in the Yonaguni island study. We combined the data from the two questionnaires, using the date and receipt number of the health check-up.

Of the 522 participants, 66 were deemed ineligible for inclusion in the study for the following reasons: missing data related to BMI ($n = 3$), blood pressure ($n = 3$), or other required characteristics ($n = 60$). The remaining 456 individuals (208 men and 248 women) were considered eligible study participants and were included in the subsequent analyses.

The study protocol was approved by the Institutional Review Committee for Ethical Issues of University of the Ryukyus (1935). After explanation of the study requirements, each participant provided their written informed consent by placing a check mark on the participation agreement form.

Data collection

Well-trained nurses measured body height and weight and blood pressure for each participant. The blood pressure measurements were conducted using an automated sphygmomanometer (SC-1800; FUKUDA COLIN Co., Ltd., Tokyo, Japan) on the right arm of the participants after they had rested a few minutes in the seated position. Blood pressures of a single measurement were recorded directly in cases with a systolic blood pressure <130 mmHg and diastolic blood pressure <85 mmHg. Otherwise, blood pressures were measured twice and the average of the first and second measurements then recorded. Each participant reported his/her body height and weight and blood pressure measured during the health check-up by filling out the questionnaire. Information on the use of anti-hypertensive agents was obtained via the questionnaire. BMI was calculated as weight (kg)/height squared (m^2) and was categorized as <25 kg/m^2 (non-obese) or ≥25 kg/m^2 (obese), with the obese group categorized further as 25≤ BMI < 30 kg/m^2 or BMI ≥ 30 kg/m^2 [13, 14]. Hypertension was defined as a systolic blood pressure ≥140 mmHg, a diastolic blood pressure ≥90 mmHg [7], and/or taking anti-hypertensive agents.

Other data collected via the self-administered questionnaires included age, alcohol drinking habit, behavior for lowering salt intake, smoking habit, exercise habit, and dietary balance. Alcohol drinking habit was classified according to whether a participant had never drunk, was a former drinker, or was a current drinker. Smoking habit was classified according to whether a participant had never smoked, was a former smoker, or was a current smoker. Behavior for lowering salt intake was reported based on the responses to the following question: "*Do you behave to lower salt intake?*" Participants were required to select one of the five following responses that most closely represented their behavior for lowering salt intake: "*always do*," "*sometimes do*," "*will do in the near future*," "*difficult to do despite willingness*," or "*never do*." Lowering salt intake was defined as "*always do*" or "*sometimes do*," while non-lowering salt intake was defined as the remaining three responses. Exercise habit was reported based on the responses to the following question: "*Do you take regular exercise?*" Participants were required to select one of the five responses, that were the same as those regarding behavior for lowering salt intake. Regular exercise was defined as "*always do*" or "*sometimes do*," while no exercise was defined as the remaining three responses. With reference to a national survey [9], dietary balance was reported based on the responses to the following question: "*How many days per week do you eat at least two meals a day with a staple food (shushoku), main dish (shusai), and side dish (fukusai)?*" Participants were required to select one of the four following responses that most closely

represented their dietary balance: "*almost everyday*," "*four or five days per week*," "*two or three days per week*," or "*almost none*." Balanced diet was defined as "*almost everyday*" or "*four or five days per week*," while unbalanced diet was defined as the remaining two responses.

Statistical analysis

All the data analyses were performed separately for men and women. Initially. we used either the unpaired *t*-test or Chi-square test to compare the characteristics between the non-obese and obese groups, defined as a BMI < 25 kg/m^2 and BMI ≥ 25 kg/m^2, respectively. Next, we compared the prevalence of hypertension in each of the two BMI groups using the Chi-square test. A logistic regression model was used to calculate the odds ratio and 95% confidence interval (CI) for hypertension in the obese group, with the non-obese group serving as the reference. The model incorporated age (continuous variable), alcohol drinking habit (current drinker or not), behavior for lowering salt intake (currently do or not), and smoking habit (current smoker or not) as potential confounding factors. Because a lack of exercise and an unbalanced diet primarily influence obesity, it is reasonable to assume that these two lifestyle factors are on the upper stream of the causal relationship between obesity and hypertension. Therefore, we did not include exercise habit and dietary balance as covariates in the model. Furthermore, referring to the concept of "the population attributable risk fraction" [16], we calculated the proportion of hypertension associated with obesity in all the hypertensive individuals. We used the following formula: [prevalence of obesity among hypertensive subjects × (odds ratio - 1)]/odds ratio [17]. The 95%CI for the corresponding proportion was calculated using the formula proposed by Greenland [18]. We also investigated the details of the corresponding proportion, by analyzing the data using similar statistical procedures after dividing the obese participants into a 25≤BMI < 30 kg/m^2 group or a BMI ≥ 30 kg/m^2 group. Finally, we explored the background of the obesity epidemic in the target island. We described the prevalence of no exercise and an unbalanced diet among all the subjects and investigated the magnitude of the associations between obesity and each adverse lifestyle profile. A logistic regression model that incorporated age (continuous variable) and either of dietary balance (unbalanced or balanced) or exercise habit (no or regular) as potential confounding factors was used to calculate the odds ratio and 95%CI for obesity in the worse lifestyle profile group (i.e., no exercise and an unbalanced diet), with the better lifestyle profile group (i.e., regular exercise and a balanced diet) serving as the reference.

The analyses were performed using JMP version15.0.0 (SAS Institute Inc., Cary, NC, USA) and Stata version 15 (StataCorp LP, College Station, TX, USA). All the probability values were two-tailed, and the significance level was set at $P < 0.05$.

Results

Characteristics of the study participants

Table 1 summarizes the mean values or proportions of the clinical characteristics for the overall study population, as well as for participants grouped as either non-obese or obese according to their BMI. For the 208 male participants, the mean (standard deviation) for age and BMI was 54.2 (16.6) years and 25.9 (5.1) kg/m², respectively. For the 248 female participants, the mean (standard deviation) for age and BMI was 54.0 (16.7) years and 23.8 (4.5) kg/m², respectively.

Compared to non-obese men, obese men took significantly more anti-hypertensive agents and tended to have higher levels of systolic blood pressure. Obese women had significantly higher levels of age and systolic and diastolic blood pressure and took significantly more anti-hypertensive agents, compared to non-obese women. For both men and women, there were no statistically significant differences in the proportions of current alcohol drinking, non-lowering salt intake, and current smoking between the non-obese and obese groups.

Obese status and hypertension prevalence

The prevalence of obesity and hypertension in all the male subjects was 54.3% and 49.0%, respectively. The prevalence of obesity and hypertension in all the female subjects was 32.3% and 43.6%, respectively.

As shown in Table 2, the obese group had a significantly higher prevalence of hypertension, compared to the non-obese group for both sexes (61.1% vs. 34.7% for men, and 67.5% vs. 32.1% for women). The odds ratio (95%CI) for hypertension in the obese group, with the non-obese group serving as the reference, was 3.73 (1.93−7.20) for men and 4.13 (2.06−8.29) for women after adjusting for age, alcohol drinking habit, behavior for lowering salt intake, and smoking habit. When the obese group was further categorized, there was a dose-response relationship between BMI and the odds ratio for hypertension in both sexes.

Proportion of hypertension associated with obesity among all the hypertensive subjects

The proportion (95%CI) of hypertension associated with obesity among all the hypertensive subjects was 49.5% (29.4%−63.9%) for men and 37.9% (22.6%−50.2%) for

Table 1 Characteristics of the study participants grouped by the absence or presence of obesity

	Total	Non-obese	Obese	*P*-value
Men	($n = 208$)	($n = 95$)	($n = 113$)	
Age, years	54.2 (16.6)	53.5 (17.4)	54.8 (15.9)	0.56
Height, cm	166.3 (6.3)	166.7 (6.3)	165.9 (6.4)	0.38
Weight, kg	71.7 (14.8)	61.0 (6.9)	80.7 (13.6)	<0.001
Body mass index, kg/m^2	25.9 (5.1)	21.9 (2.0)	29.3 (4.5)	<0.001
Currently drinking alcohol	59.6% [124]	62.1% [59]	57.5% [65]	0.50
Non-lowering salt intake	46.2% [96]	44.2% [42]	47.8% [54]	0.61
Currently smoking	27.9% [58]	26.3% [25]	29.2% [33]	0.64
Systolic blood pressure, mmHg	132.3 (15.9)	130.1 (16.5)	134.2 (15.1)	0.06
Diastolic blood pressure, mmHg	78.4 (11.1)	77.0 (11.7)	79.5 (10.5)	0.10
Use of anti-hypertensive agents	26.9% [56]	17.9% [17]	34.5% [39]	0.007
No exercise	40.4% [84]	31.6% [30]	47.8% [54]	0.02
Unbalanced diet	46.2% [96]	42.1% [40]	49.6% [56]	0.28
Women	($n = 248$)	($n = 168$)	($n = 80$)	
Age, years	54.0 (16.7)	51.8 (17.1)	58.7 (14.8)	0.002
Height, cm	154.0 (6.9)	155.2 (6.9)	151.5 (6.2)	<0.001
Weight, kg	56.2 (10.0)	51.4 (6.2)	66.3 (9.1)	<0.001
Body mass index, kg/m^2	23.8 (4.5)	21.4 (2.2)	28.9 (3.6)	<0.001
Currently drinking alcohol	29.4% [73]	28.6% [48]	31.3% [25]	0.67
Non-lowering salt intake	25.8% [64]	25.0% [42]	27.5% [22]	0.67
Currently smoking	10.5% [26]	8.9% [15]	13.8% [11]	0.25
Systolic blood pressure, mmHg	127.7 (20.4)	123.3 (20.4)	136.9 (17.2)	<0.001
Diastolic blood pressure, mmHg	74.1 (12.3)	72.1 (12.6)	78.2 (10.5)	<0.001
Use of anti-hypertensive agents	26.2% [65]	19.6% [33]	40.0% [32]	0.001
No exercise	43.2% [107]	38.1% [64]	53.8% [43]	0.02
Unbalanced diet	38.3% [95]	35.1% [59]	45.0% [36]	0.14

Obesity was defined as a body mass index ≥25 kg/m^2 [13, 14]

Data are expressed as mean (standard deviation), or % [number] of participants

The unpaired *t*-test, or Chi-square test were used to compare each characteristic in each group

women (Table 2). For both sexes, the proportion of interest was higher in the 25≤ BMI < 30 kg/m^2 group than in the BMI ≥ 30.0 kg/m^2 group.

Background of the obesity epidemic in the island

The prevalence of no exercise was 40.4% in all the male subjects and 43.2% in all the female subjects (Table 1). Meanwhile, the prevalence of unbalanced diet was 46.2% in males and 38.3% in females (Table 1).

As shown in Table 3, the no exercise group had a significantly higher prevalence of obesity in both sexes compared to that in the regular exercise group (64.3% vs. 47.6% for men, and 40.2% vs. 26.2% for women). The odds ratio (95%CI) for obesity in the no exercise group, with the regular exercise group serving as the reference, was 2.03 (1.14−3.63) for men and 2.01 (1.15−3.53) for women after adjusting for age and dietary balance. The unbalanced diet group was likely to have a higher prevalence of obesity in both sexes, compared to that in the balanced diet group, (58.3% vs. 50.9% for men, and 37.9% vs. 28.8% for women). The odds ratio (95%CI) for obesity in the unbalanced diet group, with the balanced diet group serving as the reference, was 1.32 (0.75−2.32) for men and 1.42 (0.81−2.50) for women after adjusting for age and exercise habit.

Discussion

This community-based, cross-sectional study carried out in Yonaguni island, Okinawa prefecture, one of the most obesity-prevalent areas of Japan, demonstrated that the prevalence of obesity was 54.3% and 32.3% in the male and female study participants, respectively. The prevalence of hypertension was significantly higher in obese participants. Of all the hypertensive participants in Yonaguni island, 49.5% of males and 37.9% of females were associated with obesity (i.e., similar to the population attributable risk fraction).

NIPPON DATA2010 [19] reported that the prevalence of obesity (BMI ≥ 25 kg/m^2) in Japanese people aged

Table 2 Prevalence of hypertension and the odds ratio for its presence in participants grouped by the absence or presence of obesity, and the proportion of hypertension associated with obesity among all hypertensive subjects

		Hypertension				Obesity-associated
		Cases	Prevalence	Age-adjusted odds ratio (95%CI)	Multivariate-adjusted odds ratio (95%CI)	hypertension of all hypertension (95%CI)
Men						
Non-obese	($n = 95$)	33	34.7%	1, reference	1, reference	
Obese	($n = 113$)	69	61.1%	3.63 (1.89−6.98)	3.73 (1.93−7.20)	49.5% (29.4%−63.9%)
25≤BMI < 30 kg/m²	($n = 76$)	49	64.5%	3.54 (1.73−7.23)	3.56 (1.74−7.28)	34.5%
BMI ≥ 30 kg/m²	($n = 37$)	20	54.1%	3.83 (1.57−9.38)	4.15 (1.66−10.36)	14.9%
			$P < 0.001$ for all comparisons			
Women						
Non-obese	($n = 168$)	54	32.1%	1, reference	1, reference	
Obese	($n = 80$)	54	67.5%	4.18 (2.10−8.33)	4.13 (2.06−8.29)	37.9% (22.6%−50.2%)
25≤BMI < 30 kg/m²	($n = 58$)	36	62.1%	2.99 (1.41−6.36)	2.49 (1.20−5.18)	19.9%
BMI ≥ 30 kg/m²	(n = 22)	18	81.8%	12.15 (3.24−45.58)	12.41 (3.31−46.49)	15.3%
			$P < 0.001$ for all comparisons			

BMI, body mass index; CI, confidence interval

Obesity was defined as a body mass index ≥25 kg/m^2 [13, 14]

Hypertension was defined as a systolic blood pressure ≥140 mmHg, a diastolic blood pressure ≥90 mmHg [7], and/or taking antihypertensive agents

The Chi-square test was used to compare the prevalence between the two body mass index groups or among the three body mass index groups

A logistic regression model was used to calculate the odds ratio (95% confidence interval) with the non-obese group serving as the reference after adjusting for age, alcohol drinking habit, behavior for lowering salt intake, and smoking habit

The proportion of hypertension associated with obesity among all hypertensive subjects is similar to the population-attributable risk fraction

≥20 years was 33.5% for men and 23.0% for women. Our estimated prevalence of obesity in Yonaguni island indicates that it is an important public health problem in Okinawa prefecture including Yonaguni island. In accordance with similar cross-sectional and cohort studies [11, 20], there was also a significant positive association between BMI and the prevalence of hypertension in our study participants. The relatively high odds ratio for women with a BMI ≥ 30 kg/m^2 should be interpreted with caution because of the small number of subjects and the wide 95% confidence interval of the odds ratio in this group. NIPPON DATA2010 [21] reported that the prevalence of hypertension among Japanese aged ≥20 years was 58.2% for men and 42.5% for women. The prevalence of hypertension in Yonaguni island was therefore similar to or slightly lower than that reported in Japan by NIPPON DATA2010. In comparison to a representative Japanese population, our study population had a lower prevalence of drinking alcohol and a broadly similar prevalence of smoking [21]. Although we had no data on the amount of salt intake, the intake of people in Okinawa prefecture is the lowest among those in all prefectures in Japan [9]. Given a similar prevalence of hypertension between our study population and a representative Japanese population, obesity may largely affect hypertension in our study population, in contrast to that observed in a representative Japanese population.

For public health authorities responsible for providing health education to the public and improving social environments, it is important to consider the relationship between a risk factor (cause) and a health disorder (consequence) from a population viewpoint. The corresponding epidemiological measure based on cohort studies is called “the population attributable risk fraction,” and is reflected by both the prevalence of the risk factor in the target population and the magnitude of association between the risk factor and health disorder [16]. Therefore, even if the magnitude of association of interest is similar across populations, the varied prevalence of the risk factor in each population generates a different “population attributable risk fraction” in each population. When applying the concept of “the population attributable risk fraction” to cross-sectional studies [11, 22], we estimated the proportion of hypertensive subjects associated with a BMI ≥ 25 kg/m^2 (obesity) relative to all hypertensive subjects in Yonaguni island. The results show the expected reduction in the proportion of hypertensive subjects in the target population if obesity was removed from the population.

The results of our study were compared with those of relevant studies in Japan and other countries which provided data needed to calculate the proportion of interest (i.e., similar to the population attributable risk fraction).

Table 3 Prevalence of obesity and the odds ratio for its presence in participants grouped by the absence or presence of no exercise or an unbalanced diet

		Obesity			
		Cases	Prevalence	Age-adjusted odds ratio (95%CI)	Multivariate-adjusted odds ratio (95%CI)
Men					
Exercise habit					
Regular exercise	(n = 124)	59	47.6%	1, reference	1, reference
No exercise	(*n* = 84)	54	64.3%	2.07 (1.16−3.70)	2.03 (1.14−3.63)
			P = 0.02		
Dietary balance					
Balanced diet	(*n* = 112)	57	50.9%	1, reference	1, reference
Unbalanced diet	(*n* = 96)	56	58.3%	1.39 (0.80−2.42)	1.32 (0.75−2.32)
			P = 0.28		
Women					
Exercise habit					
Regular exercise	(*n* = 141)	37	26.2%	1, reference	1, reference
No exercise	(*n* = 107)	43	40.2%	2.09 (1.20−3.66)	2.01 (1.15−3.53)
			P = 0.02		
Dietary balance					
Balanced diet	(*n* = 153)	44	28.8%	1, reference	1, reference
Unbalanced diet	(*n* = 95)	36	37.9%	1.54 (0.88−2.67)	1.42 (0.81−2.50)
			P = 0.14		

CI, confidence interval

Obesity was defined as a body mass index ≥25 kg/m^2 [13, 14]

The Chi-square test was used to compare the prevalence between the two exercise habit groups or between the two dietary balance groups

A logistic regression model was used to calculate the odds ratio (95% confidence interval) with the better profile group serving as the reference after adjusting for age, and either dietary balance or exercise habit

Although there is no recent relevant study that provides the necessary data for estimates in a representative Japanese population or in a population of another area of Japan, NIPPON DATA90 [11] reported that of all representative hypertensive individuals in Japan, 15.3% of males and 22.3% of females were associated with obesity (BMI ≥ 25 kg/m^2). The relevant proportions in our study were therefore considerably larger, especially for men, compared with those of this previous Japanese study. At that time, of all Japanese hypertensive subjects, 34.5% and 2.6% were associated with excessive alcohol intake for men and women, respectively [22]. However, there is no relevant study that has estimated the proportion of hypertension associated with excessive salt intake. Several studies in Asian countries with broadly similar physical profiles with a BMI ≥ 25 kg/m^2 regarded as obesity provide relevant data for calculations based on our methods and comparisons. The proportion of hypertension associated with obesity (BMI ≥ 25 kg/m^2) has been reported as 13.8% [23], 19.2% [24] and 29.7% [25] in China (all the results were for men and women combined), 4.8% for men and 10.4% for women in South Korea [26], 11.7% for men and 13.2% for women in India [27], 14.8% (for men and women combined) in Vietnam [28], and 17.9% for men and 26.5% for women in Myanmar [29]. In contrast to Asian countries including Japan, in Western countries where 25≤ BMI < 30 kg/m^2 is regarded as overweight and BMI ≥ 30 kg/m^2 is regarded as obesity [13], studies have shown that of all hypertensive subjects, 56.1% of male and 49.9% of female hypertensive subjects in the United States were associated with a BMI ≥ 25 kg/m^2 [30], while 32.1% of overall cases in Italy were associated with a BMI ≥ 25 kg/m^2 [31]. The current study quantified the importance of obesity for the prevention and management of hypertension in a remote island of Okinawa, Japan with an obesity epidemic. When compared with a relevant literature review, the results of our study enabled us to understand that the public health concern about obesity in Yonaguni island and Okinawa prefecture, especially for men, was considerably more serious than that reported in Japan and other Asian countries, and was comparable to that reported in Western countries. These results accentuated the novelty of our study.

As anticipated, the prevalence of an unbalanced diet, which was likely to show a modest association with obesity, was higher among residents in the island than that observed in the overall Japanese population (46.2% vs 35.6% for

men, and 38.3% vs 30.6% for women) [9]. The National Health and Nutrition Survey in Japan, 2018 [9] reported that the leading cause of an unbalanced diet was "being burdensome" in 42.3% of men and 52.4% of women who had an unbalanced diet. The results of our study were reasonable, as food choices are generally more difficult in remote areas such as the target island, compared with other areas of Japan. Due to a lack of data, we could not use dietary energy intake in the analysis to investigate the background of the obesity epidemic. Meanwhile, the prevalence of no exercise, which was associated with obesity, was lower among residents in the island than that measured in the overall Japanese population (40.4% vs 66.6% for men, and 43.2% vs 74.9% for women) [9]. These results suggest that the obesity epidemic in the island was attributable largely to dietary issues, despite the better profile of exercise habit among the residents in the island, compared to those reported for the overall Japanese population. Further studies are therefore required to explore the background of the obesity epidemic in the island from the viewpoint of other dietary and socioeconomic factors.

The current study had several unique and methodological advantages. The study was conducted in an area quite different from other areas of Japan from the viewpoints of obesity prevalence and social environments. All adult residents actually living on the target island were invited to undergo the health check-up, and the majority of examinees participated in the study. However, it was unclear how many of the residents actually living on the island participated in our study because of limitations in the residence registration system. The high prevalence of obesity among the residents in the island made it possible to perform data analysis separately for men and women despite the limited number of residents.

The current study had several limitations that should be acknowledged. First, the data on BMI and blood pressure were collected by transcribing the findings of the health check-up on the same day. According to the rule of the health check-up facility, blood pressure was measured twice only if the first measurement showed high levels of blood pressure. The mean blood pressure levels of the male and female study populations were approximately 132 and 128 mmHg for systolic blood pressure and 78 and 74 mmHg for diastolic blood pressure, respectively. The mean or lower blood pressure levels were within the "normal grade" or "high-normal grade" based on the JSH2019 [7], and were below the cut-off level for "normotension" defined in our study. Based on the theory of "regression towards the mean [16]," the study subjects in these grades had a lower level of blood pressure after the single measurement than the actual level. However, this underestimation of blood pressure may have happened merely within the "normotension" level defined in our study. Therefore, the study limitation of the single blood pressure measurement may have been negligible. Second, with respect to excessive salt intake which was assumed to be a confounding factor, we used the data on the self-reported effort to reduce salt intake rather than the amount of salt intake measured by an objective evaluation. In this regard, because the people in Okinawa prefecture have the lowest salt intake among all prefectures in Japan [9], the confounding effect of excessive salt intake on the observed results may be not as large. Finally, cross-sectional studies such as our study, have shown that the magnitude of the association between obesity and hypertension is different from that of cohort studies. Because some hypertensive subjects may modify their lifestyles in accordance with a physician's advice or health guidance, cross-sectional studies usually may underestimate the magnitude of the association of interest. In this regard, our study showed a lower prevalence of anti-hypertensive agent use in male subjects, compared to that reported in NIPPON DATA2010 [21] (26.9% vs 31.7%). Therefore, male hypertensive subjects in our study may have received less physician's advice or health guidance and may not have modified their lifestyles to the same extent as those in NIPPON DATA2010. Meanwhile, our study and NIPPON DATA2010 [21] showed a broadly similar prevalence of anti-hypertensive agent use in female subjects (26.2% and 24.6%). This limitation of the cross-sectional design may be applicable to the magnitude of association we observed between each worse lifestyle profile and obesity, as well as the prevalence of each worse lifestyle profile. Some obese subjects may have already started lifestyle modification in accordance with a physician's advice or health guidance.

Perspective of Asia

The Asian population is in general thought to have a lower prevalence of obesity, compared with the Western population [19, 23–31]. However, the results of this study offer a caution that there could be areas of Asia with a considerably high prevalence of obesity, where the public health strategy should be revised by putting emphasis on obesity for the prevention and management of hypertension and the prevention of cardiovascular disease.

Conclusion

Our study in one remote island of Okinawa prefecture where obesity is prevalent showed that hypertension in approximately one-half of males and over one-third of females was associated with obesity defined as a BMI ≥ 25 kg/m^2. The results of this study indicate an urgent need to address obesity in areas of Japan with a high prevalence of obesity in order to

prevent cardiovascular disease. This urgent need may be the same as that seen in Western countries.

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Author contributions All authors conceived and were involved in the design of the study, data acquisition, statistical analysis, interpretation of the results, and wrote the manuscript. KN supervised the study.

Compliance with ethical standards

Conflict of interest The authors declare no competing interests.

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