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OPTIMIZING CARDIOVASCULAR HEALTH: AYURVEDIC INSIGHTS INTO BLOOD FLOW THROUGH NORMAL AND STENOSED ARTERIES

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Abstract: The Ayurvedic approach to cardiovascular health offers a holistic perspective that emphasizes lifestyle, diet, and herbal interventions to maintain optimal blood flow through arteries. In this paper, we explored Ayurvedic principles and practices relevant to normal and stenosed arteries, considering the impact of diet, lifestyle, and herbal remedies on cardiovascular health. We discussed the Ayurvedic understanding of blood flow dynamics, highlighting key concepts, doshas (Vata, Pitta, Kapha), agni (digestive fire), srotas (channels of circulation). Furthermore, we examined the role of Ayurvedic herbs like Arjuna, Garlic, and Cinnamon and formulations in promoting healthy blood circulation and preventing or managing arterial stenosis. Arjuna, proves effective against atherosclerosis and aids in hyperlipidemia management. By integrating Ayurvedic principles with modern biomedical research, and introducing mathematical modelling, we aim to provide valuable insights into optimizing cardiovascular health through a holistic approach.

Keywords: Ayurveda, cardiovascular health, blood flow, arterial stenosis, herbal remedies, holistic approach.

Introduction: Cardiovascular diseases, including arterial stenosis, stand as a formidable challenge to global public health, accounting for a significant portion of morbidity and mortality across diverse populations. While modern medicine has made remarkable strides in the management of these conditions, there is a growing recognition of the limitations and side effects associated with conventional treatments. This has led to an increasing interest in exploring complementary and alternative approaches to cardiovascular health, among which Ayurveda emerges as a prominent contender [12,24,34]. Ayurveda, often hailed as the world's oldest holistic healing system, offers a comprehensive framework for understanding and promoting cardiovascular wellness. Based on timeless insights from ancient India, Ayurveda views the human body as a reflection of the broader cosmos, intricately linked and guided by the foundational laws of nature [3,15,44,62]. Central to Ayurvedic philosophy is old concept of doshas, Vata, Pitta, and Kapha, which represent three elemental forces responsible for governing various physiological functions in the body. According to Ayurveda, disturbances or imbalances in these doshas can disrupt the harmonious functioning of the body, including blood flow regulation, and predispose individuals to cardiovascular disorders [5,23,46,61]. In cardiovascular health, Ayurveda highlights the significance of Agni, the digestive fire, in supporting efficient blood flow within the body. Agni governs the process of metabolism and digestion, ensuring the proper assimilation of nutrients and the elimination of waste products. When agni is in a state of equilibrium, it fosters efficient metabolism and circulation, thereby supporting cardiovascular health [1,7,18,48,65]. Additionally, Ayurvedic texts delineate the concept of srotas, or channels of circulation, through which blood and vital nutrients are transported throughout the body. These Srotas play, crucial role in maintaining integrity of cardiovascular system and ensuring the smooth flow of blood to all tissues and organs. Understanding and applying these foundational principles of Ayurveda are essential for addressing cardiovascular concerns from a holistic perspective [2,9,26,35,41]. Ayurveda advocated for a personalized approach to health, taking into account individual constitution, lifestyle, and environmental factors. Central to this approach is the concept of dinacharya, or daily routine, which encompasses dietary habits, sleep patterns, exercise regimens, and stress management

techniques [4,10,21,47,63]. By cultivating a lifestyle that supports balance and harmony in the doshas, individuals can promote cardiovascular well-being and mitigate the risk of arterial stenosis and related disorders.

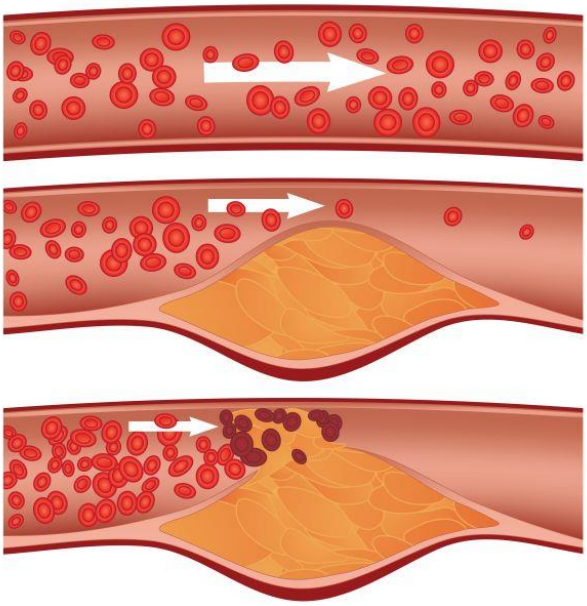

Figure. (1) Atherosclerosis

Figure. (2) Arjuna (Terminalia arjuna),

Diet plays a pivotal role in Ayurvedic management of cardiovascular health, with particular emphasis on food choices that help maintain doshic balance and support efficient circulation. According to Ayurveda, dietary factors such as excessive intake of oily, spicy, and processed foods can aggravate pitta dosha and contribute to arterial inflammation and stenosis [6,11,42,64]. A diet rich in fresh fruits and vegetables is recommended to pacify pitta dosha and promote healthy blood flow. Furthermore, Ayurvedic dietary guidelines advocate for mindful eating practices, such as eating in a calm and relaxed environment, chewing food thoroughly, and avoiding overeating. In addition to dietary modifications, Ayurveda prescribes specific lifestyle practices to support cardiovascular health and prevent imbalances in the doshas [8,13,29,45,54]. Regular exercise, tailored to individual constitution and physical capabilities, is considered essential for promoting circulation, strengthening the heart, and reducing the risk of cardiovascular diseases. Stress

management methods such as meditation, yoga, and breath control exercises are essential components of ayurveda. Ayurvedic approach to cardiovascular health by cultivating inner peace and emotional resilience, individuals can mitigate the detrimental effects of chronic stress on the cardiovascular system and promote overall well-being [17,31,51,66]. In the realm of Ayurvedic pharmacology, herbs and formulations have long been revered for their therapeutic potential in promoting cardiovascular health and addressing arterial stenosis. Traditional herbs such as Arjuna (Terminalia arjuna), Guggul (Commiphora wightii), and Punarnava (Boerhavia diffusa) have been extensively studied and prescribed for their cardioprotective properties. These herbs exhibit, pharmacological effects, and lipid-lowering activities, which contribute to improved blood flow, arterial function, and overall cardiovascular health. Ayurvedic formulations such as Triphala, Dashmool, and Chyawanprash are also renowned for their cardioprotective benefits, offering a synergistic blend of herbs and nutrients to support cardiovascular function and promote longevity. In conclusion, the Ayurvedic perspective on blood flow through normal and stenosed arteries offers valuable insights into the intricate dynamics of cardiovascular health. By integrating the principles of Ayurveda—including dosha balance, dietary and lifestyle modifications, and herbal interventions—we can cultivate a holistic approach to cardiovascular well-being [19,38,55]. With its emphasis on personalized care, preventive medicine, and natural remedies, Ayurveda holds promise as a complementary and alternative approach to modern cardiology, offering new avenues for optimizing cardiovascular health and reducing the burden of arterial stenosis and related disorders on a global scale. Ayurveda, an ancient medical system from India, has been highly esteemed for its comprehensive approach to well-being and its focus on using natural treatments for a range of health issues, including heart conditions [14,37,40]. Over the centuries, Ayurvedic practitioners have discovered and refined numerous herbal remedies for treatment, prevention, and management of cardiovascular disorders, offering patients alternative options to complement conventional medical treatments.

Among the many herbs used in Ayurveda for heart health, Arjuna (Terminalia arjuna), garlic (Allium sativum), and cinnamon (Cinnamomum verum) stand out for their remarkable

therapeutic properties. Arjuna, in particular, has been extensively studied and recognized for its cardioprotective effects. Its bark extract contains bioactive compounds such as flavonoids, tannins, and triterpenoids, which exert antioxidant, anti-inflammatory, and lipid-lowering actions [20,33,52]. Arjuna helps strengthen the heart muscles, regulate blood pressure, and improve overall cardiovascular function, making it a valuable addition to heart disease management protocols. Similarly, garlic has gained widespread recognition for its cardiovascular benefits, attributed primarily to its high content of organosulfur compounds such as allicin. These compounds exhibit antiplatelet, antithrombotic, and vasodilatory effects, which help reduce blood clot formation, improve circulation, and lower blood pressure. Garlic supplementation has been shown to support healthy cholesterol levels, prevent plaque buildup in the arteries, and reduce the risk of atherosclerosis and coronary artery disease. Cinnamon, another commonly used herb in Ayurveda, offers a myriad of health benefits, including cardiovascular support [30,39,50].

Cinnamon helps regulate blood sugar levels, lower LDL cholesterol, and enhance insulin sensitivity, making it particularly beneficial for individuals with diabetes and metabolic syndrome, who are at higher risk of cardiovascular complications. In addition to these individual herbs, Ayurvedic formulations containing a combination of herbs and other natural ingredients have also been developed to address various aspects of cardiovascular health. One such formulation is Guggul, derived from the resin of the Commiphora wightii tree [11,56,67]. Guggul extracts have been shown to reduce LDL cholesterol levels, inhibit the formation of plaque in the arteries, and improve lipid metabolism, thereby reducing the risk of cardiovascular events. While Ayurvedic herbs offer promising therapeutic benefits for heart health, it is essential to acknowledge that they may also pose certain risks and side effects, especially when used improperly or in combination with other medications. As such, it is crucial to conduct rigorous scientific research and clinical trials to evaluate the safety, efficacy, and potential interactions of these herbs in the context of cardiovascular disease management [22,27,36,53]. Furthermore, standardization of herbal extracts and quality control measures are necessary to ensure consistency and reliability in their therapeutic effects. Ayurveda presents a rich treasure trove of herbal herbs for treatment of heart issues,

offering patients natural alternatives to conventional pharmaceutical interventions. Herbs such as Arjuna, garlic, cinnamon, and Guggul have demonstrated significant potential in supporting cardiovascular health and reducing the risk of adverse cardiac events. However, further research is needed to elucidate their mechanisms of action, optimize their dosage regimens, and ensure their safety and efficacy in clinical practice [23,34,56,67].

Formulation of Problem: Heart is a muscular organ located in the chest cavity, positioned between the lungs and resting above the diaphragm. It is enveloped by the pericardium, a protective sac. At its upper end, known as the base, heart is connected to major blood vessels such as aorta, pulmonary arteries, pulmonary veins, and vena cava. Lower end of heart, called apex, is situated just above diaphragm. In terms of orientation, base of heart aligns with body's midline, while apex points towards left side. As a result of this leftward orientation, approximately two-thirds of the heart's mass is located on the left side of the body, with the remaining one-third on the right side. The heart serves as the body's primary pump, responsible for orchestrating the precise circulation of oxygenated blood throughout the vascular system [16,25,28]. It receives deoxygenated blood, which is transported through the veins to lungs for oxygenation. Once oxygenated, the blood is pumped into an artery to be distributed throughout the body. Cardiovascular diseases encompass various health conditions that impact circulatory system, including heart and blood vessels. This broad term describes ailments affecting the heart and blood vessels, leading to complications in blood flow. Conditions such as thrombosis (formation of blood clots) and hyperlipidemia (high levels of lipids in the blood) contribute to the narrowing of arteries, a phenomenon known as Atherosclerosis. Mathematically, Atherosclerosis can be represented by following equation;

$$\left.\begin{aligned} \frac{R(z)}{R_0} &= 1 - A[L_0^{(m-1)}(z-d) - (z-d)^m], && d \le z \le d + L_0 \\ &= 1, && \text{otherwise,} \end{aligned}\right\} \quad (1)$$

$$A = \frac{\delta}{R_0 L_0^m} \frac{m^{m/(m-1)}}{(m-1)}, \; z = d + L_0 / m^{1/(m-1)}.$$

Equation describes how blood moves smoothly and steadily through an artery, considering factors like its thickness and direction. It focuses on blood flow that doesn't change much over time and only happens in one direction. This equation also takes into account that blood viscosity, which is how thick or thin the blood is, can change depending on where it is in the artery.

$$\left.\begin{aligned} 0 &= -\frac{\partial P}{\partial r} + \frac{1}{r}\frac{\partial (r\tau)}{\partial z}, \\ 0 &= -\frac{\partial P}{\partial r}, \end{aligned}\right\} \qquad (2)$$

Boundary conditions are as below;

No-slip condition at the artery wall:

- $\partial u / \partial r = 0$ at $r = 0$

This condition implies that there is no relative motion between the blood and the arterial wall at the boundary.

Velocity at the artery wall:

- $u = 0$ at $r = R(z)$.

It indicates that the velocity of blood at the boundary of the artery (the lumen) is zero.

Finite wall shear stress at the artery wall:

- τ is finite at $r = 0$

This condition ensures that there is a finite shear stress exerted by the blood on the arterial wall.

Pressure boundary conditions:

- $P = P_o$ at $z = 0$
- $P = P_L$ at $z = L$ (3)

These conditions specify pressure in the inlet (z=0), outlet (z=L) of the artery, representing the upstream and downstream boundaries, respectively.

We obtained a non-Newtonian equation to represent blood flow in arteries more accurately because blood doesn't always behave like a simple fluid. Instead of following Newton's laws of viscosity (how easily a fluid flows), blood sometimes behaves differently, especially in narrow arteries or when there are obstructions. So, using a non-Newtonian equation helps us better understand how blood moves in these situations, that equation is knows as Casson's relation and commonly written as below:

$$\left.\begin{aligned} \tau^{1/2} &= \tau_0^{1/2} + (\mu)^{1/2}(-\frac{du}{dr})^{1/2}, && \text{if } \tau \geq \tau_0 \\ \left(\frac{du}{dr}\right) &= 0 && \text{if } \tau < \tau_0 \end{aligned}\right\} \quad (4)$$

Flow rate has obtained by simplifying above equaions;,

$$Q = \pi \int_0^R r^2 (-\frac{du}{dr})\, dr. \quad (5)$$

Integrating above equation;

$$Q = \frac{\pi R^4}{8\mu}(-\frac{dp}{dz})[1 - \frac{16}{7}(\frac{R_c}{R})^{1/2} + \frac{4}{3}(\frac{R_c}{R}) - \frac{1}{21}(\frac{R_c}{R})^4], \quad (6)$$

Equation (18) can be rewritten as;

$$Q = \frac{\pi R^4}{8\mu}(-\frac{dp}{dz})\, f(\bar{y}),$$

where $f(\bar{y}) = [1 - \frac{16}{7}(\bar{y})^{1/2} + \frac{4}{3}(\bar{y}) - \frac{1}{21}(\bar{y})^4],$

Equation for pressure has investigated;

$$(-\frac{dp}{dz}) = \frac{8\mu\, Q}{\pi R^4 f(\bar{y})} \quad (7)$$

$$\Delta P = P_L - P_0 = \frac{8\mu Q}{\pi R_0^4} \int_0^L \frac{dz}{(R(z)/R_0)^4\, f(\bar{y}(z))} \quad (8)$$

Results and Discussion: We have plotted equation (8) with the help of MATLAB. Atherosclerosis, changes in flow characteristics occur due to the narrowing and stiffening of

arteries caused by plaque buildup. As the artery narrows due to plaque accumulation, the flow rate of blood through the artery decreases. This reduction in flow rate can lead to inadequate perfusion of tissues and organs supplied by the affected artery. The presence of plaque increases the resistance encountered by blood flow. Increased resistance requires heart to work harder to maintain adequate blood flow, leading to increased stress on the heart. In areas where plaque is present, flow of blood will become turbulent instead of smooth. Turbulent flow can further increase stress on the artery walls and promote the formation of blood clots. The pressure gradient along the artery will change due to the presence of plaque. In areas of stenosis (narrowing), the pressure may drop due to increased resistance, while in areas of turbulence, pressure fluctuations may occur which has investigated in Figure [3]. Shear stress, the frictional force exerted by flowing blood on the artery walls, is altered in areas of plaque buildup. This disturbance in shear stress can contribute to endothelial dysfunction and further progression of atherosclerosis [32,43,49].

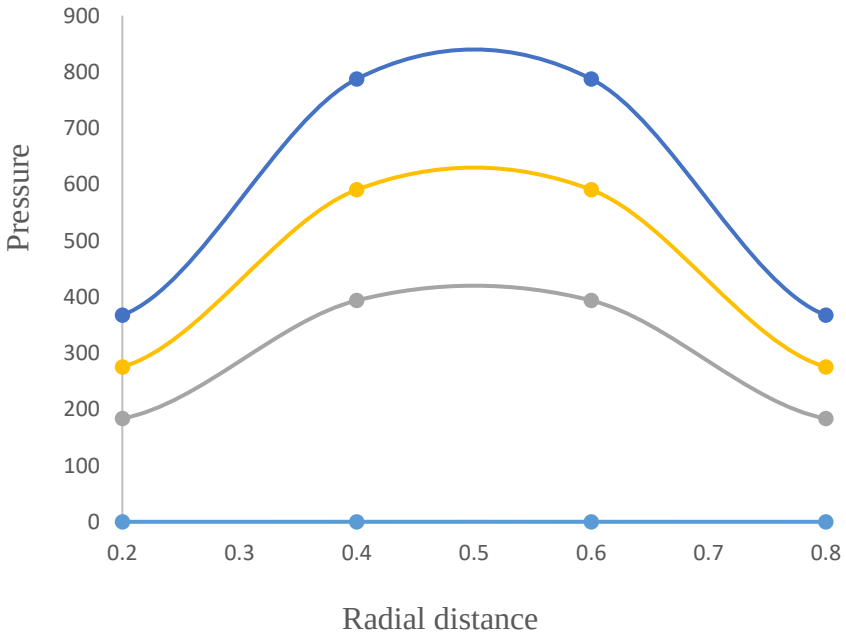

Figure (3). Pressure with radial distance (r) for different m

The presence of atherosclerosis alters the normal flow characteristics of blood in affected arteries, leading to reduced flow rates, increased resistance, turbulent flow, altered

pressure gradients, and disturbed shear stress. These changes can have significant implications for cardiovascular health and may contribute to the development of complications such as heart attack and stroke. Herbal remedies like Arjuna, also known as Kapotvadka or Somvalli, belong to the Scrophulariaceae family and are recognized for their therapeutic properties in treating atherosclerosis. They are characterized by their taste (Rasa) of Tikta (bitter) and Katu (pungent), their light (laghu) and dry (ruksha) qualities, and their post-digestive effect (Vipaka) of Katu. They possess a hot (Ushna) potency and exhibit actions that balance Kapha and Vata doshas in the body. Arjuna is classified taxonomically under the Plantae kingdom, Lamiales order, and Bacopa genus. It contains various chemical constituents that contribute to its medicinal properties. Arjuna is particularly beneficial in regulating blood pressure and supporting normal vascular functions. Additionally, it aids in the utilization of nitric acid, further promoting cardiovascular health [11,33]. Studies have demonstrated the efficacy of Arjuna in reducing both systolic and diastolic blood pressure. Bacopa monnieri, another herb belonging to the same family, has also shown promising results in lowering blood pressure levels. Research suggests that its mechanism of action involves the reduction of chronic hypertension induced by N-nitro-L-arginine methylation in animal models, thereby exerting antihypertensive effects [22,45,63].

Conclusion: Ayurveda offers valuable insights into optimizing cardiovascular health through a holistic approach that integrates diet, lifestyle, and herbal interventions. By understanding the principles of Ayurvedic medicine and incorporating them into daily life, individuals can support healthy blood flow and reduce the risk of arterial stenosis and other cardiovascular disorders. Herbs like Arjuna, Garlic, and Cinnamon, along with their formulations, play pivotal roles in cardiovascular disease management. Arjuna, for instance, proves effective against atherosclerosis and aids in hyperlipidemia management. Conducting in-depth studies on these herbs and their bioactive components can pave the way for developing advanced molecules for treating cardiovascular ailments. While herbs hold significant therapeutic potential, they also come with potential side effects, unlike synthetic medications. Clinical research is imperative to explore the phytochemicals, efficacy, safety,

and toxicity profiles of medicinal plants, ensuring their optimal utilization in cardiovascular care. Further research is needed to explore efficacy of Ayurvedic interventions in prevention and management of cardiovascular diseases, ultimately promoting holistic well-being.

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