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Review

Preventive Effects of Forest Bathing/Shinrin-Yoku on Cardiovascular Diseases: A Review of Mechanistic Evidence

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Abstract: Cardiovascular diseases (CVDs) are a group of disorders of the heart and blood vessels and include coronary heart disease, cerebrovascular disease, rheumatic heart disease, and other conditions, which are leading causes of global morbidity and mortality. It is very important to establish preventive measures against CVDs, including hypertension. Against this background, forest bathing/shinrin-yoku is attracting attention as a new method of health promotion and disease prevention. Forest bathing/shinrin-yoku is an activity that utilizes the healing effects of forests to promote people's health and prevent disease by stimulating the five senses, including sight, smell, hearing, taste, and touch, through forest visits. Since 2004, many scientific studies on the psychological and physiological effects of forest bathing/shinrin-yoku have been conducted, and many original scientific articles have been published. It has been reported that forest bathing/shinrin-yoku boosted immune system by increasing human natural killer activity and anticancer proteins in natural killer, lowered blood pressure and pulse rate, reduced stress hormones including adrenaline, noradrenaline in urine and cortisol in serum and saliva, increased the parasympathetic nervous activity and decreased the sympathetic nervous activity, improved sleep, reduced the negative emotions and increased positive feelings. In this article, the author reviewed the preventive effects of forest bathing/shinrin-yoku on CVDs from the perspectives of the effects of forest bathing/shinrin-yoku on stress hormones, parasympathetic nervous and sympathetic nervous systems, sleep, blood pressure and heart/pulse rate, and other mechanisms based on the published scientific evidence.

Keywords: adrenaline; autonomic nervous system; blood pressure; cardiovascular diseases (CVDs); forest bathing; heart rate; noradrenaline; shinrin-yoku; preventive effects; sleep; stress hormone

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1. Introduction

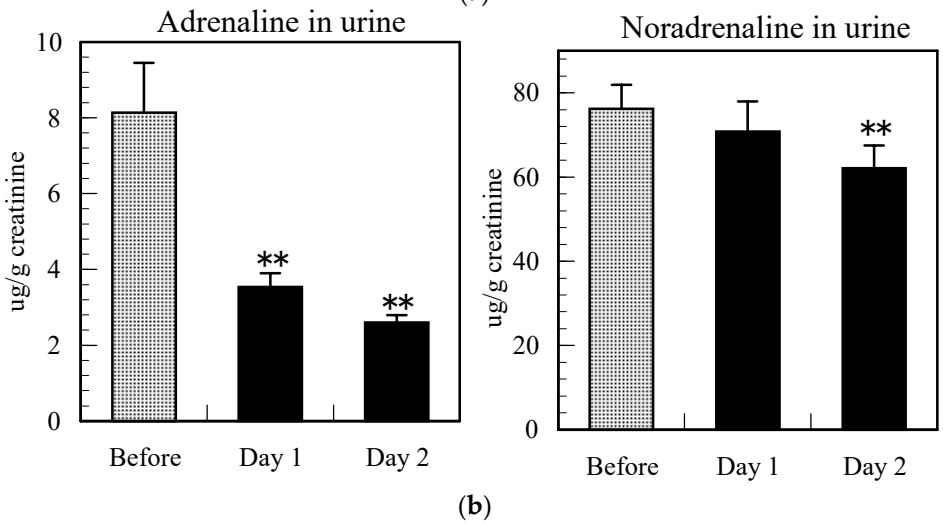
Cardiovascular diseases (CVDs) are the main causes of morbidity and mortality worldwide, affecting over 523 million people globally [1]. From 1990 to 2019, there was an overall increasing trend in the global incidence of atherosclerosis-related diseases (ischemic heart disease, ischemic stroke, and peripheral arterial disease) [2]. This poses a major health problem and a big challenge in the world. Hypertension is an important common risk factor in the onset of CVDs and stroke. It is very important to establish effective preventive measures against cardiovascular-related diseases, including hypertension [3,4]. Many researchers have tried to find potential preventive effects against lifestyle-related diseases, including CVDs from forests, and a traditional forest bathing/shinrin-yoku concept was proposed [5–7].

Shinrin-yoku is translated into Forest bathing in English. Shinrin in Japanese means 'forest', and yoku means 'bath'. Forest bathing is an activity that utilizes the healing effects

of forests to promote people's health and prevent disease by stimulating the five senses (sight, smell, hearing, taste, and touch) through forest visits. Forest bathing/shinrin-yoku was proposed in Japan in 1982 for the purpose of reducing stress and managing health, and scientific research into the health promotion and disease prevention effects of forest bathing/shinrin-yoku began in Japan in 2004 [5–9] (Figure 1a,b and Figure 2a,b).



(**a**)

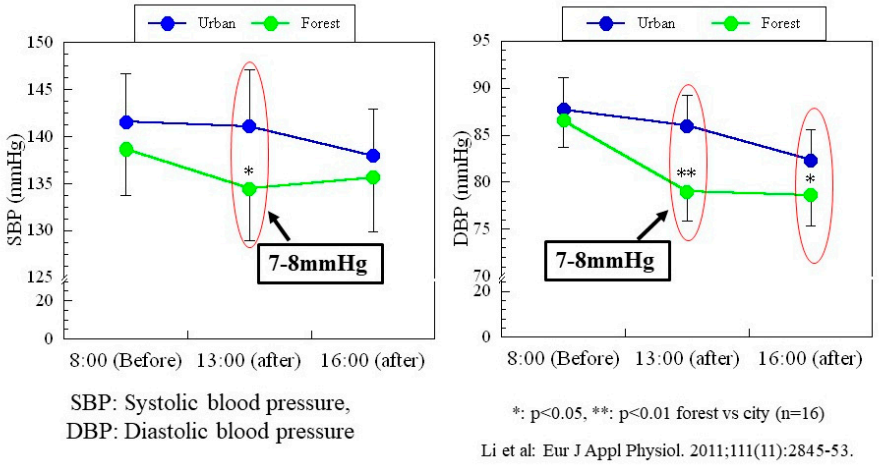


(**b**)

Figure 1. (**a**) Female subjects enjoyed forest bathing/shinrin-yoku in a Japanese cedar forest in Nagano prefecture in Japan (provided by the author); (**b**) Effect of the forest bathing/shinrin-yoku (3-day/2-night) on urinary adrenaline and noradrenaline concentrations in female subjects shown in Figure 1a. Data were presented as the mean + SE (n = 13). Two-way ANOVA with no-repeated measures indicated that forest bathing/shinrin-yoku significantly affected the adrenaline concentration in urine ($p < 0.01$). **: $p < 0.01$, significantly different from before the trip by paired t-test. Cited from Li et al. J. Biol. Regul. Homeost. Agents. 2008; 22: 45–55 [8].



(**a**)



(**b**)

Figure 2. (**a**) Male subjects enjoyed forest bathing/shinrin-yoku in a Japanese forest park in Saitama prefeture in Japan (provided by the author); (**b**) Forest bathing/shinrin-yoku significantly reduced blood pressure compared with city walking in male subjects shown in Figure 2a. Blood pressure was decreased by about 7–8 mmHg by forest bathing/shinrin-yoku. Cited from Li et al. Eur. J. Appl. Physiol. 2011; 111(11): 2845–2853 [9].

It has been reported that forest bathing/shinrin-yoku showed the following physical and mental benefits:

1. Forest bathing/shinrin-yoku acted on the central nervous system (brain) to increase vitality and significantly reduced symptoms such as tension, anxiety, depression, hostility, anger, confusion, and fatigue, making it effective in improving depressive states and is expected to have a preventive effect against depression [5–18].
2. Forest bathing/shinrin-yoku acted on the central nervous system (brain) to improve sleep and calm the brain [5,12,18–22].

3. Forest bathing/shinrin-yoku acted on the autonomic nervous system to suppress sympathetic nervous activity and increase parasympathetic nervous activity, resulting in a relaxing effect [9,10,15–17].
4. Forest bathing/shinrin-yoku acted on the immune system to enhance anti-cancer immune function, making the body less susceptible to cancer, and is expected to have a preventive effect against cancers [5–8,11,23–26].
5. Forest bathing/shinrin-yoku acted on the endocrine system to reduce stress hormones (adrenaline, noradrenaline concentration, cortisol), making it particularly effective against mental stress and applicable to stress management [8–17,27,28].
6. Forest bathing/shinrin-yoku acted on the endocrine system to increase blood serotonin concentration, making it effective in preventing depression [18].
7. Forest bathing/shinrin-yoku acted on the autonomic nervous system and endocrine system, lowering blood pressure and pulse rate and showing a preventive effect against hypertension and heart diseases [9,17,27–38].
8. Aromas derived from forests (phytoncides) played an important role in the effects of forest bathing/shinrin-yoku [5,6].
9. Walking in urban parks with lots of trees also had a relaxing effect [5,6].
10. Forest bathing/shinrin-yoku can also be applied to rehabilitation treatment [6].
11. Forest bathing/shinrin-yoku decreased blood pressure and pulse rate and showed potential beneficial effects in the prevention of CVDs [9,17,27–38].
12. In addition, Forest bathing/shinrin-yoku also showed additive beneficial effects in patients with chronic heart failure [29–31].

Regarding the potential effects of physical activity during the forest walk vs. actual forest exposure effects, Park et al. [27] showed that simply looking at forest scenery for 20 min reduced sympathetic nerve activity, increased parasympathetic nerve activity, and had a relaxing effect. Other studies reported that when the same subjects underwent forest bathing/shinrin-yoku and an urban walk with the same amount of physical activity, forest bathing/shinrin-yoku reduced blood pressure [9], pulse rate [17] and urinary adrenaline [23] and increased immune function [23] compared to the urban walk. These studies showed that forest bathing/shinrin-yoku itself had an effect, even excluding the potential effects of physical activity.

It also has been reported that neighborhood greenspace had the effect to lower the risk of CVDs, type 2 diabetes, and the incidence of overweight and obesity [39–41]. Hartig et al. [42] found that more greenspace was associated with lower all-cause and CVD mortality in communities with relatively stable populations in Sweden. Richardson and Mitchell [43] reported that the mortality rates of CDVs and respiratory diseases in males decreased with increasing green space, but no significant associations were found for females, indicating gender differences in the United Kingdom. In New Zealand, nearby green spaces were related to good cardiovascular index and mental health, independent of individual risk factors [44]. Moreover, Bikomeye et al. [45] carried out a systematic review and meta-analysis of 31 articles on the impact of greenspace or nature-based interventions on cardiovascular health-related outcomes and found that greenspace may have beneficial effects in CVD related outcomes; however, there is a need for investigation of the mechanisms by which nature-based interventions impact CVDs. In addition, Piva et al. [46] also conducted a systematic review on the effects of forest walking on physical and mental health in elderly populations and concluded that forest walking may play an important role in promoting physical and mental health in healthy and pathological elderly populations; however, the lack of high-quality studies limits the strength of the results, calling for more trials.

Why are forest bathing/shinrin-yoku (forest environments) and neighborhood greenspace associated with a lower risk of CVDs? Based on the above background, in this

paper, the author will review the preventive effects of forest bathing/shinrin-yoku on CVDs from the perspectives of the effects of forest bathing/shinrin-yoku on stress hormones, the autonomic nervous system, sleep, blood pressure and heart rate, and other factors.

Although several reviews have been published on the health-promoting and disease-preventing effects of forest bathing/shinrin-yoku [6,35,36,45,46], there has not yet been a review on the preventive effects of forest bathing/shinrin-yoku on CVDs from the perspective of various mechanisms, which makes this review original and novel.

2. Search Strategy

The forest bathing concept was proposed in Japan in 1982 [6], and research on the health-promoting effects of forest bathing began in the 1990s [5]; therefore, the author searched electronic databases (PubMed, ScienceDirect, Scopus and Google Scholar) for this review which covered the period from 1990 to 2024. The search keywords were used as follows: 'forest bathing'; 'shinrin-yoku'; 'forest therapy'; 'greenspace or greenery'; 'phytoncides'; 'blood pressure or hypertension'; 'pulse rate (heart rate)'; 'stress hormones'; 'adrenaline'; 'noradrenaline'; 'cortisol'; 'cardiovascular diseases (CVDs); 'sleep'; 'autonomic nervous system'; 'sympathetic nervous'; 'parasympathetic nervous'; 'diabetes'; 'chronic obstructive pulmonary disease (COPD'. The non-English publications were excluded. Several similar reviews were also excluded.

1. The preventive effects of forest bathing/shinrin-yoku in CVDs by reducing stress hormones

Stress is a keyword to understanding the potential preventive effects of forest bathing/shinrin-yoku on CVDs because stress can induce almost all non-communicable diseases, such as CVDs, stroke, hypertension, depression, gastric ulcer, obesity, alcoholism, panic disorder, eating disorders, and cancers [6]. In addition, noise-induced mental stress was centered on increased stress hormone levels, blood pressure, and heart rate, which in turn favor the development of cerebrocardiovascular disease, such as stroke, arterial hypertension, ischemic heart disease, and myocardial infarction [47]. It has been reported that there are three kinds of stress hormones: adrenaline (which mainly indicates mental stress), noradrenaline (which mainly indicates physical stress), and cortisol (which can indicate both) [6,48,49]. Adrenaline is released from the adrenal medulla, and the adrenaline level increases under circumstances of novelty, anticipation, unpredictability, and general emotional arousal, whereas noradrenaline is the predominant neurotransmitter released by the sympathetic system, and some of this enters the blood; the level of noradrenaline increases during increased physical activity [49]. Cortisol is released by the hypothalamic-pituitary-adrenal axis in response to stress [27]. It has been reported that forest bathing/shinrin-yoku reduces stress hormones, such as adrenaline, noradrenaline, and cortisol, and may contribute to stress management [8–17,23,27,28] (Table 1). In addition, because the effect of forest bathing/shinrin-yoku on adrenaline was greater than that on noradrenaline, the effect on mental stress was greater than on physical stress [5,8,23]. Other researchers also reported that forest bathing/shinrin-yoku reduced cortisol in saliva [12–16,27,28] (Table 1).

Regarding the gender difference in the effects of forest bathing/shinrin-yoku on stress hormones, females showed more effect than males in urinary adrenaline [8,23], which was similar to the effects on mental health [5].

In clinical practice, adrenaline and noradrenaline are used as drugs to increase blood pressure. Therefore, forest bathing/shinrin-yoku may show preventive effects in CVDs by reducing stress hormones, including adrenaline and noradrenaline.

Table 1. The main references (original articles) on the effects of forest bathing/shinrin-yoku on the levels of stress hormones such as adrenaline, noradrenaline, and cortisol compared between forest bathing/shinrin-yoku and urban walking or between before and after forest bathing/shinrin-yoku.

Authors	Journals	Methods	Subjects (Number)	Observation Period	Main Results	Ref. No.
Li et al.	Int. J. Immunopathol. Pharmacol. 2008; 21: 117–127.	Field experiment (outdoor) Comparison between forest bathing and urban walking	Healthy male subjects, aged 35–56 years (n = 12)	Three-day/2-night forest bathing + 30-day	Decrease of adrenaline in urine ($p < 0.05$ by pared t-test)	[23]
Li et al.	J. Biol. Regul. Homeost. Agents. 2008; 22: 45–55.	Field experiment (outdoor) Comparison between before and after forest bathing	Healthy female subjects, aged 25–43 years (n = 13)	3-day/two-night forest bathing + 30-day	Decreases of adrenaline ($p < 0.01$) and noradrenaline ($p < 0.01$ by pared t-test) in urine	[8]
Lee et al.	Public Health. 2011; 125(2): 93–100.	Field experiment Comparison between forest bathing and urban walking	Healthy male subjects, aged 21.2 ± 0.9 years (n = 12)	3-day/2-night forest bathing	Decrease of salivary cortisol ($p < 0.05$ by pared t-test)	[10]
Li et al.	J. Biol. Regul. Homeost. Agents 2010; 24: 157–165.	Field experiment (outdoor) Comparison between before and after forest bathing	Healthy male subjects, aged 35–53 years (n = 12)	One day forest bathing + 7-day	Decreases of adrenaline in urine ($p < 0.05$ by pared t-test) and cortisol ($p < 0.01$ by pared t-test) in serum	[11]
Kim et al.	Int. J. Environ. Res. Public Health. 2020; 17(18): 6548.	Field experiment (outdoor) Comparison between before and after forest bathing	Postmenopausal women aged 58.8 ± 3.9 (n = 35)	6 days	Decreases of cortisol in serum ($p < 0.01$ by pared t-test)	[12]
Joung et al.	Int. J. Environ. Res. Public Health. 2020; 17(9): 3266.	Field experiment (outdoor) Comparison between forest bathing and urban walking	College students (14 males and 8 females, aged 20.9 ± 1.3 years) (n = 22)	15 min	Decreases of salivary cortisol ($p < 0.01$ by pared t-test)	[13]
Queirolo et al.	Front. Psychol. 2024; 15: 1458418.	Field experiment (outdoor) Comparison between before and after forest bathing	Healthy participants (10 men and 19 women, mean age = 48.8, SD = 9) (n = 29)	2 days	Decreases of salivary cortisol ($p < 0.05$ by e Wilcoxon rank test)	[14]
Li et al.	Eur. J. Appl. Physiol. 2011; 111(11): 2845–2853.	Field experiment (outdoor) Comparison between forest bathing and urban walking	Healthy male subjects (57.4 ± 11.6 years) (n = 16)	Two-day forest bathing and city trip	Reduced blood pressure and urinary noradrenaline ($p < 0.05$ by pared t-test)	[9]
Li et al.	Evid. Based Complement. Alternat. Med. 2016; 2016: 2587381.	Field experiment (outdoor) Comparison between forest bathing and urban walking	Middle-aged male subjects (40 to 69 years, 51.2 ± 8.8) (n = 19)	Two-day forest bathing	Decreases of urinary adrenaline ($p < 0.05$ by pared t-test) and heart rate ($p < 0.01$ by pared t-test)	[17]
Yamaguchi et al.	J. Int. Med. Res. 2006; 34: 152–159.	Field experiment (outdoor) Comparison between forest bathing and urban walking	Male students aged from 21 to 23 (n = 86)	Two-day forest bathing	Decrease of salivary amylase activity ($p < 0.05$ by pared t-test)	[16]
Tsunetsugu et al.	J. Physiol. Anthropol. 2007; 26(2): 135–142.	Field experiments (outdoor) Comparison between forest bathing and urban walking	Male students aged 21–23 (22.0 ± 1.0) (n = 12)	15 min forest bathing	Decrease in salivary cortisol level ($p < 0.05$ by pared t-test)	[15]
Park et al.	Environ. Health Prev. Med. 2010; 15: 18–26.	Field experiments (outdoor) Comparison between forest bathing and urban walking	Male university students aged 21.7 ± 1.5 (n = 280)	20 min forest bathing	Decrease in salivary cortisol level ($p < 0.01$ by pared t-test)	[27]
Ochiai et al.	Int. J. Environ. Res. Public Health. 2015; 12(12): 15222–15232.	Field experiment (outdoor) Comparison between forest bathing and urban walking	Middle-aged females (62.2 ± 9.4 years) (n = 17)	Two-day forest bathing	Decrease in salivary cortisol level ($p < 0.05$ by pared t-test)	[28]

2. The preventive effects of forest bathing/shinrin-yoku in CVDs by stabilizing the balance of the autonomic nervous system

Stress hormones and the autonomic nervous system influence each other. Forest bathing/shinrin-yoku affected CVD not only through stress hormones but also through the autonomic nervous system [5]. The autonomic nervous system consists of the sympathetic nervous system and the parasympathetic nervous system. The balance of the sympathetic and parasympathetic nervous systems plays a pivotal role in the regulation of blood pressure and heart rate: sympathetic nervous activity increases, whereas parasympathetic nervous activity reduces blood pressure and heart rate [48,49]. Heart rate variability (HRV), as well as blood pressure and pulse rate (heart rate), are frequently employed to estimate changes in autonomic nervous activity. The R–R interval obtained from electrocardiograms is used to asses HRV. The power of the low-frequency (LF; 0.04–0.15 Hz) and high-frequency (HF; 0.15–0.4 Hz) components of the obtained heart rate power spectrum for each minute are generally calculated. HF power is considered to reflect parasympathetic nervous activity, and either LF/HF or LF/(LF + HF) is considered to be an index of sympathetic nervous activity [50]. Previous studies indicated that subjects in a forest environment had more enhanced parasympathetic and lower sympathetic nervous activity than those in an urban environment [15,27]. HRV analysis is thus a useful method for detecting the sympathetic and parasympathetic nervous activity separately on a minute-by-minute basis [51]. Sympathetic nervous activity can also be determined by measuring the levels of urinary adrenaline and/or noradrenaline [48], and there are significant correlations between blood pressure and urinary adrenaline and noradrenaline levels [49]. It has been reported that forest bathing/shinrin-yoku reduced urinary adrenaline and noradrenaline levels [8,9,23]. A number of CVDs have been shown to be characterized by a marked increase in sympathetic drive to the heart and the peripheral circulation, including essential hypertension, congestive heart failure, cardiac arrhythmias, obesity, metabolic syndrome, obstructive sleep apnea, and chronic renal disease. This indicated that higher activity of the sympathetic nervous system was a very important risk factor for cardiovascular diseases [52]. On the other hand, it has been reported that forest bathing/shinrin-yoku reduced sympathetic nervous activity, increased parasympathetic nervous activity, and regulated the balance of autonomic nerves [9,15–17,51]. As a result, forest environments reduced blood pressure and heart rate (Table 2) and had relaxing effects [15–17,51].

Table 2. Forest bathing/shinrin-yoku significantly decreased the pulse rate in male subjects. Heart rate (pulse rate) is a basic index of activity of the autonomic nervous system [17].

Time	Urban Area	Forest Bathing/Shinrin-yoku	*p* Value * (Urban vs. Forest)	Remark
10:40	72.7	67.8	<0.05	Walking
11:00	75.3	71.7	<0.05	Walking
11:20	80.2	74.2	<0.01	Walking
11:40	79.2	73.5	<0.01	Walking
12:00	77.6	73.7	<0.05	Walking
12:20	78.3	74.2	<0.05	Walking
12:40	68.3	66.4	>0.05	Lunch break
13:20	72.1	70.8	>0.05	Lunch break
13:40	77.8	75.3	>0.05	Lunch break
14:00	82.8	76.5	<0.01	Walking
14:20	82.5	75.3	<0.01	Walking
14:40	82.4	75.9	<0.01	Walking
15:00	80.6	74.4	<0.01	Walking

On both trips, the subjects walked 2.6 km for 80 min each in the morning and afternoon on Saturdays. Pulse rates were measured every 20 min during the trips. *: Forest vs. urban by paired *t*-test (n = 19).

Taken together, forest bathing/shinrin-yoku had the potential preventive effects against CVDs by reducing the activity of the sympathetic nervous system.

3. The preventive effects of forest bathing/shinrin-yoku in CVDs by improving sleep

Forest bathing/shinrin-yoku affects CVD not only through stress hormones and the autonomic nervous system but also through sleep [5]. Several studies have reported the association and mechanism between CVDs and sleep disorders (insomnia) [53,54]. Moreover, the Japanese Circulation Society (JCS) has proposed that sleep is a cardiovascular risk factor in the JCS 2023 Guideline on Diagnosis and Treatment of Sleep Disordered Breathing in Cardiovascular Disease [55]. Excessive sympathetic excitation increases blood pressure and induces sleep disorders. Other mechanisms also contributed to this effect and to the increase in cardiovascular risk. The result of the meta-analysis of cross-sectional studies or longitudinal studies showed a significant association between short sleep duration and hypertension [56]. The above studies indicated that sleep disorders were important risk factors for CVDs. It has been reported that forest bathing/shinrin-yoku trips significantly improved sleep quality and sleep duration [5,18–22]. Two-day/3-night forest bathing/shinrin-yoku trip significantly increased sleep duration in middle-aged male subjects [5]. Walking in forests also significantly improved sleep quality, including sleepiness on rising and the feeling of being refreshed [18]. In addition, two hours of forest bathing/shinrin-yoku improved nocturnal sleep conditions for individuals with sleep complaints, possibly as a result of exercise and emotional improvement [19]. Morita et al. [20] investigated the effect of forest bathing/shinrin-yoku on the prevalence of insomnia symptoms in the general Japanese population and found that increasing the frequency of forest bathing/shinrin-yoku may be effective in preventing insomnia in women but not in men, suggesting a gender difference. Quan et al. [21] also reported that the effects of forest-based health and wellness experience on the sleep indicators showed both individual and gender differences; sleep quality generally improved better for females than males. Hassan and Zhang [22] investigated the effect of sleeping in a forest on sleep quality measured by electroencephalography and found that there was a statistically significant decrease in systolic blood pressure after the participants slept in a forest environment compared to when they slept in a room (control). Moreover, a notable increase in alpha- and beta-wave frequencies was detected in the forest environment, suggesting the improvement of sleeping quality by forest bathing/shinrin-yoku. Polysomnography is a physiological test that examines sleep status and is used to diagnose sleep-related disorders. Polysomnography tests record biological phenomena such as electroencephalograms, eye movements, electromyograms, respiratory movements, electrocardiograms, and transcutaneous arterial oxygen saturation. Kim et al. conducted a 6-day forest therapy program with 35 postmenopausal women and measured sleep situation by polysomnography and sleep questionnaires before and after the program. Polysomnography showed sleep efficiency increased to 89.3 $\pm$ 4.3% ($p < 0.01$), and waking after sleep onset reduced to 47.4 $\pm$ 22.3 min ($p < 0.01$). The total sleep time also increased to 428.5 min, and sleep latency was 11.1 $\pm$ 11.0 min, suggesting that forest therapy could be a good alternative to nonpharmacological treatment for mitigating insomnia in postmenopausal women [12].

Taken together, forest bathing/shinrin-yoku may show preventive effects in CVDs by improving sleep.

4. The preventive effects of forest bathing/shinrin-yoku in CVDs by reducing blood pressure and heart rate

Forest bathing/shinrin-yoku affected CVD not only through the effects of stress hormones, the autonomic nervous system, and sleep but also through the effects of blood pressure and heart rate [5,6]. In clinical practice, adrenaline and noradrenaline are used as drugs to increase blood pressure. Therefore, the sympathetic nerve and stress hormones, including

adrenaline, noradrenaline, and cortisol, increase blood pressure [49]. It has been reported that forest bathing/shinrin-yoku trip decreased sympathetic nervous activity and levels of adrenaline and noradrenaline in urine and cortisol in serum and saliva [8–17,27,28,51]; therefore, the author hypothesized that forest bathing/shinrin-yoku may decrease blood pressure and pulse rate by reducing the levels of adrenaline, noradrenaline and cortisol. In fact, many studies have reported that forest bathing/shinrin-yoku decreased blood pressure in subjects with high-normal blood pressure [9,28,32–38] (Table 3).

Table 3. The main references (original articles) on the effects of forest bathing/shinrin-yoku on blood pressure and pulse rate compared between forest bathing/shinrin-yoku and urban walking or between before and after forest bathing/shinrin-yoku.

Authors	Journals	Methods	Subjects (Number)	Observation Period	Main Results	Ref. No
Tsunetsugu et al.	J. Physiol. Anthropol. 2007; 26(2): 135–142.	Field experiments (outdoor) Comparison between forest bathing and urban walking	Male university students aged from 21 to 23 (22.0 ± 1.0) (n = 12)	15 min forest bathing	Decrease in blood pressure ($p < 0.05$, $p < 0.01$ by pared t-test) and pulse rate ($p < 0.05$, $p < 0.01$ by pared t-test)	[15]
Park et al.	Environ. Health Prev. Med. 2010; 15: 18–26.	Field experiments (outdoor) Comparison between forest bathing and urban walking	Male university students aged 21.7 ± 1.5 year (n = 280)	20 min forest bathing	Decrease in blood pressure ($p < 0.05$, $p < 0.01$ by pared t-test) and pulse rate ($p < 0.01$ by pared t-test)	[27]
Li et al.	Eur. J. Appl. Physiol. 2011; 111(11): 2845–2853.	Field experiment (outdoor) Comparison between forest bathing and urban walking	Male subjects with high-normal blood pressure (57.4 ± 11.6 years) (n = 16)	One day forest bathing	Reduced blood pressure ($p < 0.05$, $p < 0.01$ by pared t-test) and urinary noradrenaline ($p < 0.05$ by pared t-test) Increases in adiponectin and DHEA-S (all $p < 0.05$ by pared t-test)	[9]
Lee et al.	Public Health. 2011; 125(2): 93–100.	Field experiment Comparison between forest bathing and urban walking	Healthy male subjects, aged 21.2 ± 0.9 years (n = 12)	Three-day/2-night forest bathing	Decrease of pulse rate ($p <$ 0.01 by pared t-test)	[10]
Mao et al.	J. Cardiol. 2012; 60(6): 495–502.	Field experiment (outdoor) Comparison between forest bathing and urban walking	Hypertension patients with 60 to 75 years (n = 30)	7-day/7-night forest bathing	Reduction in blood pressure ($p < 0.05$ by Mann–Whitney U test)	[32]
Ochiai et al.	Int. J. Environ. Res. Public Health. 2015; 12(3): 2532–2542.	Field experiment (outdoor) Comparison between forest bathing and urban walking	Middle-aged males ((56 ± 13.0)) (n = 9)	One-day forest bathing	Decrease in blood pressure ($p < 0.01$ by pared t-test)	[28]
Li et al.	Evid. Based Complement. Alternat. Med. 2016; 2016: 2587381.	Field experiment (outdoor) Comparison between forest bathing and urban walking	Middle-aged male subjects (40 to 69 years, 51.2 ± 8.8) (n = 19)	One day forest bathing	Decreases of Urinary adrenaline ($p < 0.05$ by pared t-test) and heart rate (pulse rate) ($p < 0.01$ by pared t-test)	[17]
Yu et al.	Int. J. Environ. Res. Public Health, 2017; 14(8): 897.	Field experiments (outdoor) Comparison between before and after forest bathing	Middle-aged subjects (60.0 ± 7.44 years) (n = 128)	Two-hour	Decreases in blood pressure ($p < 0.01$ by pared t-test) and pulse rate ($p < 0.01$ by pared t-test)	[33]
Furuyashiki et al.	Environ. Health Prev. Med. 2019; 24(1): 46.	Field experiments (outdoor) Comparison between before and after forest bathing	Male: n = 69, female: n = 86, 19–59 years old (44.0 ± 9.6) (n = 155)	One day forest bathing	Decreases in blood pressure ($p < 0.01$ by pared t-test)	[34]
Huang et al.	Forests, 2023, 14(1), 75	Field experiments (outdoor) Comparison between forest bathing and urban walking	Non-hospitalized hypertensive patients aged 60 to 75 years (n = 20)	Three-day forest bathing	Decreases in blood pressure ($p < 0.05$ by Kruskal–Wallis test)	[37]

To prove my above hypothesis, my research team examined the effects of forest bathing/shinrin-yoku on blood pressure in middle-aged male subjects who did not take antihypertensive drugs [9]. The subjects walked for two hours each in the morning and afternoon for a total distance of about 6 km in the forest park/urban area and then returned to Tokyo. The subjects consumed the same number of calories during the two trips. To control for the effects of alcohol, the subjects did not consume alcohol during the study period. Blood and urine were sampled on the morning before the trips and on the morning after the trips under fasting conditions. Blood pressure was measured before, during, and after the trips. The physical activity of the subjects was monitored with a pedometer. There was no difference in caloric consumption between the two trips. As shown in Table 4, both systolic and diastolic blood pressure levels during forest bathing/shinrin-yoku were significantly lower than those during city walking. On the other hand, there was no significant difference in both systolic and diastolic blood pressure levels between before forest bathing/shinrin-yoku and before city walking. The decreases in blood pressure after walking in the forest park were about 7 mmHg for both systolic blood pressure (SBP) (from 141.1 to 134.5 mmHg) and diastolic blood pressure (DBP) (from 86.0 to 79.0 mmHg). The antihypertensive effect of forest bathing/shinrin-yoku was comparable to that of antihypertensive agents (Table 4). Moreover, forest bathing/shinrin-yoku had no side effects and was free compared to antihypertensive drugs. This was hitting three birds with one stone.

Table 4. Forest bathing/shinrin-yoku significantly reduced blood pressure compared with city walking.

	Mean ± SE 8:00 (Before)	**Mean ± SE 13:00 (After)**	**Mean ± SE 16:00 (After)**
City walking (SBP)	141.6 ± 5.2	141.1 ± 6.0	137.9 ± 5.0
Forest bathing/shinrin-yoku (SBP)	138.7 ± 4.9	134.5 ± 5.5 *	135.7 ± 5.7
City walking (DBP)	87.7 ± 3.5	86.0 ± 3.4	82.3 ± 3.3
Forest bathing/shinrin-yoku (DBP)	86.5 ± 2.9	79.0 ± 3.2 **	78.6 ± 3.3 *

The subjects walked for two hours each in the morning and afternoon for a total distance of about 6 km in the forest park or urban area, and blood pressure was measured before, during, and after the trips. *: $p < 0.05$, **: $p < 0.01$ forest vs. city by pared t-test ($n = 16$). Blood pressure was decreased by about 7 mmHg by forest bathing/shinrin-yoku [9].

Mao et al. [32] also found that a 7-day/7-night forest bathing/shinrin-yoku trip in a broad-leaved evergreen forest had beneficial effects on patients with hypertension by suppressing the renin-angiotensin system and inflammation. In addition, Ochiai et al. [28] and Yu et al. [33] reported that walking in forest parks reduced blood pressure in middle-aged males with high-normal blood pressure. Furuyashiki et al. [34] investigated the physiological and psychological effects of one day of forest bathing/shinrin-yoku in 155 subjects and found that all participants showed significant decreases in SBP and DBP after the forest bathing/shinrin-yoku. Moreover, Ideno et al. [35] systematically reviewed the medical literature and performed a meta-analysis from four databases searched for the period before May 2016 with a language restriction of English and Japanese to evaluate the preventive effects of the forest environments on blood pressure and found that forest bathing/shinrin-yoku significantly decreased blood pressures. Yau and Loke [36] also reviewed 14 studies on the effects of forest therapy and concluded that forest therapy had physiologically and psychologically relaxing effects on middle-aged and elderly subjects with pre-hypertension and hypertension. We also found that walking in forest environments decreased pulse rate in male subjects [17]. Recently, Huang et al. [37] evaluated the antihypertensive effects of forest bathing/shinrin-yoku in a *Cinnamomum camphora* (*C. camphora*) forest environment in four seasons in China and found that the effect of forest bathing/shinrin-yoku on decreasing blood pressure was particularly pronounced during summer and autumn.

People with poor sleep patterns and insomnia were associated with an increased risk for hypertension [57–59]. Forest bathing/shinrin-yoku may improve sleep [5,12,18–22].

Taken together, forest bathing/shinrin-yoku lowered blood pressure and pulse rate through the following mechanisms (Figure 3):

(1) Forest bathing/shinrin-yoku decreased blood pressure and pulse rate by lowering adrenaline and noradrenaline in urine [8,9,17,23], salivary cortisol [10,12–15,27,51], and cortisol in serum [11]. In clinical medicine, it is well known that adrenaline, noradrenaline, and cortisol increase blood pressure and pulse rate.
(2) Forest bathing/shinrin-yoku lowered blood pressure by suppressing sympathetic nervous activity and by enhancing parasympathetic nervous activity [9,15–17,27,51].
(3) Forest bathing/shinrin-yoku reduced blood pressure by improving sleep [5,12,18–22].
(4) Forest bathing/shinrin-yoku has been reported to lower blood pressure by suppressing the renin-angiotensin system [32].

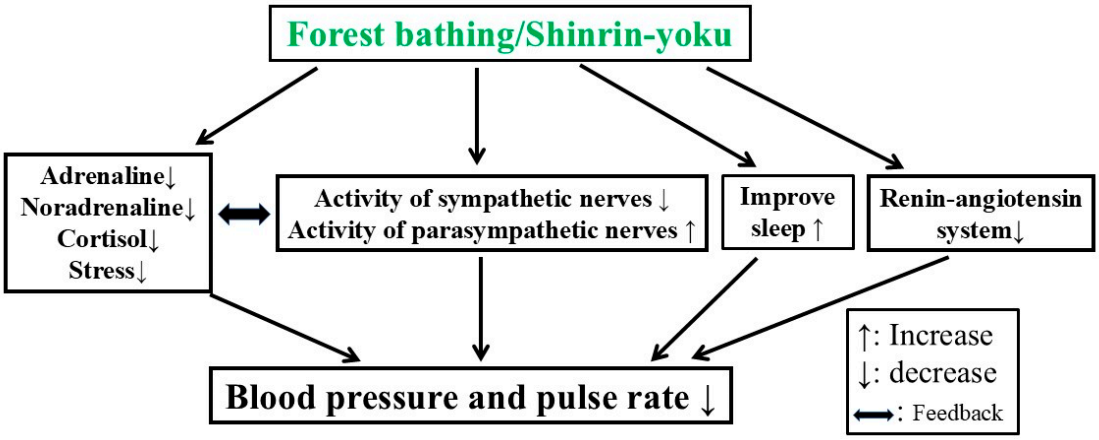


Figure 3. Mechanism of forest bathing/shinrin-yoku on blood pressure and pulse rate from the perspectives of stress hormones, autonomic nervous system, sleep and renin-angiotensin system.

5. The potential preventive effects of forest bathing/shinrin-yoku in CVDs by increasing adiponectin and DHEA-S

Adiponectin is a serum protein hormone specifically produced by adipose tissue. Studies have shown that adiponectin showed protective effects on several metabolic disorders, including obesity, type 2 diabetes mellitus, cardiovascular disease, and metabolic syndrome [60]. The level of dehydroepiandrosterone sulfate DHEA-S, the major secretory product of the adrenal gland, declines dramatically with age, concurrent with the onset of degenerative changes and chronic diseases associated with aging [61,62]. Epidemiological evidence in humans suggested that DHEA-S had cardioprotective, antiobesity, and antidiabetic properties [61]. Forest bathing/shinrin-yoku significantly increased serum adiponectin and dehydroepiandrosterone sulfate (DHEA-S) levels (Table 5) [9,17].

Table 5. Effect of forest bathing/shinrin-yoku and city walking on serum adiponectin and DHEA-S concentrations.

	City Walking (Before)	City Walking (After)	Forest Bathing/Shinrin-yoku (Before)	Forest Bathing/Shinrin-yoku (After)
Adiponectin (mean ± SD)	7.71 ± 2.65	7.70 ± 2.41	7.66 ± 3.10	8.18 ± 3.26 *
DHEA-S (mean ± SD)	1677.88 ± 696.22	1782 ± 738.52	1609.13 ± 636.21	1722.06 ± 688.18 *

The subjects walked for two hours each in the morning and afternoon for a total distance of about 6 km in the forest park or urban area. Blood was sampled on the morning before the trips and on the morning after the trips under fasting conditions. $n = 16$. *: $p < 0.05$ difference between after and before the forest walk according to the paired t-test [9].

6. Preventive effects of forest bathing/shinrin-yoku in patients with chronic heart failure

Chronic heart failure (CHF) is a global health burden and also a common disorder worldwide with increasing morbidity and mortality [63]. Several studies have reported beneficial effects of forest bathing/shinrin-yoku on CHF by measuring the effects of forest bathing/shinrin-yoku on the CVD related pathological factors, including endothelin-1, and constituents of the renin-angiotensin system, including renin, angiotensinogen, angiotensin II, and angiotensin II receptor type 1 or 2 (AT1 or AT2) on patients with CHF [29–31]. These results provided direct evidence that forest bathing/shinrin-yoku had beneficial effects in patients with CHF and suggested its potential as an effective adjunctive therapy for CVDs.

It is well known that type 2 diabetes mellitus (DM) and chronic obstructive pulmonary disease (COPD) are also risk factors for CVDs [64–69]. Ohtsuka et al. [70] reported that the mean blood glucose level after forest walking changed from 179 mg/dL to 108 mg/dL ($p < 0.0001$). The level of glycated haemoglobin A1c also decreased from 6.9% (before the first forest bathing/shinrin-yoku) to 6.5% (after the last forest bathing/shinrin-yoku; $p < 0.05$), suggesting the preventive effect of forest bathing/shinrin-yoku on type 2 DM [70]. The authors presumed that the forest environment caused changes in hormonal secretion and autonomic nervous functions and that, in addition to the increased calorie consumption and improved insulin sensitivity, walking in a forest environment had other beneficial effects in decreasing blood glucose levels. In addition, Jia et al. [71] found that forest bathing/shinrin-yoku showed benefits on elderly patients with COPD by decreasing levels of pro-inflammatory cytokines including interleukin-6, interleukin-8, interferon-γ, interleukin-1β and C-reactive protein (all $p < 0.05$ city vs. forest) and stress hormones such as cortisol and adrenaline (all $p < 0.05$ city vs. fores). Recently, Tsao et al. [72] reported that forest bathing/shinrin-yoku showed beneficial effects than urban parks on cardiovascular functions (CVFs) by measuring SBP, central end SBP, heart rate, left ventricle dP/dt max, and cardiac output in participants. This study provided evidence of the potential beneficial effects of walking in forest parks in Taiwan on CVFs. In addition, neighborhood greenspace is associated with a lower risk of cardiovascular diseases, type 2 diabetes, and overweight and obesity [39–44]. Moreover, Bikomeye et al. [45] conducted a systematic review of 31 experimental studies on the impact of greenspace or nature-based interventions on cardiovascular health-related outcomes and found that greenspace may have beneficial effects in CVD-related outcomes. Giacinto et al. [73] found that urban forests with greater biodiversity were related to a lower mortality rate for CVDs and stroke in California. A simulation of a tree-planting policy for Los Angeles based on certain estimates suggested that if these relationships are causal, investing in biodiverse street trees could be a cost-effective way to reduce cardiovascular disease-related mortality in urban areas, indicating the importance of urban greening in preventing CVDs [73]. In China, increasing greenspace could improve poststroke functional status; therefore, greenspace planning can be a potential intervention to prevent poststroke disability [74].

Taken together, based on the evidence mentioned above, as shown in Figure 4, forest bathing/shinrin-yoku) may become a new potential preventive method in CVDs by multiple mechanisms. However, more studies are needed on the preventive effects of forest bathing/shirin-yoku in CVDs.

The mechanism of why forest bathing has the above effects is explained below.

1. The effects of forest bathing were the combined effects of the five senses (sight, smell, hearing, touch, and taste). The olfactory effect (phytoncides) played an important role.
2. It has been reported that phytoncides increased NK cell anti-cancer proteins such as perforin, granulysin, granzymes, CD56, and CD107a and increased NK activity via the ERK/AKT pathway in vitro [75,76]. It has also been reported that inhalation of phytoncides reduced stress hormones in subjects and increased NK cell count and

NK cell anti-cancer proteins, thereby increasing NK activity [77,78]. It has also been reported that the immune system affects the mental, nervous, and endocrine systems through the psycho-neuro-endocrino-immune network [5].

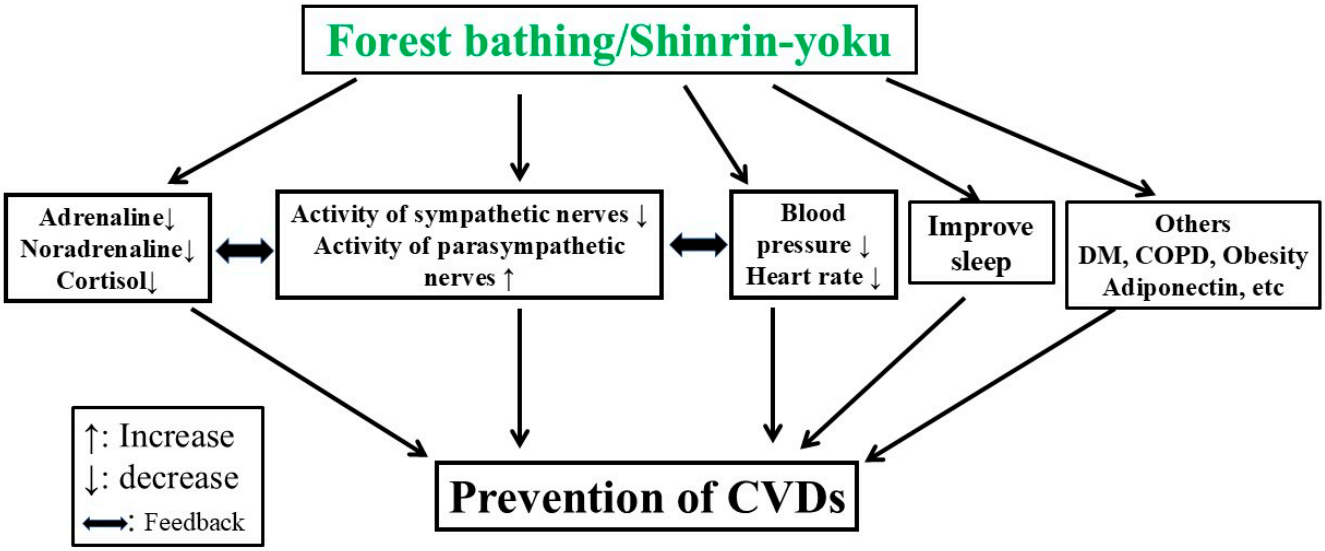


Figure 4. Mechanism of forest bathing/shinrin-yoku on the prevention of CVDs from the perspectives of stress hormones, autonomic nervous system, sleep, blood pressure and heart rate, and other factors.

In previous studies, the following three methods have been used to evaluate the effects of forest bathing/shinrin-yoku.

1. Comparison of forest bathing/shinrin-yoku with urban walks using a crossover design: This method can overcome sequence bias.
2. Comparison of forest bathing with urban walks without a crossover design: This method creates sequence bias.
3. Comparison before and after forest bathing: This method is most prone to bias.
4. The author recommends a comparison of forest bathing/shinrin-yoku with urban walks using a crossover design to evaluate the effects of forest bathing/shinrin-yoku.

3. Limitations

This review has the following limitations:

1. This is a review article, and the article focuses on the results of each study on the effects of forest bathing/shinrin-yoku; therefore, it is difficult to make consistency in methods and sample size.
2. This review is based on the mechanistic evidence and did not conduct meta-analyses. Future meta-analyses will be required on the preventive effects of forest bathing/shinrin-yoku on CVDs.
3. Due to the lack of enough evidence from previous studies, it is difficult to identify the gender-specific effects, long-term outcomes, and comparison with urban greenery exposure.
4. At the present stage, forest bathing/shinrin-yoku is recognized as preventive medicine, but it is not clinical medicine; therefore, no comparative studies can be found on the blood pressure-lowering effects of forest bathing/shinrin-yoku and the effects of pharmacological interventions. Therefore, it is difficult to expand the discussion on how forest therapy compares to pharmacological interventions. Future studies will be required on this topic.

4. Conclusions and Directions for Future Research

1. Forest bathing/shinrin-yoku will become a new preventive medicine for stress management and the prevention of CVDs in the implications for public health policies.
2. In the future, forest bathing/shinrin-yoku may be a new clinical medicine to treat some CVDs such as hypertension and heart diseases, sleep disorders, and so on in the implications for clinical practice.
3. Further empirical studies on the gender-specific effects and the long-term effects of forest bathing/shinrin-yoku.
4. It is also necessary to conduct controlled trials and interdisciplinary studies on the effects of bathing/shinrin-yoku on CVDs.

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