

Review Article

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Pulmonary, Cardiovascular, and Hemodynamic Effects of Pranayama or Yogic Breathing

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Abstract

Deep or yogic breathing or Pranayama has numerous health benefits. This article enumerates pulmonary, cardiovascular, and hemodynamic effects of deep breathing. These effects appear at the time a deep breath is initiated and persists as long as the breath continues. Hence, the beneficial effects are instant and prolonged as long as it does not exceed certain threshold. The effects of Pranayama are discussed from a critical care perspective in modulating pulmonary and cardio-hemodynamic functions as a complement to main stream medicine. The practice is simple and easily applicable in counteracting the effects of critical illness on ultimate organ dysfunction. Moreover, Pranayama practice initiated prior to illness may counteract the undesirable effect of critical illness and help in the process of healing and recovery. It may also be cost effective and as an attractive reimbursable health practice in maintaining wellbeing for the health insurance industry.

Keywords: pranayama, yogic breathing, deep breathing, cardiac, pulmonary, parasympathetic-sympathetic, complimentary medicine.

“Chale vate chittam nischale nischalam bhavet
Yoght sthanuyvapnoti tato vuyum nirodhayet”

Respiration, being disturbed, the mind becomes disturbed.

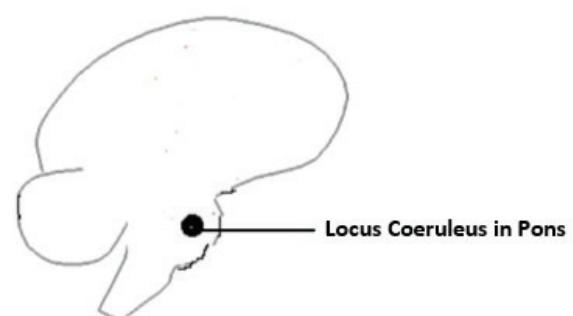
By restraining respiration, the yogi gets steadiness of mind.

— Hatha Yoga Pradapika. Yogi Svatmaram

Introduction

“Prana” stands for vital energy and “Ayama” to extend [1]. Pranayama is an art of prolongation and breathe control, which helps to bring breath to conscious awareness; helps to reshape breathing habits and patterns [2]. Pranayama has been in vogue for centuries and practiced in India, although, more recently, it has become widespread and popular all around the world. It is an integral part of complimentary medical practice. There are many techniques of Pranayama in practice. It consists of inspiration termed as Puraka, inspiratory pause or Antara Kumbhaka, exhalation or Rechaka and pause at the end of exhalation or Bahir Kumbhaka [3] and in its extreme form is called Nisshesha Retchaka [4]. Pranayama can be classified into slow or rapid types.

Figure 1
Vertical Section of the Brain



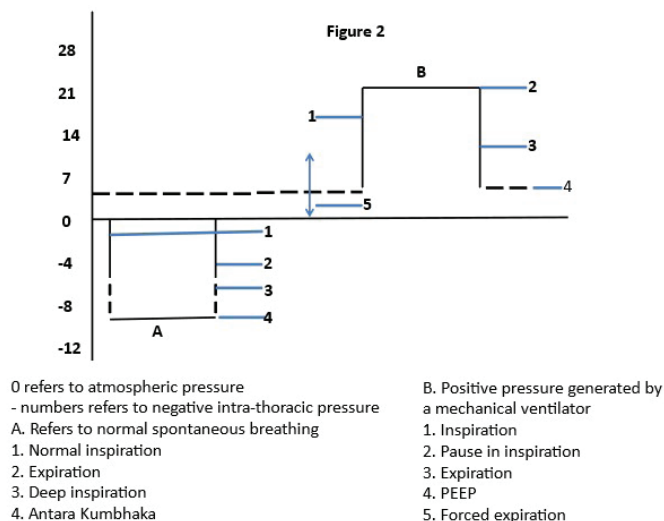
Locus Coeruleus {LC} (Figure 1) is a nucleus located bilaterally in Pons situated in the posterior part of the brain [5]. Synchronization between respiration and attention takes place via LC. Pranayama could influence stability and or the depth of the synchronization decreasing the energy required to maintain attention and lessening shifting of unintended attention [6]. Pranayama decreases respiratory frequency in addition to modulating arousal as well as improved vagal tone and diminished carbon dioxide (CO₂) sensitivity on the respiratory center which in turn, plays a part in

decreasing respiratory frequency via reduction in LC oscillations [7].

General physiological effects of Panayama:

Nissessa rethaka induces brief episodic intermittent hypoxia resulting in many different adaptive responses such as an increase in erythropoietin including in chronic renal failure, improving hemoglobin level in the blood, an increase in vascular endothelial growth factor (VEGF) inducing coronary collateral circulation, decreased BP, and improving perfusion, favored stem cell migration which may potentially be useful in patients with Parkinsons and osteoarthritis, an induction of P53 leading to prevention of cancer, resistance to cellular damage leads to counteracting aging processes [4]. Although the effects of Pranayama are divided into respiratory, cardiovascular and hemodynamic effects, there is a close coordination and interdependence between these systems so that they act as one single unit. The chest can be considered as a box enclosing 2 pumps, namely, the heart and the lungs with great vessels aorta and vena cava as well as 2 hollow structures consisting of the esophagus and the trachea. All these structures are exposed to the variation in pressure brought about by the movement of the chest.

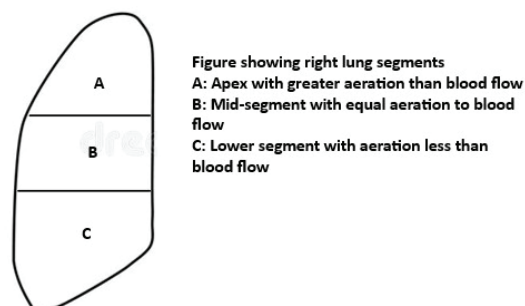
Respiratory effects of Pranayama:



During inspiration the chest expands resulting in a descent of the diaphragm, the chief muscle of inspiration, which pushes the abdominal content downwards and outwards resulting in the movement of abdominal wall outwards and the reverse is true during expiration resulting in abdominal wall moving inwards resulting in a squeeze on the abdominal contents and hence the elevation of the diaphragm and the movement of the chest inwards compressing the lungs and eliminating air out into the atmosphere [8]. During this activity due to a pressure gradient between the atmosphere and the airway as well as a pressure gradient within the airway (-ve pressure), air moves into the air sacs or alveoli and out (+ve pressure) into the atmosphere [9]. A normal ratio between inspiration (I) to expiration (E) is 1 to 2 (I:E = 1: 2), that is expiration is normally twice as long as that of inspiration. In stressful situations however, respiration speeds up [10] (hyperventilation) resulting in low CO₂ levels and an increase in blood pH resulting in harmful effects on various organs. Reversing the I:E ratio, that is, prolonged inspiration and a short expiration lead to a decrease in vagal tone and an increase in heart rate [11]. Decreased vagal tone has benefits as will be discussed later. It is important to teach oneself to maintain deep respiratory efforts during stress or anxiety provoking situations. Therefore,

the practice of Pranayama helps to learn and maintain appropriate breathing technique as well as to increase lung capacity, enhance respiratory muscle function and to ensure patency of upper airway [12]. These benefits may be used in treating obstructive sleep apnea (OSA) which is characterized by the absence of air movement in and out of the lungs during sleep caused by airway obstruction due to the relaxation of soft tissue around the airway during sleep as well as the tongue falling back. Subjects suffering from OSA are treated with positive airway pressure using continuous positive airway pressure or CPAP. However, CPAP therapy can induce central apnea (brain induced absence of breathing). Deep breathing also helps to increase the capacity to exchange more air rich in oxygen with blood and to improve the gas exchange reserve or Functional Residual Capacity (FRC). 12 weeks of Pranayama training improved commonly measured pulmonary function tests in young subjects compared to a control group [13]. In clinical practice in an Intensive Care Unit (ICU) setting, subjects who are on invasive mechanical ventilators are subjected to an inspiratory time, an expiratory time, and where an inspiratory pause (at end inspiration) is used to measure plateau pressure which is kept under 30 cm of water to prevent injury to the lungs [14]. On the other hand, pause at the end of an exhalation termed Positive End Expiratory Pressure (PEEP) of 3-5 cm of water is used to prevent complete deflation at end exhalation during mechanical ventilation (or artificial support of breathing), while in a spontaneously breathing subject not on mechanical ventilator, pressure at end-exhalation is equal to atmospheric pressure [15] (Figure 2). In patients who have stiff lungs or poor compliance, a recruitment maneuver (sustain hyperinflation for a short period of time) is used to enlist collapsed, unused alveoli after certain procedures. In Antara Kumbhaka in a spontaneously breathing subject has a similar effect to that of a recruiting maneuver. There are different wave patterns described during the use of invasive mechanical ventilator. One of the wave patterns termed “square wave” or “rectangular wave pattern” resembles that of wave generated by the Pranayama practice as was described above [16]. The advantage of a square wave pattern involves the induction of a short inspiratory time leading to a prolonged expiration time and similar to Antara Kumbhaka result in the prevention of air trapping in the lungs, that which is advantageous in asthmatics [17]. Another benefit is that there is a reduction in the average airway pressure and an improvement in heart function [18]. Although lifesaving, invasive mechanical ventilation leads to many complications and therefore the goal is to liberate subjects from these devices as early as possible. Teaching Pranayama may be useful to patients prior to major surgical procedures or at early stages of acquired lung diseases in order to maintain pulmonary function and effectively rehabilitate after liberation from mechanical ventilation.

Figure 3

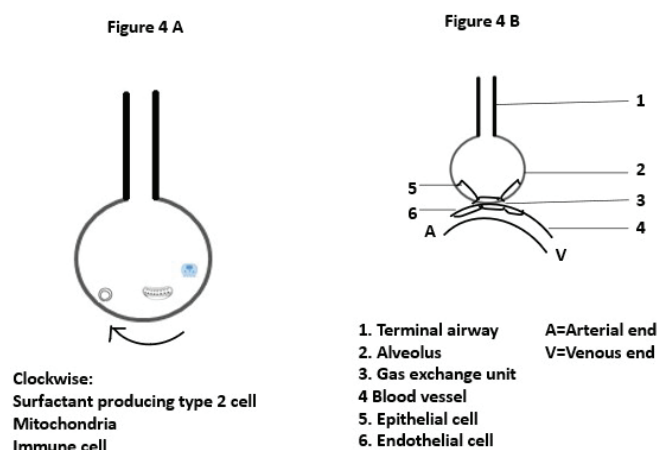


West JB: Ventilation/Blood Flow and Gas Exchange, 5th ed. Oxford: Blackwell; 1990

Each Lung can be divided into 3 segments based on the relationship

between airflow into the lung and blood flow to the lungs (Figure 3). The top or epical portion of the lungs in an erect posture receives less aeration, and it receives even less blood flow, resulting in an air to blood flow ratio of greater than 1. This ratio is equal in mid lung regions and is <1 in lower lung region indicating greater blood flow in the lower regions of the lung. Pranayama potentially can improve airflow to these lower regions of the lungs, thus bringing the ration closer to 1 and improve oxygen inflow into the blood and carbon dioxide elimination from the blood into the alveoli and thereby supplying needed oxygen to the tissues of the body [19].

Pranayama effect on lung inflation:



It has been shown [20] that alveoli (Figure 4B) which are grape like structures at the end of an airway or respiratory bronchioles, contain vesicles or sacks that are filled with a phospholipid rich structure called surfactant. The surfactant is produced by a special type of cells called type 2 cells in the lungs (Figure 4A). The property of this surfactant is to prevent alveolar collapse at low lung volume and to preserve small airway patency during normal as well as forced respiration [21]. Patency of the alveoli at the end of an exhalation makes it possible to inflate the alveoli with less inspiratory pressure following the next inhalation and hence conserve energy. This concept is exemplified by, for example, blowing air into a balloon. Initially the balloon may require an increased pressure to inflate, but subsequently it is easier to complete the inflation without much effort. Using special microscopy, it was shown in a mice model that expansion of an alveolus releases the surfactant into the alveolus from its vesicle to maintain its patency. One may logically conclude that Pranayama, which involves deep breathing, would then help in maintaining alveolar patency and prevent complete alveolar collapse through surfactant release thereby resulting in energy conservation during the inflation of these lung units of respiration. In addition, Pranayama practice helps all alveoli to participate in the gas exchange which involves movement of oxygen from alveoli to the blood stream where it is used for cellular function in exchange for the carbon dioxide generated from cellular metabolism that is moved into alveoli to be excreted out into the atmosphere, an essential function of the lungs. There are on an average 500 million alveoli in an adult lung. There are only 2 layers of thin membranes separating alveolar gas from blood, namely an endothelial layer (lining the blood vessel) and an epithelial layer covering an alveolus (Figure 4B) [22]. Therefore, it is important to keep alveoli patent for efficient gas exchange. Hence, it is essential to recruit as many alveoli as possible for gas exchange. Pranayama practice comes in handy in improving efficient gas exchange by preventing alveolar collapse and thus decrease ventilation-perfusion mismatch (V/Q) and intra-pulmonary shunt. In patients with pneumonia including COVID-19 there is inflammation of the affected parts

of the lung which may be bilateral and extensive, the resulting inflammation induces an inhibition of surfactant produced by type 2 pneumocytes (specialized lung cells) which results in the collapse of the alveoli and fluid accumulation that leads to a loss of gas exchange units of the lungs leading to hypoxemia (low oxygen tension in the blood) and a condition termed as Acute Respiratory Distress Syndrome or ARDS [23]. ARDS from COVID-19 carries a high mortality rate of 52% and there are no specific therapies to treat ARDS [24]. Therapy includes mainly supportive management, however, the use of anti-inflammatory agents such as corticosteroid is promising [25] and in severe cases mechanical ventilation is used to support the failing lungs. Although, it is unknown at this time whether the practice of deep inspiratory efforts would help to improve oxygenation and avoid invasive mechanical respiratory support, it is used effectively in preventing lung collapse or atelectasis in ICU patients to improve lung function following post-surgery [26] and early inflammatory respiratory processes in combination with chest physical therapy (CPT). In those instances, Pranayama can be used as a simple maneuver to avoid deterioration in lung function. Such practice necessitates prior teaching of Pranayama technique to patients.

Cardiovascular and hemodynamic effects:

At the end of a normal exhalation, negative intrathoracic pressure becomes less negative and reaches atmospheric pressure at end exhalation (figure 2). Forcing expiration beyond this point may be counter-productive (figure 2, part A, #5) especially after a deep inspiration since it can generate a very high positive airway pressure (5 cm to 40 cm to greater than 100 cm of water) which would impeded blood return to the right side of the heart and result in decreased blood outflow to the other organs of the body resulting in injury to organs including the lungs [27]. Another concept is the principle of driving pressure which is the difference between plateau pressure and PEEP and if kept below 15 cm of water minimizes barotrauma (trauma from excessive pressure) to the lungs while on a mechanical ventilator [28]. Pressure generated in the intra-thoracic space or chest cavity while on a mechanical ventilator is positive unlike in a spontaneously breathing subject which generates a negative intra-thoracic pressure. Therefore, driving pressure in a spontaneously breathing subject is zero or is in the negative range thus protecting lung from injury.

Generating a negative intra-thoracic pressure is beneficial in that it increases venous return from both upper and lower parts of the body to the right side of the heart thus increasing cardiac output and improving blood circulation to various organs [29]. In deep inspiration following Pranayama, therefore one would improve blood circulation and, at the same time, stimulates the parasympathetic nervous system [30] to slow the heart rate and improve circulation to the heart. A study in heart failure patients showed that pranayama combined with meditation and standard medical therapy resulted in a significantly slower heart rate, systolic and diastolic blood pressure (BP) [31]. It appears that following right nostril yogic breathing a significant increase in systolic, diastolic and mean BP was documented, whereas alternate nostril breathing decreased systolic and diastolic BP, left nostril breathing lowered systolic and mean BP [32]. These variations need to be considered when teaching Pranayama techniques to individuals with hypertension. The practice of slow type of pranayama (3-4 breaths per minute) and Bhramari pranayama (humming bee breath which produces a soft humming sound on exhalation) resulted in a reduction of heart rate, myocardial workload, and myocardial oxygen consumption [33, 34]. Another advantage of parasympathetic stimulation is that it leads to an anti-inflammatory response [19, 35] resulting in a beneficial immune regulation which helps to counteract pro-inflammatory response

from infectious agents such as COVID-19.

Other cardiovascular and autonomic effects of deep breathing:

Cardiovascular and respiratory control systems are coupled reciprocally. While each system affects the other, respiration with slower oscillation has a stronger influence on the cardio-vascular system than arterial blood pressure has on the breathing pattern. Cardio-respiratory coupling (CRC) enhances efficacy of gas exchange by matching ventilation to perfusion. CRC deteriorates during stress and is enhanced during relaxation and slow-wave sleep. Slow deep breathing enhances CRC over a longer time scale rather than a shorter time period [36].

Reaction time is used as an index of an ability to inhibit pre-motor response, and reduced reaction time which signifies increased alertness, quicker information processing, and reduced distractibility. Slow deep breathing consisting of 4 seconds inhalation followed by 6 seconds exhalation in Sukhasana (pleasure posture) for 5 minutes significantly improved the participating subject's concentration and an insignificant decrease in both systolic and diastolic BP [37]. Another type of pranayama called Sheetali pranayama is practiced by inhalation through the mouth and exhalation through the nostrils. This practice would produce a cool sensation in the throat, stimulate the vagal nerve and evoke transient increase in cardiac parasympathetic activity and decreased blood pressure via baroreceptor reflex. It is well known that slow deep breathing leads to augmentation of Baroreceptor Reflex Sensitivity (BRS) resulting in decreased sympathetic activation and thus lowering BP [38]. Forced Deep Breathing (FDB) was used to prevent Deep Vein Thrombosis (DVT) in subjects with plaster cast mobilization of lower extremity. It is hypothesized that the pump function of lung was augmented by forced deep breaths aided by maximal tidal volume and flow speed. Forced deep breaths (FDB) promoted peak blood flow velocity greater than an Intermittent Pneumatic Compression (IPC) device in the superficial femoral vein irrespective of age and posture. IPC device was equivalent to some anti-coagulant prophylaxis against DVT. FDB can be applied in shelters used in disaster situations such as earthquake and tsunami where one finds crowded conditions impeding physical activity and movement that are so essential to prevent DVT. However, caution needs to be used in subjects with cardiovascular disease complicated by DVT [39].

Obesity with added risk factors such as hypertension, high LDL, low HDL lipoproteins, predisposes one to premature atherosclerotic heart disease leading to arterial stiffness. Sympathetic activity may also play a role in this process. Arterial stiffness results in a faster pulse wave velocity (PWV) leading to a faster return of reflected wave from the periphery to the heart during systole. The consequence of increased PWV is an elevated ascending aortic systolic and pulse pressure, thus increasing left ventricular after load making the left side of the heart work harder. Slow breathing was used to decrease sympathetic activity and significantly reduce albeit transiently peripheral arterial stiffness in obese adolescent compared to normal-weight controls. Thus, by using simple deep breathing technique at 6 breaths per minute, it is possible to prevent cardiovascular complications and accompanying endothelial dysfunction related to obesity and consequent metabolic abnormalities [40]. In addition, insulin resistance induced by obesity leads to autonomic abnormality leading to a lowered baroreceptor reflex sensitivity (BRS). A decreased BRS caused by increased plasma levels of insulin, leptin, and angiotensin 2 results in thickness and stiffness of the carotid vessel wall and is also known to reduce BRS. A restraint on central autonomic center may result in increased sympathetic activity. All these causes lead to a functional impairment of autonomic nervous system which

can be reversed by slow deep breathing [41].

Heart rate variability is induced by respiratory effort via respiratory sinus arrhythmia (RSA) through baroreceptor reflex activity with HR increasing during inhalation and decreasing during exhalation via parasympathetic nervous system activity. RSA dependence on respiratory rate has a resonance property with amplitude increasing at a low respiratory rate of 5-6 times/minute. There are also respiratory and pulse dependent oscillation in peripheral blood flow. The respiratory dependent oscillation in the peripheral blood flow occurs by two mechanisms, namely, firstly by the respiratory pump which is responsible for venous return to the heart and the secondly mechanism via respiratory modulation of the autonomic nervous system that influences cutaneous blood flow via sympathetic-parasympathetic balance. Cutaneous blood vessels in fingers are influenced by sympathetic innervation which constrict in response to inspiration unlike forearm cutaneous vessels which dilate due to parasympathetic innervation. Deep inspiration thus influences peripheral blood flow in response to deep breathing [42].

Deep slow breathing at 6 breaths/minute also improves tolerance to syncopal episode from any cause via induction of negative intrathoracic pressure and modulation of autonomic function [43].

Climbing to a high altitude compared to sea level results in hypoxemia, hyperventilation, respiratory alkalosis, pulmonary edema and pulmonary hypertension. Slow deep breathing leads to improved and efficient ventilation, with an increase in alveolar ventilation and reduced dead space ventilation. It also corrected hypoxemia by increasing alveolar volume and capillary-alveolar gas exchange. Correction of elevated pulmonary arterial and systemic arterial pressures were also achieved [44].

Deep breathing at 6 breaths per minute reduced the frequency of PVCs at least by 50% in responders due to vagal modulation of the sinoatrial and atrioventricular nodes [45].

Deep breathing can be used to uncover sympathetic-parasympathetic imbalance. Reduced heart variability in response to deep breathing indicates an imbalance in sympathetic-parasympathetic balance which would lead to cardiac autonomic dysregulation that was seen in psychiatric patients and their 1st degree relatives suggesting a genetic predisposition. Diagnosing cardiac dysregulation helps to prevent associated cardiac morbidity and mortality [46].

It is not uncommon to see an elevation of blood pressure (BP) especially the systolic component in response to visits to a physician's office termed White Coat Hypertension (WCH). The mechanism for elevation in BP is thought to be due to over activation of the sympathetic nervous system in response to the physician office environment. In order to diagnose WCH it may be necessary to employ complex diagnostic protocol. However, a simple test of deep breathing over 30 seconds called Deep Breathing Test (DBT) may help to uncover WCH. DBT lowers BP by enhancing baroreceptor reflex activity via vagal stimulation thus overcoming an overactive sympathetic nervous system. Diagnosis of WCH is essential to differentiate WCH from resistant essential hypertension for therapeutic purposes so that unnecessary treatment can be avoided [47].

RESPeRATE is a paced breathing device that guides subjects to deep breathing and gradually helps to extend expiration to slow respiratory rate to less than 6 breaths per minute by using 2 different tones, one for expiration and the other for inspiration [48]. This device helps subjects to learn deep breathing practices

and is used to standardize deep breathing technique in studies using such methods.

Table 1:

Respiratory	Cardiovascular
↑ lung capacity & FRC	↑ vagal tone
Enhanced muscle function	↓ HR
Patent upper airway	↑ venous return
Improvement in PFT	↑ CO
Prevention of air trapping	Improved coronary circulation
↓ in mean airway pressure	Changes in BP
Improved V/Q matching in lower lung fields	↓ myocardial work load
Facilitates surfactant release	↓ myocardial VO ₂
Facilitates gas exchange	Enhanced cardiac function

[↑ = increase; ↓ = decrease; FRC = Functional Residual Capacity; HR = heart rate; PFT = Pulmonary Function Test; CO = cardiac output; BP = blood pressure; V/Q = ventilation to perfusion ratio; VO₂ = oxygen consumption.]

In conclusion, it can be surmised that pranayama or yogic breathing is a simple and inexpensive way to keep organs such as the heart and the lungs in good health by improving lung function and stabilizing cardiovascular function (Table 1). The beneficial effects also extend to the maintenance of other organ functions by maintaining a healthy lung and the heart.

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