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The Effect of Yoga Practice on Hypertension: A review

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Abstract
This extensive review examined the current body of evidence regarding the efficacy of yoga in managing hypertension. It elucidates the potential mechanisms underlying these effects and provides insights into practical implications and future research directions. Hypertension, a condition affecting over 1.28 billion adults worldwide, poses a significant risk of cardiovascular complications. Yoga, an ancient practice originating in India, combines physical posture, breathing exercises, and meditation to promote overall well-being and alleviate stress. Several studies have explored the effects of yoga on blood pressure, with promising results. This review delves into the classification and causes of hypertension, consequences of uncontrolled hypertension, and definition and origins of yoga. It also highlights the different forms of yoga practice and the philosophical principles and theoretical mechanisms underlying the potential effects of yoga on hypertension.

Key word: Yoga, yoga practice, blood pressure, hypertension, review

1. Introduction

Hypertension, often referred to as abnormally elevated blood pressure, is a critical global public health concern, affecting over 1.28 billion adults worldwide [1]. This condition poses a significant risk for cardiovascular complications, including stroke, myocardial infarction, and heart failure, and contributes significantly to the worldwide burden of disease [2]. Yoga, an ancient practice that originated in India, has garnered attention as a potential intervention for hypertension.[3] It is a holistic approach that combines physical postures, breathing exercises, and meditation to promote overall well-being and alleviating stress [4]. Yoga, an age-old mind-body practice indigenous to India, has garnered increasing interest as a complementary and alternative therapeutic intervention for myriad health conditions including hypertension. By encompassing physical postures (asanas), respiratory exercises (pranayama), meditation, and relaxation techniques, yoga aims to foster unity between the body, mind, and spirit [3].

The practice of yoga is not only beneficial for physical health, but also has a profound impact on mental and emotional well-being. Through the integration of physical posture, breathing exercises, and meditation, yoga can help individuals achieve a greater sense of balance and harmony in their lives. The holistic approach to yoga makes it a powerful tool for promoting overall well-being and reducing stress, making it an increasingly popular practice among individuals seeking to improve their overall health and well-being [6].

Several studies have explored the effects of yoga on blood pressure with promising results [5]. A recent meta-analysis of 39 randomized controlled trials found that yoga can lead to significant reductions in both systolic and diastolic blood pressure [1]. Moreover, these findings were not limited to a specific population as the meta-analysis included individuals from diverse age groups, genders, and ethnicities, suggesting that yoga may be a beneficial intervention for a wide range of individuals looking to manage their hypertension. Additionally, the studies included in the meta-analysis used various yoga styles and techniques, further supporting the potential effectiveness of yoga as a complementary approach to traditional blood pressure management strategies. [7]. This extensive review sought to examine the current body of evidence on the efficacy of yoga in managing hypertension, elucidate the potential mechanisms underlying its effects, and provide insights into practical implications and future research directions.

2. Understanding Hypertension

2.1 Classification of hypertension

The American College of Cardiology and the American Heart Association define hypertension as a persistent increase in systolic blood pressure (SBP) of at least 140 mmHg or diastolic blood pressure (DBP) of at least 90 mmHg [4]. The condition can be categorised into various stages depending on the severity of blood pressure, as illustrated in (Table 1).

2.2. Causes and risk factors

Hypertension can be categorised as primary (essential) or secondary based on the underlying cause. Primary hypertension accounts for most cases and is frequently multifactorial, influenced by genetic and environmental factors, such as obesity, physical inactivity, unhealthy diet, excessive alcohol consumption, and stress [5]. Secondary hypertension can arise from underlying medical conditions, including renal disorders, endocrine disorders, and sleep apnoea [6]. Furthermore, certain medications, such as corticosteroids, can also contribute to the development of secondary hypertension by causing hormonal imbalances or by affecting the renin-angiotensin-aldosterone system [7]. Additionally, obesity and excessive alcohol consumption can increase the risk of developing secondary hypertension [8].

2.3. Consequences of uncontrolled hypertension

Uncontrolled hypertension, if left untreated, can result in severe complications including damage to various organs and systems in the body. Untreated hypertension increases the risk of developing conditions, such as heart disease, stroke, and kidney failure (Fig. 1).

1. Cardiovascular disorders include coronary artery disease (CAD) and heart failure [7]
2. Cerebrovascular diseases include stroke and vascular dementia [8]
3. Renal impairment and end-stage renal disease [9]
4. Retinopathy and vision loss [10]

3. Yoga: An Overview

Yoga is a holistic system of physical, mental, and spiritual practices that has roots in ancient India. It aims to integrate the body, mind, and spirit, resulting in overall well-being and self-awareness. The term "yoga" is derived from the Sanskrit word "yuj", which means "to yoke" or "to unite", reflecting its objective of uniting the individual with the universal consciousness. Yoga is a holistic practice that originated in ancient India and has since become popular worldwide. This involves a combination of physical posture, breathing techniques, and meditation, all of which are designed to promote physical and mental well-being. Although yoga has been practiced for thousands of years, it has only recently gained widespread recognition and acceptance in the Western world. This is partly due to the growing interest in alternative forms of medicine and the realisation of the benefits of mind-body practices. In addition to its physical benefits, yoga improves mental clarity, reduces stress and anxiety, and

promotes overall well-being. As a result, it is widely used as complementary therapy in many healthcare settings. Yoga practice is a personal journey, and each individual's experience is unique. Whether you are a beginner or an experienced practitioner, yoga offers something to everyone.

Yoga's popularity has grown significantly over the past few years, as more people recognize its numerous benefits, including improved flexibility, stress reduction, and overall well-being. Consequently, yoga has become a popular form of exercise and relaxation for individuals of all ages and backgrounds, providing a holistic approach to physical and mental health. In recent years, the benefits of yoga have been widely recognized, leading to its integration into various fitness and wellness programs worldwide [11-13].

3.1 Different forms of yoga practice

There are various forms of yoga, each with unique emphasis and techniques. Some of the most practiced styles include: the practice of yoga has evolved over time, and today, there are many different forms of yoga available. Some of the most popular forms include Hatha yoga, which focuses on physical postures and breathing techniques, Ashtanga yoga, which is a more rigorous and physically demanding form of yoga, Vinyasa yoga, which is a flowing style of yoga that emphasizes smooth transitions between poses, Kundalini yoga, which incorporates breathwork, meditation, and physical postures to awaken the body's inner energy, and Yin yoga, which is a slower-paced style of yoga that focuses on stretching and relaxation. Each form of yoga has unique benefits and can provide different experiences for practitioners. It is important to choose a form of yoga that aligns with your goals and interests as well as your physical abilities and limitations. When selecting a form of yoga, it is crucial to consider factors such as physical abilities and limitations, goals and interests, and any other relevant considerations that may impact yoga practice. The different forms of yoga practice are depicted in Fig.2.

1. Hatha Yoga: Focuses on physical postures (asanas) and breathing exercises (pranayama) [12].
2. Vinyasa/Power Yoga: Involves a dynamic flow of postures synchronised with breathing patterns [13].
3. Iyengar yoga: Emphasises precision and alignment in postures, often using props for support [14].
4. Restorative Yoga: Incorporates gentle poses supported by props, promoting deep relaxation [15].
5. Kundalini Yoga: Combines physical postures, breathwork, mantras, and meditation [16].

3.2 Philosophy and principles of yoga relevant to hypertension management

Yoga is rooted in philosophical principles that can be beneficial in managing hypertension. These principles include the following.

1. Ahimsa (non-violence): Promotes a peaceful and non-harming approach to oneself and others, reducing stress and negative emotions.[17]

2. Yama and Niyama: Ethical guidelines and self-disciplinary practices that encourage healthy lifestyle choices.[18]

3. Pranayama: Breathing exercises that can promote relaxation and regulate autonomic functions.[19]

4. Dharana and Dhyana: Concentration and meditation practices that cultivate mindfulness and stress reduction.[20]

Yoga is an ancient Indian philosophy and practice that encompasses the physical, mental, and spiritual dimensions. Several principles and techniques within yoga can be beneficial for managing hypertension and high blood pressure. One of the fundamental principles of yoga is ahimsa, which refers to non-violence or non-harm towards oneself and others [21]. This principle encourages a peaceful and compassionate approach to life, reducing negative emotions and stress that can contribute to hypertension.

Yama and niyama are ethical guidelines and self-disciplinary practices in yoga that promote a healthy lifestyle [22]. Yamas such as satya (truthfulness), asteya (non-stealing), and brahmacharya (moderation) can help individuals develop self-control and avoid behaviors that may exacerbate hypertension. Niyamas such as saucha (cleanliness), santosha (contentment), and tapas (disciplined use of energy) emphasise the importance of maintaining a balanced and healthy lifestyle.

Pranayama, or breath control exercises, are a crucial aspect of yoga practice [23]. Specific breathing techniques such as nadi shodhana (alternate nostril breathing) and bhramari (humming bee breath) can promote relaxation, reduce stress and anxiety, and regulate autonomic functions, all of which can contribute to lowering blood pressure, and dharana (concentration) and dhyana (meditation) can cultivate mindfulness and awareness [24]. Regular meditation reduces stress, anxiety, and negative emotions, which are known risk factors for hypertension. Mindfulness practices can also enhance self-awareness and promote positive lifestyle changes such as adopting a healthy diet and regular exercise.

In addition to these philosophical principles, physical practice of yoga asanas (postures) can also be beneficial for managing hypertension. Certain yoga poses, such as forward bends, inversions, and restorative poses, can promote relaxation and improve blood circulation,

potentially reducing blood pressure [25]. It is important to note that, while yoga can be a complementary approach to managing hypertension, it should not replace conventional medical treatment and should be practiced under the guidance of a qualified yoga instructor, especially for individuals with hypertension or other medical conditions.

4. Theoretical Mechanisms of Yoga on Hypertension

4.1 Physiological mechanisms

Yoga reduces blood pressure through various physiological mechanisms, including activation of the parasympathetic nervous system, release of nitric oxide, and improvement of endothelial function. These physiological mechanisms explain how yoga can be an effective intervention for the management of hypertension, making it a valuable complementary therapy in clinical practice. Incorporating yoga into lifestyle modifications and pharmacological therapies can lead to a comprehensive approach to hypertension management, highlighting its potential as a useful adjunct therapy in clinical settings [Fig.3 and Fig.4].

4.1.1 Effects on the autonomic nervous system

The autonomic nervous system (ANS) plays a crucial role in regulating various physiological processes, including heart rate, blood pressure, and dilation or constriction of blood vessels. The ANS comprises two main branches: the sympathetic nervous system, responsible for the "fight or flight" response, and the parasympathetic nervous system, which governs the "rest and digest" response. Hypertension, or high blood pressure, is associated with an imbalance in the autonomic nervous system, characterised by increased sympathetic activity and decreased parasympathetic activity. This imbalance can lead to increased heart rate, constriction of blood vessels, and elevated blood pressure. Several studies have demonstrated that regular yoga practice, particularly pranayama (breathing exercises) and meditation, can modulate the activity of the autonomic nervous system in a beneficial way. Some key mechanisms by which yoga may positively affect the ANS and contribute to the management of hypertension.

4.1.2 Increased Parasympathetic Activity: Yoga practices, such as slow and controlled breathing exercises (pranayama) and meditation, have been shown to enhance parasympathetic activity. This increased parasympathetic tone can lead to a reduction in heart rate, decreased vascular resistance, and improved blood flow, ultimately lowering blood pressure levels. The benefits of increased parasympathetic tone extend beyond cardiovascular health, as it can also contribute to a sense of relaxation and well-being, allowing individuals to better cope with stress and anxiety. Furthermore, research has shown that individuals with a higher parasympathetic tone tend to have better immune function and lower levels of inflammation, which can lead to improved overall health and well-being [25].

4.1.3 Reduced Sympathetic Overactivity: Chronic stress and anxiety can contribute to increased sympathetic nervous system activity, leading to an elevated heart rate, vasoconstriction, and higher blood pressure. Yoga practices promote relaxation and reduce stress responses, thereby decreasing sympathetic overactivity and mitigating the adverse effects on blood pressure.

4.1.4. Improved Heart Rate Variability: Heart rate variability (HRV) is a measure of the variation in the time intervals between consecutive heartbeats. A higher HRV is associated with better cardiovascular health and autonomic function. Studies have shown that regular yoga practice can increase HRV, indicating improved autonomic regulation and balance between sympathetic and parasympathetic branches.

4.1.5. Reduction in Stress Hormones: As mentioned earlier, yoga can lower levels of stress hormones, such as cortisol. This reduction in stress hormone levels can further contribute to the restoration of autonomic balance and reduction of sympathetic overactivity. Physiological changes induced by yoga practice, particularly modulation of the autonomic nervous system, have been shown to have a positive impact on overall cardiovascular health and well-being. Regular yoga practice may serve as a beneficial adjunct to traditional pharmacological interventions for hypertension management by promoting parasympathetic activity, reducing sympathetic overactivity, and improving autonomic balance. It is important to note that while yoga can be a valuable complementary therapy, it should not replace the conventional medical treatments prescribed by healthcare professionals. However, when combined with lifestyle modifications and traditional therapies, regular yoga practice may offer additional benefits in managing hypertension and promoting overall cardiovascular health [26,27].

5. Impact on Stress Hormones

Chronic stress is a well-known risk factor for hypertension or high blood pressure. When the body experiences prolonged periods of stress, it triggers the release of stress hormones, particularly cortisol, from adrenal glands. Cortisol is a steroid hormone that plays a crucial role in stress response in the body. Elevated cortisol levels have been associated with various adverse health effects including hypertension.

Several studies have demonstrated that regular yoga can effectively lower cortisol levels and reduce stress responses in the body. Yoga incorporates various techniques such as physical postures (asanas), breathing exercises (pranayama), and meditation, which can induce a state of relaxation and calmness. These practices have been shown to activate the parasympathetic nervous system, which is responsible for the "rest and digest" response, counteracting the effects of the sympathetic nervous system's "fight or flight" response. By promoting relaxation

and mitigating physiological stress responses, yoga can help reduce the production and release of stress hormones, such as cortisol. As a result, the body experiences a decrease in physiological effects associated with chronic stress, including elevated blood pressure. By lowering cortisol levels and promoting a more relaxed state, yoga may contribute to the reduction of blood pressure levels in individuals with hypertension or those at risk of developing the condition [28,29].

6. Vasodilatory Effects

The endothelium is the inner lining of the blood vessels, and its proper function is crucial for regulating vascular tone and blood flow. Endothelial dysfunction, characterised by impaired vasodilation (widening of blood vessels), is a key factor that contributes to the development of hypertension. Research suggests that regular yoga may improve endothelial function and promote vasodilation, thereby reducing peripheral resistance and lowering blood pressure. Several mechanisms have been proposed to explain the vasodilatory effect of yoga.

6.1 Improved Nitric Oxide Production: Nitric oxide (NO) is a potent vasodilator produced by the endothelial cells. Studies have shown that yoga can increase the bioavailability of nitric oxide, leading to improved vasodilation and better blood flow.

6.2 Reduced Oxidative Stress: Oxidative stress impairs endothelial function and contributes to the development of hypertension. Yoga has been associated with a reduction in oxidative stress markers, potentially protecting the endothelium and promoting vasodilation.

6.3 Enhanced Parasympathetic Activity: As mentioned earlier, yoga activates the parasympathetic nervous system, which is responsible for promoting relaxation. This relaxation response can lead to vasodilation and reduction in peripheral resistance, ultimately lowering blood pressure.

6.4 Increased Flexibility and Circulation: The physical postures (asanas) in yoga can improve flexibility and circulation throughout the body, potentially enhancing blood flow and reducing peripheral resistance. By promoting vasodilation and improving endothelial function, regular yoga practice may help lower blood pressure levels in individuals with hypertension or those at risk of developing hypertension. This vasodilatory effect, combined with the reduction in stress hormones, contributes to the potential benefits of yoga in managing hypertension and promoting cardiovascular health [30,31].

7. Psychological mechanisms

7.1 Stress Reduction and Relaxation Response

Stress is a significant contributing factor in the development and exacerbation of hypertension. Yoga incorporates various relaxation techniques, such as deep breathing exercises

(pranayama), meditation, and mindfulness practices, which can elicit a relaxation response and reduce perceived stress levels, thereby contributing to lower blood pressure. The relaxation response is a physiological state characterised by decreased sympathetic nervous system activity, reduced muscle tension, and a general feeling of calmness and tranquillity. This response counteracts the body's stress response, which is associated with an increased heart rate, constriction of blood vessels, and elevated blood pressure.

Deep breathing exercises, a core component of yoga practice, have been shown to stimulate the parasympathetic nervous system, promote relaxation, and reduce stress responses. Meditation and mindfulness practices help cultivate present-moment awareness, reduce rumination about stressful thoughts, and facilitate a sense of calm and inner peace. By eliciting a relaxation response and reducing perceived stress levels, yoga can indirectly lower blood pressure by modulating the autonomic nervous system, reducing the production of stress hormones such as cortisol, and promoting overall physiological and psychological relaxation [32,33].

7.2 Psychological Well-being and Mood Regulation

Yoga has been associated with improvements in psychological well-being, mood regulation, and emotional regulation, which can indirectly impact blood pressure by reducing stress and promoting healthier coping mechanisms. Chronic stress, anxiety, and negative emotional states contribute to the development and exacerbation of hypertension. Yoga practices, such as physical postures (asanas), breathing exercises, and meditation, have been shown to reduce symptoms of depression, anxiety, and stress while enhancing overall psychological well-being and emotional regulation.

By promoting a more positive emotional state and improving coping mechanisms, yoga can indirectly contribute to lowering blood pressure levels. Individuals with better emotional regulation and coping skills are better equipped to manage stress and respond to challenging situations in a more adaptive manner, thereby reducing the physiological impact of stress on the body, including its effects on blood pressure. Additionally, yoga encourages self-awareness, self-acceptance, and a sense of inner calm, which can further contribute to psychological well-being and reduce the negative impact of stress on cardiovascular health [34,35].

8. Lifestyle Factors

The philosophical principles of yoga, such as non-violence (ahimsa) and self-discipline (niyama), can encourage the adoption of healthier dietary habits that can contribute to weight management and lower blood pressure. Yoga emphasis on non-violence and compassion

towards all living beings can promote a plant-based or vegetarian diet, which has been associated with lower blood pressure levels and a reduced risk of hypertension. Additionally, the principle of self-discipline (niyama) encourages moderate and mindful consumption, potentially reducing the intake of unhealthy foods and promoting portion control.

By encouraging healthier dietary choices and promoting a more conscious relationship with food, yoga can indirectly contribute to weight management and lower blood pressure. Maintaining healthy body weight and reducing the intake of sodium, saturated fats, and processed foods are known to have a positive impact on blood pressure regulation [36].

8.1 Encouragement of Physical Activity

Many forms of yoga involve physical postures and movements that contribute to increased physical activity levels, which can positively impact blood pressure regulation. Regular physical activity has been consistently associated with a lower risk of hypertension and better management of blood pressure levels. Yoga asanas (postures) and vinyasas (flowing sequences) provide a form of low-impact exercise that can improve cardiovascular fitness, increase muscle strength and flexibility, and promote physical wellbeing. By incorporating physical activity into yoga practice, individuals can benefit from the blood pressure-lowering effects of exercise, which include improved endothelial function, increased insulin sensitivity, and improved regulation of the autonomic nervous system [37].

8.2 Promotion of Healthy Sleep Patterns

Yoga practices, such as gentle stretching and relaxation techniques, can improve sleep quality, which is essential for regulating physiological processes, including blood pressure control.

Sleep disturbances and poor sleep quality have been linked to an increased risk for hypertension and other cardiovascular disorders. Yoga can promote better sleep by reducing stress and anxiety, improving relaxation, and facilitating gentle physical exercise. Certain yoga practices, such as restorative poses and yoga nidra (yogic sleep), are specifically designed to induce deep relaxation and promote better sleep quality. By improving sleep patterns, yoga can indirectly contribute to the regulation of physiological processes, including blood pressure control, as the body and mind are better able to rest and recover at night. Hence,the psychological mechanisms and lifestyle factors associated with yoga practice can have a positive impact on blood pressure regulation through various pathways, including stress reduction, improved emotional well-being, healthier dietary habits, increased physical activity, and better sleep quality [38].

9. Evidence from Clinical Studies

Numerous clinical trials have explored the potential benefits of yoga in reducing blood pressure in individuals with hypertension. In a randomised controlled trial, 86 hypertensive patients were assigned to either an 11-week intervention involving yoga practices, such as asanas (postures), pranayama (breathing exercises), and meditation, or a control group. The results showed that The yoga group experienced a significant decrease of 13.9 mmHg in systolic blood pressure and 10.6 mmHg in diastolic blood pressure, indicating the antihypertensive effects of yoga [39]. Another controlled trial in a primary care setting involved 83 participants matched for systolic blood pressure, randomised into a yoga or control group. The yoga group received an 8-week yoga intervention, whereas the control group continued with usual care. The yoga group experienced greater reductions in both systolic and diastolic blood pressure, as well as improved quality of life scores, than the control group [41].

Several systematic reviews and meta-analyses have synthesised evidence from multiple clinical trials to further substantiate the potential benefits of yoga in managing hypertension. A systematic review and meta-analysis conducted by researchers aggregated evidence from 17 clinical trials and found that yoga seemed to be effective in reducing blood pressure in both prehypertensive and hypertensive patients relative to no treatment [40]. However, the authors emphasised the need for additional high-quality research to strengthen these findings. A meta-analysis of 17 randomised controlled trials with 962 patients assessed the effects of yoga on multiple cardiovascular disease risk factors. The results showed that practising yoga led to a significantly reduced systolic blood pressure by 6.57 mmHg and diastolic blood pressure by 4.92 mmHg compared to no-treatment controls, suggesting that yoga may be an effective method for lowering hypertension and overall cardiovascular risk [36].

A systematic review and meta-analysis evaluated controlled trials on the effectiveness of hatha yoga (a branch of yoga focused on physical posture) in managing hypertension. The analysis revealed that Hatha yoga interventions resulted in significantly greater reductions in mean arterial blood pressure compared to controls, amounting to a difference of 8.4 mmHg. This finding supports the use of hatha yoga as a complementary treatment for hypertension [49]. Another systematic review examined randomised controlled trials that assessed the effectiveness of yoga in the management of hypertension. Their analysis of 49 randomised control trials (RCTs) involving 3,517 hypertensive patients found that yoga produced clinically meaningful reductions in both systolic blood pressure (9.08 mmHg) and diastolic blood pressure (6.95 mmHg) compared to the control groups [50].

A systematic review and meta-analysis published in the American Journal of Lifestyle Medicine specifically assessed the impact of yoga on hypertension. The analysis revealed that yoga interventions were effective in reducing both systolic and diastolic blood pressure when compared with the control groups [56]. Although the exact mechanisms underlying the antihypertensive effects of yoga have not been fully elucidated, several potential pathways have been proposed.

Weight Loss and Improved Exercise Tolerance: The American Heart Association's scientific statement highlighted that mind-body practices such as yoga and meditation could help lower blood pressure by facilitating weight loss and enhancing exercise tolerance, both of which are known to contribute to blood pressure reduction [43].

Stress Reduction and Neurohumoral Modulation: Yoga has been associated with decreased stress levels and modulation of the neurohumoral system, which can lead to reduced sympathetic activity and improved baroreflex sensitivity, thereby lowering blood pressure [47].

Reduction in Oxidative Stress and Inflammation: Yoga practices may help mitigate oxidative stress and inflammation, which are implicated in the pathogenesis of hypertension [47].

Improved Respiratory Function: A study evaluated the effect of a short-term intensive yoga program on respiratory muscle strength and pulmonary function in healthy young adults. The yoga program led to improvements in respiratory muscle performance and lung function parameters, such as forced vital capacity and peak expiratory flow rate, which could potentially contribute to better cardiovascular health and blood pressure regulation [57].

Psychological Well-being and Mindfulness: A cross-sectional study investigated the associations between engagement in yoga practices, mindfulness levels, and psychological well-being indicators in a sample of 263 participants. The results revealed that greater involvement in yoga and higher mindfulness scores were associated with better psychological well-being, implying that yoga may have mental health benefits that could indirectly impact hypertension management [48]. Furthermore, a randomised clinical trial assessed the effects of a mindfulness-based stress-reduction program, which involved meditation practices similar to yoga, on 86 overweight/obese women. The study found that mindfulness intervention led to improvements in cardiovascular risk markers, such as blood pressure, suggesting that mind-

body practices may have beneficial effects on hypertension through their influence on stress, weight, and related risk factors [49].

Several authoritative organisations have recognised the potential benefits of yoga and lifestyle modifications in the management of hypertension. The Eighth Joint National Committee (JNC 8) published evidence-based guidelines for managing high blood pressure in adults in 2014. In addition to recommending antihypertensive medications, the guidelines recommend the adoption of lifestyle modifications such as increased physical activity, weight loss, dietary changes, and reduced alcohol intake as complementary interventions for lowering blood pressure and cardiovascular risk [45]. Although further research is needed, some studies have explored the potential cost-effectiveness and additional benefits of incorporating yoga into hypertension management strategies. A literature review investigated the probable health consequences and cost-effectiveness of yoga in managing chronic disorders, particularly hypertension, along with related productivity loss. The authors proposed that yoga might be a cost-effective complementary intervention to decrease hypertension and enhance productivity, although additional economic evaluation research is required [46].

Furthermore, a systematic review and meta-analysis investigated the effects of hatha yoga on blood pressure, glucose metabolism, and depression in patients with chronic kidney disease and diabetes mellitus. While further research is needed, the findings suggest that hatha yoga may have potential benefits in improving these outcomes, which could have implications for hypertension management [51]. Additionally, a systematic review and meta-analysis, although not specifically focused on hypertension, investigated the impact of mind-body practices, including yoga, on sleep quality in healthy adults and populations with chronic diseases. These findings suggest that these practices can improve sleep quality, which may indirectly benefit hypertension [58].

Recent studies have explored novel approaches to incorporate yoga into hypertension management strategies. A randomised pilot study conducted in 2023 evaluated the effects of a mobile app yogic breathing program in 110 patients with uncomplicated hypertension. After a 4-week period, the group that used the yoga breathing app demonstrated a significant decrease in systolic blood pressure (7.1 mmHg) and diastolic blood pressure (5.3 mmHg) compared to the control group [57]. This finding highlights the potential of leveraging technology to deliver yoga-based interventions for hypertension management. Moreover, a systematic review examined physician-led lifestyle intervention programs, which may include components such as yoga to prevent diabetes and cardiovascular diseases, such as hypertension, in South Asian

communities. Comprehensive lifestyle programs incorporating yoga may aid in the prevention and management of hypertension [59].

A randomised controlled trial evaluated the impact of exercise training on the hypertension status and blood pressure response to hypertensive stimuli. The results demonstrated that exercise training enhanced hypertension status and diminished blood pressure reactivity, emphasising the significance of physical activity in combination with practices like yoga [60].Although substantial evidence supports the potential benefits of yoga in managing hypertension, further high-quality research is warranted to fully understand the mechanisms, optimal implementation strategies, and long-term effects of integrating yoga with hypertension management protocols.

10.Discussion

The findings of this comprehensive review underscore the potential benefits of yoga in managing hypertension, a widespread and significant risk factor for cardiovascular disease. Numerous studies have demonstrated significant reductions in both systolic and diastolic blood pressure among individuals practising various forms of yoga [61,63,64]. These positive effects have been observed across diverse populations, including individuals with prehypertension, stage 1 and stage 2 hypertension, and comorbid conditions such as diabetes and obesity [66-68]. One of the key mechanisms proposed to explain the antihypertensive effects of yoga is the practice of Pranayama, breath control exercises, and meditation techniques. These practices are believed to induce a state of relaxation and reduce sympathetic nervous system activation, thereby lowering blood pressure [69]. Additionally, the physical postures (asanas) involved in yoga practice can improve flexibility, strength, and overall physical fitness, which may contribute to lowering blood pressure through mechanisms such as improved vascular function and reduced peripheral resistance [70].

Furthermore, yoga's emphasis on mindfulness and stress management techniques may help mitigate the deleterious effects of chronic stress on blood pressure regulation [71]. Chronic stress has been linked to increased activation of the hypothalamic-pituitary-adrenal (HPA) axis and sympathetic nervous system, leading to elevated levels of cortisol and other stress hormones, which can contribute to hypertension [72]. By promoting relaxation and enhancing stress-coping mechanisms, yoga may help modulate these physiological responses and reduce the risk of stress-related hypertension. It is noteworthy that different styles of yoga, such as Hatha, Iyengar, and Vinyasa, have been studied, and the findings suggest that various forms of yoga can be beneficial for individuals with hypertension [73-75]. However, the optimal duration, frequency, and intensity of yoga practice for blood pressure management remain

unclear, and further research is warranted to establish evidence-based guidelines. Additionally, research investigating the potential synergistic effects of combining yoga with other lifestyle interventions, such as dietary modifications and aerobic exercise, may provide valuable insights into comprehensive hypertension management strategies [76].

The practical implications of incorporating yoga in hypertension management are significant. Yoga offers a non-pharmacological, cost-effective, and accessible intervention with minimal adverse effects [77]. It can be practiced by individuals of different ages and physical abilities, making it a suitable complementary therapy for a wide population range. Additionally, the holistic nature of yoga, which addresses physical, mental, and spiritual aspects, may enhance overall well-being and promote long-term adherence to a healthy lifestyle [78].

Despite these promising findings, several limitations and directions for future research should be considered. Many studies have relatively small sample sizes and short follow-up periods, necessitating larger-scale, long-term randomised controlled trials to establish the long-term effects of yoga on hypertension and its potential implications for cardiovascular outcomes [79]. Moreover, standardised protocols for yoga interventions and objective measures of adherence and compliance should be developed to facilitate comparisons across studies and ensure reproducibility [80]. Furthermore, future research should explore the potential mechanisms underlying the effects of yoga on hypertension in greater depth. Although the proposed mechanisms of reduced stress, improved physical fitness, and enhanced mindfulness are plausible, more rigorous studies are needed to elucidate the specific physiological pathways involved. This could include investigations into changes in autonomic nervous system activity, endothelial function, and inflammatory markers associated with yoga practice [81].

Additionally, future research should examine the potential differential effects of yoga based on factors such as age, sex, ethnicity, and the presence of comorbidities. It is possible that certain subgroups may benefit from yoga interventions, and tailoring yoga programs to specific populations could enhance their effectiveness [82].

11. Strengths and limitations of the evidence

The available evidence from clinical studies has several strengths including:

1. A randomized controlled trial design provides higher levels of evidence.
2. The inclusion of various yoga styles and intervention durations allows the assessment of different approaches.
3. The measurement of both office and ambulatory BP provides a more comprehensive understanding of these effects.

However, there are limitations to consider.

1. Heterogeneity in yoga interventions and study populations makes it challenging to directly compare and generalise the findings.
2. The relatively small sample sizes in some studies limit statistical power and generalisability.
3. Potential for publication bias: Studies with positive findings may be more likely to be published.
4. The lack of long-term follow-up data limits the assessment of the sustained effects over time.

12. Practical Implications

12.1. Recommendations for incorporating yoga into hypertension management

Based on the available evidence, incorporating yoga as adjunctive therapy in hypertension management can be considered a reasonable approach. However, it is essential to recognise that yoga should not replace conventional pharmacological and non-pharmacological interventions but rather complement them as part of a comprehensive treatment plan.

Healthcare professionals may consider recommending yoga practice to patients with hypertension or elevated blood pressure, particularly those interested in exploring complementary and integrative approaches. It is crucial to work closely with qualified yoga instructors or integrative health professionals to develop individualised yoga programs tailored to patients' needs, preferences, and health statuses.

When recommending yoga for hypertension management, healthcare professionals should consider the following factors.

1. Baseline blood pressure levels and cardiovascular risk profiles.
2. Potential contraindications or precautions for specific yoga postures or practices.
3. Patient physical abilities, limitations, and underlying medical conditions.
4. Patient preferences, motivations, and willingness to adhere to regular yoga practice.

12.2 Considerations for healthcare professionals and patients

Healthcare professionals should be aware of the potential benefits and limitations of yoga in the management of hypertension. They should provide guidance on appropriate yoga styles, intensity levels, and safety precautions as well as monitor patients' progress and any potential adverse effects.

Patients should be encouraged to engage in regular yoga practice under the guidance of qualified instructors and communicate any concerns or challenges they may experience. It is also essential for patients to continue adhering to their prescribed medical treatments and

lifestyle modifications, as yoga should be considered as a complementary therapy rather than a replacement for conventional interventions.

13. Potential challenges and barriers to implementation

While incorporating yoga into hypertension management holds promise, there are potential challenges and barriers to consider.

1. Limited availability of qualified yoga instructors with specific training in hypertension management.
2. Potential accessibility and cost barriers for some individuals or communities.
3. Cultural or personal beliefs and attitudes towards complementary and alternative therapies.
4. Limited insurance coverage or reimbursement for yoga-based interventions in some healthcare systems.
5. Lack of standardised guidelines or protocols for integrating yoga into hypertension management programs.

Addressing these challenges may require collaborative efforts among healthcare professionals, yoga instructors, policymakers, and stakeholders to ensure the safe, effective, and accessible implementation of yoga-based interventions for hypertension management.

14. Future Directions and Research Gaps

14.1. Areas for Further Research

Although the available evidence is encouraging, several areas require further research to address the remaining gaps and limitations.

1. Standardization of Yoga Interventions: Developing standardized yoga protocols specific for hypertension management, including optimal duration, frequency, and intensity of practice.
2. Long-term Follow-up Studies: Investigating the long-term sustainability of the blood pressure-lowering effects of yoga and its potential impact on cardiovascular outcomes.
3. Exploration of Individual Differences: Examining the influence of factors such as age, sex, ethnicity, comorbidities, and baseline blood pressure levels on the effectiveness of yoga interventions.
4. Comparative Effectiveness Studies: Comparison of the efficacy of yoga with other non-pharmacological interventions and exploration of potential synergistic effects when combined with conventional treatments.
5. Cost-effectiveness Analyses: Evaluating the cost-effectiveness of incorporating yoga into hypertension management programs from a healthcare perspective.

14.2 Suggestions for improving study design and methodologies

To improve the quality and generalizability of future studies, the following methodological considerations were suggested.

1. Increasing sample sizes and conducting multicenter studies to enhance statistical power and generalizability.
2. Rigorous randomization and blinding procedures were performed to minimize potential bias.
3. Diverse study populations were included, such as individuals from various age groups, ethnicities, and socioeconomic backgrounds.
4. Standardized outcome measures included 24-hour ambulatory blood pressure monitoring and validated questionnaires for evaluating quality of life and psychological well-being.
5. Providing comprehensive reporting of intervention details, adherence rates, and adverse events.

14.3 Potential avenues for exploring the long-term effects of yoga on hypertension

To enhance our understanding of the long-term effects of yoga on hypertension and cardiovascular outcomes, it is crucial to explore several avenues of future research.

1. Longitudinal cohort studies: Regular practice of yoga among individuals should be followed over an extended period to assess the durability of blood pressure reduction and its potential effects on cardiovascular events, morbidity, and mortality.
2. Implementation Science Research: The effectiveness of and barriers to implementing yoga-based interventions in real-world settings, such as primary care clinics, community centres, and workplace wellness programs, should be investigated.
3. Integration with digital health technologies: The potential of delivering yoga interventions through telemedicine or mobile health applications should be explored, and their effectiveness evaluated.

Conclusion

This comprehensive review examined the current evidence on the effects of yoga on hypertension management. Findings from numerous clinical trials, systematic reviews, and meta-analyses suggest that yoga interventions can significantly reduce both systolic and diastolic blood pressure levels, particularly in individuals with hypertension or elevated blood pressure. The potential mechanisms underlying the blood pressure-lowering effects of yoga are multifaceted, involving physiological factors, such as modulation of the autonomic nervous system, reduction of stress hormones, and improved endothelial function, as well as psychological and lifestyle factors, including stress reduction, enhanced emotional well-being, and promotion of healthy behaviors. While the available evidence is promising, it is important

to recognize the limitations and heterogeneity of the studies as well as the need for further research to address the remaining gaps and uncertainties.

The findings of this review have important implications in clinical practice and public health. Incorporating yoga as adjunctive therapy in hypertension management could provide a safe, cost-effective, and accessible complementary approach to conventional treatments, potentially improving patient outcomes and quality of life. Healthcare professionals should consider recommending yoga practice to suitable patients with hypertension or elevated blood pressure, while ensuring appropriate guidance, monitoring, and integration with conventional medical care. Collaborative efforts among healthcare providers, yoga instructors, and policymakers are crucial to facilitate the safe and effective implementation of yoga-based interventions in various healthcare settings.

From a public health perspective, promoting yoga as a lifestyle intervention for hypertension management could contribute to the prevention and control of cardiovascular diseases and reduce the associated burden on the healthcare systems and societies. Efforts should be made to increase the awareness, accessibility, and affordability of yoga programs tailored for hypertension management, particularly in communities with high prevalence rates of hypertension and limited access to healthcare resources.

In conclusion, this comprehensive review highlights the potential benefits of yoga as a complementary approach for hypertension management. While further research is needed to address the remaining gaps and uncertainties, the existing evidence suggests that yoga can be a valuable addition to conventional treatments, offering a holistic approach that addresses not only the physical aspects of hypertension, but also the psychological and lifestyle factors that contribute to this condition. By embracing yoga as a complementary therapy, healthcare professionals and public health initiatives can provide individuals with a comprehensive and integrative approach to hypertension management, empowering them to take an active role in their health and well-being, while potentially reducing the burden of cardiovascular diseases on healthcare systems and societies worldwide.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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