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Radhika Kapoor
Department of Ayurvedic Medicine, Vedic Healing Institute, Jaipur, Rajasthan, India

Aarav Patel
Department of Ayurvedic Medicine, Vedic Healing Institute, Jaipur, Rajasthan, India

Corresponding Author:
Radhika Kapoor
Department of Ayurvedic Medicine, Vedic Healing Institute, Jaipur, Rajasthan, India

Pranayama as a therapeutic tool for modulating oxidative stress and inflammation in cardiovascular diseases

Radhika Kapoor and Aarav Patel

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Abstract
Cardiovascular diseases (CVDs) are the leading cause of death globally, with oxidative stress and chronic inflammation recognized as central mechanisms in their pathogenesis. This paper explores the therapeutic potential of Pranayama (controlled breathing) as an adjunct to conventional treatment for CVDs. Pranayama practices, such as Nadi Shodhana and Bhramari, are examined for their ability to modulate key physiological factors particularly oxidative stress, inflammation, and autonomic nervous system (ANS) function critical to cardiovascular health. Drawing upon both modern scientific findings and Ayurvedic principles, the paper investigates how Pranayama influences heart rate variability (HRV), enhances antioxidant defenses, and reduces pro-inflammatory cytokines like C-reactive protein (CRP) and Interleukin-6 (IL-6). The study also integrates Ayurvedic concepts, emphasizing the regulation of the Doshas (Vata, Pitta, Kapha) and their role in maintaining heart health. By examining the impact of Pranayama on oxidative stress markers such as Malondialdehyde (MDA) and its contribution to overall cardiovascular function, this paper provides an evidence-based framework for incorporating Pranayama into modern cardiovascular care. The findings highlight Pranayama as an effective, non-pharmacological intervention for both prevention and management of CVDs, offering a holistic approach to cardiovascular health rooted in ancient wisdom and supported by contemporary research.

Keywords: Pranayama, cardiovascular diseases, oxidative stress, inflammation, heart rate variability

1. Introduction
Cardiovascular diseases (CVDs) are the leading cause of death globally, accounting for approximately 31% of all deaths worldwide. According to the World Health Organization (WHO), CVDs are responsible for more than 17.9 million deaths annually, which translates to about one-third of the global mortality rate. Of these deaths, over 75% occur in low- and middle-income countries. In India alone, it is estimated that more than 4 million people die each year due to heart disease, making it the country with the highest burden of CVD-related deaths in the world.

The pathophysiology of CVDs is complex and multifactorial, but a common thread in many cardiovascular disorders is the presence of oxidative stress (OS) and chronic inflammation. Oxidative stress occurs when there is an imbalance between the production of reactive oxygen species (ROS) and the body's antioxidant defense systems. ROS, including superoxide anions, hydroxyl radicals, and hydrogen peroxide, are unstable molecules that cause damage to cell membranes, proteins, lipids, and DNA, leading to endothelial dysfunction, a key early event in the development of atherosclerosis. Atherosclerosis, the build-up of plaque within the arterial walls, is a major contributor to conditions such as coronary artery disease, heart attacks, and strokes.

Inflammation, both acute and chronic, is another critical factor that contributes to the initiation and progression of CVDs. Chronic low-grade inflammation, often driven by elevated ROS levels, leads to the activation of the endothelial cells, the lining of blood vessels, causing them to become more permeable and promoting the recruitment of immune cells to the sites of injury. This inflammatory response results in plaque instability, which can lead to heart attacks and strokes when the plaque ruptures and forms blood clots.

The global economic and social burden of CVDs is substantial, and the rise of these diseases is exacerbated by various risk factors, including poor dietary habits, lack of physical activity, tobacco use, and increasing urbanization. The Global Burden of Disease Study 2019 reports that CVDs were responsible for 40% of global disability-adjusted life years (DALYs), a measure of the overall disease burden, and over $863 billion is spent annually on the management of heart disease in the United States alone.

In India, CVDs have emerged as the leading cause of death, especially among the urban population. The Indian Heart Association (IHA) estimates that nearly 50% of adults in urban India have at least one risk factor for heart disease. Hypertension (high blood pressure) is one of the most prevalent risk factors, affecting approximately 30% of the adult population in India. Furthermore, diabetes, which is closely linked to CVDs, affects more than 77 million people in India, with projections indicating that this number will increase by 50% by 2030.

Conventional medical treatments for CVDs typically focus on managing risk factors such as high blood pressure, cholesterol, and diabetes, and include the use of pharmaceuticals like statins, beta-blockers, and antihypertensive agents. While these treatments can be effective in controlling symptoms and reducing the risk of heart events, they often come with side effects and do not address the underlying causes of CVDs, such as oxidative stress and inflammation.

Main Objective

The objective of this paper is to explore the therapeutic potential of Pranayama (controlled breathing) as a complementary approach for managing and preventing Cardiovascular Diseases (CVDs).

Literature Review

Pranayama, an integral practice in Yoga, has garnered significant attention in both Ayurvedic and modern scientific communities due to its profound effects on the cardiovascular system. This literature review explores recent findings on the impact of Pranayama on cardiovascular health, with a particular focus on its ability to modulate oxidative stress, inflammation, and autonomic nervous system (ANS) function.

Oxidative stress is a major contributing factor in the pathogenesis of cardiovascular diseases (CVDs). The American Heart Association (AHA) has emphasized that ROS play a central role in endothelial injury, which accelerates atherosclerosis. Studies have shown that oxidative damage to lipoproteins, such as low-density lipoproteins (LDL), leads to the formation of atherosclerotic plaques and increases the risk of coronary artery disease (CAD) and stroke.

In this context, Pranayama has been shown to significantly reduce oxidative stress by enhancing the activity of antioxidant enzymes. SOD and PON-1 are key antioxidants that neutralize ROS and protect against endothelial dysfunction. Pramanik *et al*. (2009) [8] found that Nadi Shodhana (alternate nostril breathing) increased SOD activity and reduced MDA (malondialdehyde) levels in participants, suggesting that Pranayama can reduce lipid peroxidation and oxidative damage. Furthermore, a study by Telles *et al*. (2012) [10] demonstrated that Bhramari Pranayama enhanced the activity of glutathione peroxidase, another antioxidant enzyme, in individuals with hypertension, underscoring its potential to counteract oxidative stress in cardiovascular conditions.

Chronic inflammation is a well-established risk factor for the development and progression of cardiovascular diseases. The release of inflammatory cytokines, such as IL-6, TNF-α, and CRP, leads to endothelial cell dysfunction, plaque formation, and thrombosis. Elevated levels of these markers are associated with increased cardiovascular morbidity and mortality.

Recent studies suggest that Pranayama can modulate the inflammatory response by enhancing parasympathetic nervous system (PNS) activity. The PNS, primarily mediated by the vagus nerve, is involved in the regulation of the immune system through the cholinergic anti-inflammatory pathway. Khayat *et al*. (2015) demonstrated that Bhramari Pranayama, through its vagal activation, significantly reduced CRP and IL-6 levels in individuals with chronic stress and hypertension. Similarly, Sharma *et al*. (2013) observed that Nadi Shodhana reduced TNF-α and IL-1β levels in patients with metabolic syndrome, a condition closely linked to cardiovascular risk.

These findings highlight that Pranayama's anti-inflammatory effects are mediated by autonomic regulation, with the activation of the vagus nerve playing a key role in reducing the pro-inflammatory cytokine production and restoring balance in the cardiovascular system.

Heart rate variability (HRV) is an important marker of the balance between the sympathetic and parasympathetic branches of the autonomic nervous system (ANS). High HRV is a sign of healthy autonomic regulation, while low HRV is associated with increased cardiovascular risk. Chronic stress and dysregulation of the ANS lead to a predominance of sympathetic nervous activity (fight-or-flight response) and a suppression of parasympathetic activity, contributing to an increased risk of CVDs.

Several studies have shown that Pranayama can significantly improve HRV by increasing parasympathetic activity and decreasing sympathetic dominance. Vempati *et al*. (2009) demonstrated that Nadi Shodhana increased HRV in healthy adults, suggesting that this technique may enhance autonomic function and cardiovascular health. A systematic review by Zhao *et al*. (2015) further confirmed that slow, controlled breathing exercises, such as Pranayama, lead to a sustained increase in HRV, which is linked to improved heart function and lower cardiovascular risk.

Moreover, Bhramari Pranayama has been shown to induce parasympathetic dominance, as evidenced by a study conducted by Bhavanani *et al*. (2012) [9]. The practice significantly improved HRV in medical students, reducing stress and improving emotional regulation. This improvement in autonomic function is essential for maintaining cardiovascular health, as it helps reduce the harmful effects of stress on the heart and blood vessels.

Beyond its effects on physiological markers of cardiovascular health, Pranayama has also been studied for its clinical outcomes in patients with CVDs. In a randomized controlled trial by Pramanik *et al*. (2009) [8], individuals with hypertension who practiced Nadi Shodhana showed significant reductions in both systolic and diastolic blood pressure. Similarly, Khayat *et al*. (2015) found that Pranayama interventions, including Bhramari, improved

cardiac function and reduced stress in patients recovering from heart surgery.

Additionally, Yadav *et al*. (2017) studied the impact of Sitali and Sitkari Pranayama on patients with a history of myocardial infarction. The results indicated that these cooling Pranayama practices improved left ventricular function, reduced stress-induced arrhythmias, and promoted overall recovery. These clinical findings underscore the potential of Pranayama not only for preventing cardiovascular diseases but also for enhancing recovery in patients with existing heart conditions.

In Ayurveda, cardiovascular diseases are categorized under the umbrella of Hridroga (heart diseases), which are believed to arise from an imbalance in the Doshas Vata, Pitta, and Kapha. According to Ayurvedic principles, Vata governs circulation, and its imbalance leads to irregularities in heart rhythm and circulation, while Pitta is associated with heat, inflammation, and metabolic derangements, which contribute to atherosclerosis and heart disease.

Pranayama, in Ayurvedic practice, is considered a vital tool to restore balance among the Doshas. Techniques such as Nadi Shodhana help regulate Vata and Pitta, promoting circulation and reducing inflammation. Moreover, Bhramari Pranayama, known for its calming effects, is particularly effective for balancing Pitta, reducing the internal heat associated with inflammation and stress. This is supported by classical Ayurvedic texts such as the Ashtanga Hridaya, which emphasize the role of breath regulation in maintaining heart health.

Ayurvedic practitioners recommend Pranayama as part of a comprehensive approach to managing Hridroga, alongside dietary changes, lifestyle modifications, and the use of herbs that support heart health, such as Arjuna (Terminalia arjuna) and Ashwagandha (Withania somnifera).

2. The Classical Foundation of Pranayama in Yogic and Ayurvedic Texts

The practice of Pranayama, deeply rooted in the philosophy of the Upanishads and the systematic framework of Patanjali's Yoga Sutras, is far more than simple breathing; it is the mastery of the life force itself.

2.1. Prana, Ayama, and the Essence of Life

The etymological breakdown of the term Pranayama (प्राणायाम) into *Prana* (vital energy) and *Ayama* (extension or control) signifies a deliberate effort to extend and regulate the subtle energy that animates all creation. The Upanishads grant *Prana* the highest authority, asserting its pervasive and protective role.

A poignant illustration of this reverence is found in the Kena Upanishad:-

प्राणस्येदं वशे सर्वं त्रिदिवे यत्प्रतिष्ठितम् । मातेव पुत्रान्रक्शस्व श्रीश्च प्रज्ञां च विधेहि न इति ॥

"Pranasyedam vaśe sarvaṁ tridive yatpratiṣṭhitam. Māteva putrānrakṣasva śrīśca prajñāṁ ca vidhehi na iti."

(Translation: Everything in the three worlds is under the control of Prana. O Prana, protect us like a mother protects her sons, and bestow upon us affluence and knowledge.)

This verse establishes *Prana* as the regulator of all universal and individual phenomena. Within the body, the Pancha Prana Vayu govern specific functions. By regulating the act of breathing (the gross manifestation of *Prana*), the practitioner gains access to and mastery over the subtler movements, crucially including Vyana Vayu, the very force that distributes nutrients and energy (including blood and nerve impulses) throughout the body, originating from and governing the function of the heart.

2.2. Hridaya

In Ayurveda, the Hridaya is regarded as the anchor point of Ojas (the supreme essence of vitality, immunity, and resilience). The finest, most subtle form of *Ojas* resides in the heart, sustaining life and consciousness. When the heart is subjected to chronic stress, worry, and emotional turmoil (vitiation of *Mano Vaha Srotas*), *Ojas* is diminished, leading to a state of vulnerability to disease.

Pranayama's direct influence on the mind-body axis is its most profound contribution to cardiac health. By stabilizing the rhythmic movement of the breath (*Prana Vayu*), the practice simultaneously calms the turbulent energy of the mind (*Mano Vaha Srotas*). This cultivation of Sattvic qualities peace, clarity, and emotional equilibrium protects the Ojas in the *Hridaya*, shielding the heart from the degenerative effects of chronic psychological stress and its resultant neurohormonal damage.

The three phases of Pranayama-Puraka (inhalation), Rechaka (exhalation), and Kumbhaka (retention) are a sophisticated mechanism for not just oxygenating the body but for purposefully regulating the flow of *Prana* within the *Nadis* (subtle energy channels), particularly Ida (lunar, parasympathetic) and Pingala (solar, sympathetic), leading to a balanced state conducive to healing.

3. Modulating Oxidative Stress and Inflammation

The modern therapeutic efficacy of Pranayama in CVD is largely attributed to its profound, measurable impact on the Autonomic Nervous System (ANS) and its subsequent biochemical effects on oxidative and inflammatory pathways.

3.1. Autonomic Rebalancing and Heart Rate Variability

Chronic stress, a major CVD risk factor, is characterized by a persistent activation of the Sympathetic Nervous System (SNS). This sympathetic overdrive triggers a cascade of detrimental effects on the cardiovascular system: increased heart rate, elevated blood pressure, peripheral vasoconstriction, and the release of inflammatory mediators.

Pranayama, particularly slow and rhythmic techniques (e.g., *Nadi Shodhana* and *Savitri Pranayama*), acts as a non-invasive Vagal Nerve Stimulator. By prolonging the exhalation phase, it immediately activates the Parasympathetic Nervous System (PNS). The measurable outcome of this shift is an improvement in Heart Rate Variability (HRV), which is the beat-to-beat variation in heart rhythm. A higher HRV signifies a healthy, flexible ANS and is a predictor of lower cardiac risk. The resultant decrease in the SNS-driven production of catecholamines (stress hormones) reduces the cardiac workload and prevents the *Dosha* imbalance from taking hold.

3.2 Reduction of Oxidative Stress and Enhanced Antioxidant Capacity

Oxidative stress (OS) occurs when the production of Reactive Oxygen Species (ROS)-such as superoxide anions and hydroxyl radicals-overwhelms the body's endogenous

antioxidant defenses. ROS damages cellular DNA, proteins, and crucially, lipids, leading to the oxidation of LDL cholesterol and the initiation of atherosclerotic plaque formation.

Pranayama intervenes powerfully at this cellular level:

- **Lipid Peroxidation Markers:** Clinical studies consistently demonstrate that regular Pranayama practice leads to a significant decrease in serum levels of **Malondialdehyde (MDA)**. MDA is a prime end-product of polyunsaturated fatty acid peroxidation and serves as a reliable marker for quantifying OS and cellular damage.
- **Endogenous Antioxidant Enzymes:** Simultaneously, Pranayama enhances the activity and concentration of key antioxidant enzymes, significantly boosting the body's defensive capabilities. This includes:
- **Superoxide Dismutase (SOD):** A vital enzyme that catalyzes the conversion of the highly reactive superoxide radical into less reactive hydrogen peroxide.
- **Paraoxonase-1 (PON-1):** An enzyme associated with high-density lipoprotein (HDL), known for its ability to hydrolyze oxidized lipids in low-density lipoprotein (LDL) and atherosclerotic lesions, thus conferring crucial anti-atherogenic protection. The upregulation of PON-1 activity by Pranayama is a direct, quantifiable mechanism for CVD risk reduction.

3.3. Mitigation of Chronic Systemic Inflammation

Chronic, low-grade systemic inflammation is the "soil" in which atherosclerosis thrives. Inflammation is mediated by the release of pro-inflammatory cytokines, which lead to endothelial activation and dysfunction.

The PNS activation induced by slow breathing acts via the cholinergic anti-inflammatory pathway. Acetylcholine release dampens the activity of immune cells, leading to a down-regulation of the inflammatory cascade. This results in the observed reduction of inflammatory biomarkers:

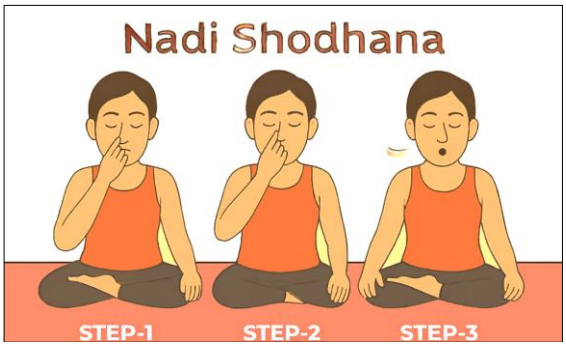
- **C-Reactive Protein (CRP):** A widely used marker of systemic inflammation; its reduction is directly correlated with lower cardiac risk.
- **Pro-inflammatory Cytokines:** Lower circulating levels of mediators such as Interleukin-6 (IL-6) and Tumor Necrosis Factor-alpha (TNF-α) are found in practitioners, indicating a systemic shift away from a pro-atherogenic state.
- **Endothelial Function:** By reducing OS and inflammation, Pranayama enhances the bioavailability of Nitric Oxide (NO), a critical molecule for vasodilation and anti-platelet activity, thereby restoring healthy endothelial function-the earliest protective step against atherosclerosis.

4. Pranayama in Modern Ayurvedic Cardiology (*Hridroga Chikitsa*)

Pranayama, the regulated control of breath, is central to both Ayurvedic and yogic traditions. These techniques influence the autonomic nervous system (ANS), reducing oxidative stress (OS), modulating inflammation, and offering a holistic approach to heart health. Here, we explore key Pranayama practices, their physiological effects on the heart, and their therapeutic benefits in the prevention and management of cardiovascular diseases (CVD).

4.1 Nadi Shodhana (Alternate Nostril Breathing)

Technique: Nadi Shodhana involves inhaling through one nostril while closing the other, followed by exhalation through the opposite nostril. This practice alternates between nostrils, promoting the flow of Prana throughout the body



Nadi Shodhana directly influences the balance between the sympathetic (Pingala) and parasympathetic (Ida) nervous systems, reducing the fight-or-flight response. This promotes heart rate variability (HRV), which is a sign of healthy cardiovascular function and low cardiac risk.

"नाडी शोधनं सम्यक् सन्धीकरणं हृदयोऽलंबं प्राणा मूर्च्छा पुनर्नवा।"

("Nadi Shodhanam samyak sandhikaranam hridayo'lam bam prana murccha punarnava").

Translation: Proper Nadi Shodhana purifies the channels and brings balance to the heart, revitalizing Prana (life energy).

Studies show that Nadi Shodhana reduces oxidative stress markers such as Malondialdehyde (MDA) and increases antioxidant enzyme activity like Superoxide Dismutase (SOD). This action prevents the cellular damage associated with conditions like atherosclerosis and hypertension.

4.2. Bhramari (Humming Bee Breath)

Technique: Bhramari involves closing the ears and exhaling while making a humming sound, a practice that calms the mind and induces a state of tranquility.

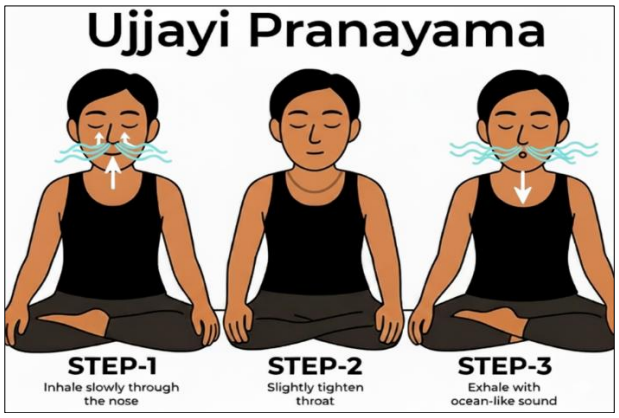
Bhramari stimulates the vagus nerve, which plays a key role in parasympathetic nervous system activation. This results in a decrease in heart rate and blood pressure, contributing to better heart function and reduced risk of cardiovascular events such as stroke and heart attack.

"प्रणवो ब्रह्मा सत्यं सदा धर्मं धरा-धारकं।"
("Pranavo Brahma Satyaṁ Sadaa Dharmaṁ Dhara-Dhaarakaṁ.")

Translation: The breath of Pranayama protects and stabilizes the heart, aligning it with the cosmic rhythm and truth.

Vascular Health and Nitric Oxide Production: Bhramari has been shown to increase Nitric Oxide (NO) production, a molecule essential for vasodilation and improved blood flow. This leads to healthier arteries and a reduced risk of plaque buildup in the blood vessels.

4.3. Ujjayi (Victorious Breath)
Technique: Ujjayi involves breathing through the nose with a slight constriction of the glottis, producing a soft hissing sound. This breath is slow, deep, and controlled, often used during meditation and yoga postures.



Impact on Cardiovascular Health:

- **Regulation of Vata and Heart Rhythm**: Ujjayi helps regulate Vata Dosha, particularly Vyana Vayu, which governs the heart's rhythm and circulation. The practice calms the nervous system and stabilizes irregular heartbeats (arrhythmias), making it especially beneficial for those with cardiac instability.

"उज्जायिनं प्रज्वरं पित्तं सन्तापं विपरीतं च।"
("Ujjayinam prajvaram pittam santapam vipareetam cha")

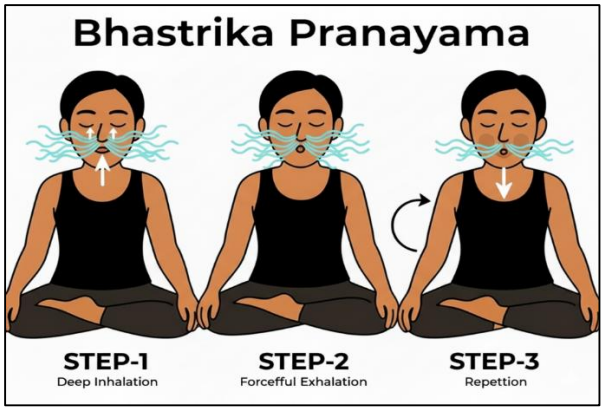
Translation: Ujjayi breath cools the fiery excess of Pitta and balances the heart, soothing the cardiovascular system.

Blood Pressure Control: Research confirms that Ujjayi reduces systolic and diastolic blood pressure, offering a non-invasive tool for managing hypertension. It also calms the mind, preventing the cardiovascular damage caused by stress and anxiety.

4.4 Bhastrika (Bellows Breath)
Technique: Bhastrika involves rapid and forceful inhalations and exhalations, increasing the oxygen intake and energizing the body. This technique is likened to the pumping of a bellows, stimulating both body and mind.

Impact on Cardiovascular Health

- **Improved Circulation:** Bhastrika stimulates the circulatory system by increasing heart rate and blood flow, delivering oxygen to tissues more efficiently. It is particularly beneficial for those suffering from sluggish circulation or low blood oxygen levels.

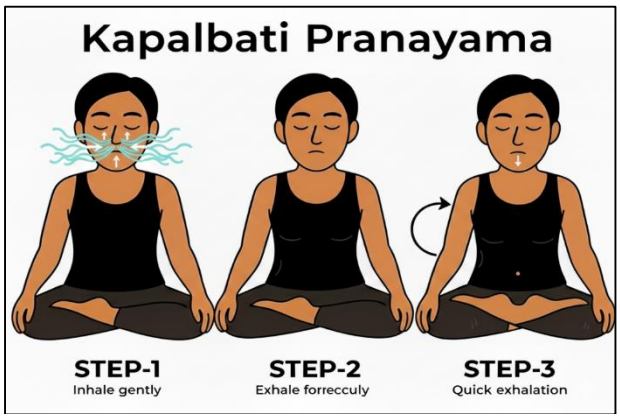


"भस्त्रिका वायुवर्धनं, रक्तशुद्धि प्रदायकं।"
("Bhastrika vayuvardhanam, rakta shuddhi pradaya kam")

Translation: Bhastrika strengthens the breath, purifies the blood, and enhances the vitality of the heart.

Energy Boost: Regular practice of Bhastrika increases the body's energy levels and enhances metabolism. This boost in energy helps in improving the overall functionality of the cardiovascular system.

4.5. Kapalbhati (Skull Shining Breath)
Technique: Kapalbhati involves rapid, forceful exhalations with passive inhalations. This practice focuses on the abdominal muscles, which contract to expel air with force.



Detoxification: Kapalbhati is a powerful detoxifying practice that expels toxins from the body, improves circulation, and clears blockages from the arteries, contributing to better heart health.

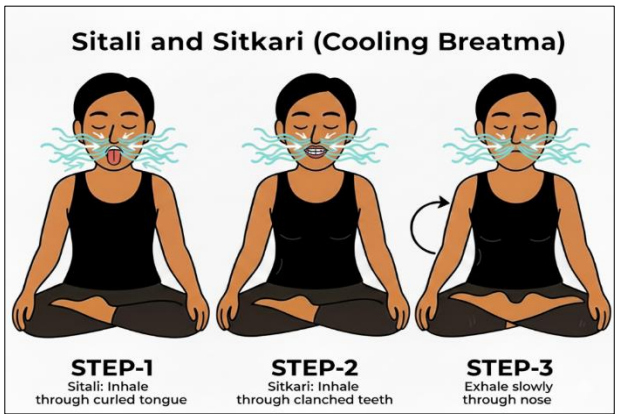
"कपालभाती हृदय कीर्ति, रक्तवृद्धि वर्धयाम्।"
("Kapalbhati hridaya kirti, raktavardhi vardhayam.")

Translation: Kapalbhati purifies the heart, increases blood circulation, and boosts vitality.

Improved Lipid Metabolism: This technique aids in balancing lipid levels in the blood and supports the regulation of cholesterol, thus lowering the risk of atherosclerosis.

4.6. Sitali and Sitkari (Cooling Breaths)

Technique: In Sitali, the practitioner inhales through the mouth, curling the tongue, while Sitkari involves inhaling through the teeth. Both techniques are designed to cool the body and calm the mind.



Pitta Balancing: Sitali and Sitkari are excellent for reducing Pitta, the Dosha responsible for heat and inflammation in the body. Excessive heat can lead to chronic inflammation and arterial damage, which are risk factors for cardiovascular disease.

"शीतलि शीतेन हृदयं शुद्धि कुर्यात् पित्तजं।"

("Sheetali sheeten hridayam shuddhi kuryat pittajam").

Translation: The cooling breath of Sitali purifies the heart, reducing the inflammation caused by Pitta and restoring balance.

Stress Reduction and Anti-inflammatory Effects: These practices help lower blood pressure and reduce stress, which is one of the main contributors to cardiovascular diseases. They also reduce markers of inflammation, such as C-Reactive Protein (CRP), and improve endothelial function.

5. Conclusion

Pranayama is validated by both ancient *Shastra* and modern science as a potent therapeutic agent against the central pathologies of CVD: oxidative stress and inflammation. By restoring the balance of the ANS and regulating the flow of Prana Vayu, the practice functionally corrects the derangements of Vyana Vayu, preserves the quality of Ojas, and optimizes cellular defense mechanisms. The evidence for increased antioxidant enzymes (SOD, PON-1) and reduced OS markers (MDA) provides a clear biochemical mechanism for its anti-atherogenic effect. For the practitioner of Ayurvedic medicine, Pranayama offers an indispensable, non-pharmacological strategy for *Hridroga Chikitsa*, fostering deep-seated physiological and psychological balance essential for true Hridaya-Swasthya (cardiac health). Integrating this breath-science into mainstream cardiac care represents a vital step toward a comprehensive, integrative approach to chronic disease management

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