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Original Article

Association between Radon Hot Spring Bathing and Health Conditions: A Cross-Sectional Study in Misasa, Japan

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No epidemiological studies have examined the health effects of daily bathing in radon hot springs. In this cross-sectional study, we investigated the associations between radon hot spring bathing and health conditions. The target population was 5,250 adults ≥ 20 years old in the town of Misasa, Japan. We collected information about the participants' bathing habits and alleviation of a variety of disease symptoms, and their self-rated health (SRH). Unadjusted and adjusted odds ratios (ORs) and 95% confidence intervals (CI) were calculated. In both the adjusted and unadjusted models of hypertension, significant associations between the > 1 × /week hot spring bathing and the alleviation of hypertension symptoms were observed compared to the group whose hot spring bathing was < 1 × /week: adjusted model, OR 5.40 (95%CI: 1.98-14.74); unadjusted model, 3.67 (1.50-8.99) and for gastroenteritis: adjusted model, 9.18 (1.15-72.96); unadjusted model, 7.62 (1.59-36.49). Compared to the no-bathing group, higher SRH was significantly associated with both bathing < 1 × /week: unadjusted model, 2.27 (1.53-3.37) and > 1 × /week: adjusted model, 1.91 (1.15-3.19). These findings suggest that bathing in radon hot springs is associated with higher SRH and the alleviation of hypertension and gastroenteritis.

Key words: radon hot spring, bathing habit, self-rated health, cross-section study

Radon (^{222}Rn), a radioactive noble gas, is a well-known risk factor for lung cancer. For example, miners' occupational exposure to high doses of radon and its progeny increased their risk of lung cancer [1, 2]. It was also reported that daily exposure to low doses of indoor radon increases the risk of lung cancer by 16% per 100 Bq/m^3 [3]. Radon is estimated to be the second leading cause of lung cancer, after smoking [4].

In contrast, radon hot springs have been used in the treatment of pain-related diseases such as rheumatoid arthritis (RA) [5-7] and osteoarthritis [8, 9]. The probable mechanism of radon therapy involves small amounts of reactive oxygen species induced by α-rays emitted from radon, activating antioxidative functions [10]. This activation results in the inhibition of inflammation, which plays a critical role in the development of RA and osteoarthritis. Thus, radon exposure has very different outcomes depending on the exposure conditions.

Although the mean indoor radon concentration in Misasa, Japan (a town of ~6,000 residents in Tottori

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Prefecture) was reported to be three times higher at 60 Bq/m^3 than in the control area (20 Bq/m^3), the cancer mortality rates and incidences of all cancers in Misasa, Asahi (Kamo, Takase) and east part of Takeda districts in Misasa did not differ significantly from those Mitoku, Oshika, and west part of Takeda districts [11]. However, that report does not include any data on the residents' bathing habits in radon hot springs. Since the radon concentration in indoor hot springs is much higher than the general indoor radon concentration, bathing in a radon hot spring should not be ignored when the health effects of radon are estimated. Another report showed that superoxide dismutase activity (which has an antioxidant effect) and p53 levels were significantly higher in women and men living in Misasa, respectively [12]. These findings may be associated with cancer mortality.

Residents of a radon hot springs district in Pingshan County, China were described as having enhanced immune function, suggesting radiation hormesis effects [13]. In addition, prolonged bathing in radon hot springs reduces 8-hydroxydeoxyguanosine (a marker of oxidative damage of DNA) and increases antioxidant function [14].

To the best of our knowledge, there have been no epidemiological surveys targeting adult residents of radon hot spring districts to examine the health effects of daily bathing in radon hot springs. We conducted the present study to examine the associations between bathing in radon hot springs and different health conditions.

Methods

Study design and participants. In this cross-sectional study, we surveyed individuals from March 4 to March 25, 2022. The target population included residents of Misasa, Tottori prefecture, Japan, who were ≥20 years old as of February 1, 2022 (n = 5,250; men, 2,467; women, 2,783). There are six areas in Misasa: Misasa (n = 2,105; men, 965; women, 1,140), Mitoku (n = 557; men, 262; women, 295), Kamo (n = 1,376; men, 658; women, 718), Oshika (n = 440; men, 214; women, 226), Takase (n = 222; men, 102; women, 120), and Takeda (n = 550; men, 266; women, 284). All radon hot springs (31 facilities) are located in the Misasa area. Participants provided written informed consent; those who did not provide consent were excluded.

This study was conducted in compliance with the Declaration of Helsinki and the Ethical Guidelines for Medical and Health Research Involving Human Subjects issued by Ministry of Education, Culture, Sports, Science and Technology, Ministry of Health, Labour and Welfare, and Ministry of Economy, Trade and Industry. The study was approved by the Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences and the Okayama University Hospital Ethics Committee (approval no. K2201-040), and the study is reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines [15].

Data collection and variable definitions. The Misasa town office distributed self-administered questionnaires to each resident and collected them by mail. The questionnaires asked the residents about their hot spring bathing frequency, duration of bathing sessions, and the number of years of bathing as exposure variables. The participants provided answers in the following categories: frequency of bathing in a hot spring (no bathing, bathing in the past, < 1 time/year, 1-11 times/year, 1-3 times/month, 1-2 times/week, 6 times/week, or every day), hot spring bathing duration (< 10 min, 10- < 20 min, 20-30 min, > 30 min), and the number of years of hot spring bathing (< 5 years, 5-10 years, 10- < 20 years, 20-30 years, > 30 years).

We divided the participants who had a habit of bathing in a radon hot spring into two groups (< 1 × /week, n = 635 and > 1 × /week, n = 313) depending on the estimated total annual bathing time, *i.e.*, using the data of the frequency and duration of bathing and the estimated radon concentration in the indoor hot spring (~530 Bq/m^3) [16]. However, the radon concentration varied depending on the indoor hot spring. The estimated total annual hot spring bathing duration for the > 1 × /week group was > 520 min. In contrast, the total bathing duration ranged from 360 to 480 min (radon concentration, 2,080 Bq/m^3). An important factor in hot spring bathing in addition to radon exposure is thermal effects. It was reported that not only radon therapy but also thermal treatment increased antioxidative and immune functions in humans [17]. We thus set a cut-off value based on the bathing time (> 520 min/year; 1 × /week).

We chose the alleviation of symptoms of hypertension, diabetes, gout, chronic respiratory disease, gastroenteritis, and dyslipidemia as the primary outcome variable. Alleviation was measured by the yes/no question: "Were the symptoms alleviated after radon hot spring bathing compared to before bathing?"

We used self-rated health (SRH) as a secondary outcome variable. The participants' SRH was measured with a single question: "In general, would you say your health is very good, good, fair, not so good, or poor?" The participants were presented with a Likert scale with 1 to 5 values, with 1 indicating good health and 5 indicating bad health. In the present study, we defined 'very good' and 'good' responses as indicating good health. We also collected individual and demographic information about the participants including sex, age, height, weight, residential area, tobacco smoking status, alcohol drinking status, socioeconomic status (SES), and the number of people living in the participant's household as well as the participant's reasons for bathing, quitting bathing, or not bathing. Subjective SES was measured using a single question: "Where would you put yourself socioeconomically on this scale" on a ladder with numbers from 1 to 9, on which 1 indicates wealthy and 9 indicates financial suffering. The targeted population for evaluating the primary outcome included all individuals who took a bath in a radon hot spring. The participants who took a bath in a radon hot spring were asked whether their symptom(s) improved after having taken a bath.

Statistical analysis. We conducted a logistic regression analysis to evaluate the relationship between bathing in a radon hot springs and the alleviation of symptoms of hypertension, diabetes, gout, chronic respiratory disease, gastroenteritis, and dyslipidemia. Unadjusted and adjusted models (for sex, age, alcohol, and SES as potential confounders) along with the odds ratios (ORs) and 95% confidence intervals (CIs) were calculated. Since no data regarding the alleviation of symptoms was obtained from individuals who did not bathe in a radon hot springs, those who bathed $<1\times$/week were taken as the reference group. We also calculated unadjusted and adjusted (for sex, age, alcohol, and SES) ORs and 95%CIs to evaluate the relationship between bathing in a radon hot springs and SRH. The participants who did not bathe in a radon hot springs were used as the reference group. We excluded the participants who did not provide a response on some variables.

Results

Demographic characteristics of the study participants. Among the mailed questionnaires, 2,044 were returned (39% response rate), and 1,888 individuals agreed to participate in the survey. The number of residents in each district is shown in Fig. 1. Forty percent of the residents lived in the Misasa district, where radon hot springs are located. The demographic characteristics showed that approx. 51% of the residents had bathed in a radon hot springs; 17% of the residents bathed routinely. The majority of the participants who reported being in the habit of bathing in a radon hot springs lived in the Misasa district, most likely because the hot springs are located in this area. There were no marked differences in other indicators among the bathing groups (Table 1).

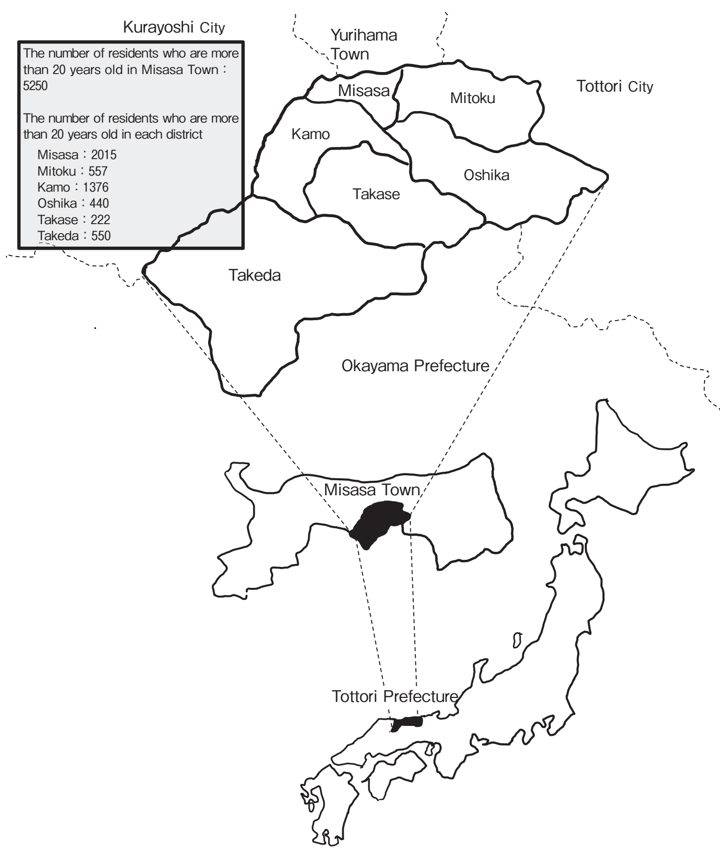

Fig. 1 Map of the Misasa district.

Table 1 Demographic characteristics of study subjects obtained from questionnaires of residents in Misasa town, February-March, 2021 (n = 1,862)

	No bathing n = 493	Bathing in the past n = 421	Less than once a week n = 635	More than once a week n = 313
Sex % n (%)				
Male	206 (43)	175 (42)	313 (50)	137 (44)
Female	276 (57)	241 (58)	315 (50)	172 (56)
Age, mean (SD)	63.7 (17.9)	66.3 (16.1)	59.5 (16.7)	68.5 (15.3)
BMI, mean (SD)	22.3 (3.6)	22.7 (3.4)	22.6 (3.1)	22.5 (3.0)
Residential Area n (%)				
Oshika	65 (13)	29 (7)	71 (11)	14 (4)
Mitoku	50 (10)	58 (14)	93 (15)	12 (4)
Misasa	129 (26)	150 (36)	177 (28)	241 (77)
Kamo	155 (32)	109 (26)	189 (30)	25 (8)
Takase	35 (7)	14 (3)	29 (5)	7 (2)
Takeda	57 (12)	58 (14)	76 (12)	14 (4)
Smoking Status n (%)				
Non-smoker	308 (65)	243 (60)	366 (58)	366 (58)
Smoker in the past	109 (23)	114 (28)	190 (30)	190 (30)
Smoker	60 (13)	48 (12)	71 (11)	71 (11)
Alcohol Drinking Status n (%)				
No drinking	280 (58)	210 (51)	235 (37)	146 (47)
1-3 times/month	49 (10)	69 (17)	130 (21)	42 (14)
1-2 times/week	32 (7)	37 (9)	52 (8)	24 (8)
3-6 times/week	35 (7)	35 (9)	84 (13)	31 (10)
Everyday	85 (18)	61 (15)	129 (20)	65 (21)
Socio-Economic Status, mean (SD)	5.73 (1.45)	5.70 (1.46)	5.26 (1.50)	5.64 (1.59)
Number of people living together, mean (SD)	3.41 (1.67)	3.12 (1.64)	3.62 (1.75)	2.74 (1.58)

SD, standard deviation.

Reasons for bathing, quitting bathing, and not bathing. The main reason for bathing was pleasure (38%). Other reasons were health maintenance, the vicinity, and communication with others. The respondents who did not have a bath in their homes bathed in a radon hot springs. Medical treatment was a minor reason for bathing (Table 2).

Reasons for quitting bathing were limited time (27%), the COVID-19 pandemic (17%), and no interest (10%). Economic problems, remoteness, and the installation of a bath at home may motivate an individual to quit bathing in a radon hot springs (Table 2).

The dominant reasons for not bathing in the radon hot springs were no interest and limited time. Generally, the reasons for not bathing were similar to those for quitting bathing (Table 2).

Logistic regression analysis of symptom alleviation. Table 3 summarizes the alleviation of several diseases' symptoms by radon hot spring bathing. Bathing in a radon hot springs > 1 × /week was significantly associated with the alleviation of hypertension (unadjusted OR 3.67, 95%CI: 1.50-8.99; adjusted OR 5.40, 95%CI: 1.98-14.74) and significantly associated with the alleviation of gastroenteritis (unadjusted OR 7.62, 95%CI: 1.59-36.49; adjusted OR 9.18, 95%CI: 1.15-72.96). No associations were observed in the other examined disorders. In this analysis, there was no data for the no-bathing group, and thus the effectiveness of bathing < 1 × /week was not evaluated (Table 3).

Logistic regression analysis of radon hot spring bathing for higher SRH. After adjusting for confounding factors, the results of the regression analysis showed significant associations between the SRH values of the no-bathing group and the bathing group (< 1 × /

Table 2 The reasons of bathing, quitting bathing, and no bathing (*n*=1,411)

	No bathing	Bathing in the past	Less than once a week	More than once a week
Reasons for bathing *n* (%)				
Pleasure	–	115 (38)	241 (53)	39 (18)
Health maintenance	–	58 (19)	62 (14)	64 (29)
Vicinity	–	46 (15)	40 (9)	81 (37)
Communication with others	–	38 (12)	66 (14)	4 (2)
No bathroom in the house	–	16 (5)	5 (1)	13 (6)
Medical treatment	–	13 (4)	8 (2)	6 (3)
Others	–	20 (7)	37 (8)	11 (5)
Reasons for quitting bathing *n* (%)				
No time	–	94 (27)	–	–
COVID-19	–	60 (17)	–	–
No interest	–	36 (10)	–	–
Economic problem	–	31 (9)	–	–
Remoteness	–	30 (8)	–	–
Installing a bathroom	–	25 (7)	–	–
Change in life style	–	19 (5)	–	–
Aging / disease	–	19 (5)	–	–
Others	–	40 (11)	–	–
Reasons for no bathing *n* (%)				
No interest	155 (41)	14 (13)	–	–
No time	102 (27)	35 (32)	–	–
Bathing in the house	25 (7)	4 (4)	–	–
Remoteness	22 (6)	11 (10)	–	–
Economic problem	18 (5)	12 (11)	–	–
No chance	13 (3)	1 (1)	–	–
Others	45 (12)	33 (30)	–	–

week, adjusted OR 1.44, 95%CI: 0.91-2.29; >1×/week, adjusted OR 1.91, 95%CI: 1.15-3.19). As the adjusted OR for those who bathed in a radon hot springs >1×/week was higher than that for those who bathed <1×/week, a dose-response relationship was observed (Table 4).

Discussion

The results of our analyses demonstrated that bathing in a radon hot springs was associated with higher SRH and the alleviation of hypertension and gastroenteritis. Radon inhalation has beneficial effects for medical use. Although the methods and conditions of radon therapy in Misasa, Japan, and countries in Europe are similar, radon concentrations in treatment rooms differ among medical facilities. Nevertheless, all concentrations of medical radon therapy have similar effects.

No direct evidence that radon itself alleviates hypertension has been reported, but radon inhalation increases the levels of α-atrial natriuretic polypeptide, which decreases blood pressure by relaxing the vascular smooth muscles and decreases the level of vasopressin, a hormone that increases blood pressure [18]. A spa treatment combining radon and carbon dioxide effectively lowered blood pressure [18], and balneotherapy using mineral radon water did not decrease blood pressure [19]. Our present findings showed that the OR of hypertensive individuals who bathed in a radon hot springs >1×/week was significantly higher than the OR of the individuals who bathed in a radon hot springs <1×/week. Our findings may differ from those of previous studies due to differences in bathing conditions [18-20].

We reported that in mice, radon inhalation and the consumption of radon hot spring water inhibited ethanol-induced gastric mucosal injury [21]. The probable mechanism is that radon inhalation and radon hot spring water consumption inhibit alcohol-induced oxi-

Table 3 The results of logistic regression analysis of radon hot spring bathing for alleviation of symptoms (n = 330)

Disorder	Bathing	Unadjusted model OR (95%CI)	Adjusted model OR (95%CI)
Hypertension	Less than once a week (n = 68) (improved n = 8, no change n = 60)	1.00 (Control)	1.00 (Control)
	More than once a week (n = 67) (improved n = 22, no change n = 45)	3.67 (1.50 to 8.99)	5.40 (1.98 to 14.74)
Diabetes	Less than once a week (n = 20) (improved n = 3, no change n = 17)	1.00 (Control)	1.00 (Control)
	More than once a week (n = 36) (improved n = 11, no change n = 25)	2.49 (0.60 to 10.29)	3.19 (0.43 to 23.43)
Gout	Less than once a week (n = 17) (improved n = 7, no change n = 10)	1.00 (Control)	1.00 (Control)
	More than once a week (n = 15) (improved n = 9, no change n = 6)	2.14 (0.52 to 8.81)	4.00 (0.45 to 35.87)
Chronic respiratory disease	Less than once a week (n = 19) (improve n = 11, no change n = 8)	1.00 (Control)	1.00 (Control)
	More than once a week (n = 16) (improved n = 10, no change n = 6)	1.21 (0.31 to 4.73)	1.24 (0.24 to 6.41)
Gastroenteritis	Less than once a week (n = 17) (improved n = 7, no change n = 10)	1.00 (Control)	1.00 (Control)
	More than once a week (n = 19) (improved n = 16, no change n = 3)	7.62 (1.59 to 36.49)	9.18 (1.15 to 72.96)
Dyslipidemia	Less than once a week (n = 17) (improved n = 2, no change n = 15)	1.00 (Control)	1.00 (Control)
	More than once a week (n=19) (improved n=6, no change n=13)	3.46 (0.59 to 20.21)	1.69 (0.19 to 15.05)

OR, odds ratio; 95%CI, 95% confidence interval; SES, socioeconomic status. Adjusted for sex, age, alcohol, and SES.

Table 4 The results of logistic regression analysis of radon hot spring bathing for higher SRH (n = 1,501)

	Unadjusted model OR (95%CI)	Adjusted model OR (95%CI)
No bathing (n = 553)	1.00 (Control)	1.00 (Control)
Less than once a week (n = 635)	2.27 (1.53 to 3.37)	1.44 (0.91 to 2.29)
More than once a week (n = 313)	1.49 (0.96 to 2.30)	1.91 (1.15 to 3.19)

SRH, self-rated health; OR, odds ratio; 95%CI, 95% confidence interval; SES, socioeconomic status. Adjusted for sex, age, alcohol, and SES.

dative stress by activating antioxidative functions. Radon inhalation also has anti-inflammatory effects. For example, healthy mice exposed to radon showed increased levels of helper T-cell (Th1, Th2, and Th17)-related cytokines while maintaining the balance among each T-cell-related immune response [22]. In an investigation using SKG/Jcl mice (RA model mice), the level of interleukin (IL)-6 (a Th17-related cytokine) was higher and the levels of Th1- (IL-12 [p70], IL-2, and interferon-γ) and Th2-related cytokines (IL-4 and IL-10) were lower than those of control mice. However, these cytokine values approach the normal levels [22].

Another study indicated that although lipopolysaccharide treatment increases the levels of Th1- and Th17-related cytokines in mice, radon inhalation decreases these cytokines. Thus, radon inhalation has immunomodulatory effects [23]. Radon therapy was also reported to increase antioxidative functions and immune function in patients [8]. In the present study, the ORs of gastroenteritis patients who bathed $>1\times$/week in a radon hot springs were significantly higher than those who bathed in a radon hot springs $<1\times$/week. This result may be associated with antioxidant and/or immunomodulatory effects. Further studies are needed to clarify its mechanism.

Since radon inhalation inhibits oxidative stress-induced diseases, we speculate that diabetes [24], gout [25], chronic respiratory disease [26], and dyslipidemia [27], which are induced by oxidative stress, are likely to be inhibited by radon inhalation. However, these ORs did not increase in the present population. One of the probable reasons for this result is that the ORs cannot be compared with the no-bathing group. Another reason may be that the bathing frequency was insufficient to alleviate the symptoms of these diseases.

We also observed that the ORs of the participants' SRH were significantly associated with their bathing habits. A high frequency of radon hot spring bathing was associated with a slower onset of functional disability in an earlier investigation [28]. It was also reported that a high frequency of radon hot spring bathing can reduce depression/dejection mood scores and tension/anxiety and increase SRH [29]. Full baths significantly decreased the fatigue score and improved the quality-of-sleep score when the baths' water level was higher than the armpits [29]. In addition, the use of bath additives resulted in significantly higher SRH and better sleep quality [29]. It is thus apparent that bathing in radon hot spring water can improve health conditions.

The health conditions shown in Table 2 (diseases and aging) were minor reasons to quit bathing. According to our earlier study, bathing in radon hot springs may improve health conditions [30], but our present investigation did not obtain direct evidence of this.

One of the strengths of this study was that it comprehensively targeted all adults in the town of Misasa. Second, since no epidemiological surveys have been reported on this topic, our findings provide important insights into the association between health conditions and bathing in radon hot springs. Although this was a cross-sectional study, the symptom-alleviation results allowed us to evaluate incidental aspects of the association.

Some study limitations should be considered. First, because this was a cross-sectional study, the causal direction between SRH and bathing in radon hot springs is unclear, and healthier people may have been more likely to bathe in the radon hot springs. Second, because the response rate was relatively low (39%), the applicability of the results to the entire target population should be considered carefully, and the generalizability of our findings may be limited. In addition, people who have more interest in their own health status as well as in bathing in radon hot springs are more likely to have responded to the survey. This may have resulted in a biased sample with more healthy respondents than that in the general population, resulting in self-selection bias. Third, we were unable to evaluate thermal effects. More studies are necessary to compare the thermal effects with/without radon. Fourth, unmeasured confounding factors that could have introduced bias may limit the interpretation of the results of this study. Lastly, since we did not have any information on the participants' treatment status, we suggest that a more detailed survey is necessary to clarify the effects of radon hot spring bathing.

In conclusion, bathing in radon hot springs has been associated with higher self-reported health and the alleviation of both hypertension and gastroenteritis. Further data are required to clarify the thermal effects of radon hot spring bathing.

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