Review Article

Yoga and heart rate variability

Gopal Krushna Pal

Department of Physiology, Jawaharlal Institute of Postgraduate Medical Education and Research, Puducherry, India

Abstract

Yoga is the union with the divine. Though there are different types of yoga, the primary objective of all yoga practices is to ensure an integral health, free from common health problems and stress-related disorders. Sympathovagal balance is the cornerstone of a stable homeostasis. Sympathovagal imbalance (SVI) has been reported to be associated with diabetes, hypertension, heart disease and other metabolic disorders. SVI has been documented to promote degeneration and decay and is the basis of all cause morbidity and mortality. Heart rate and heart rate variability (HRV) are measures of sympathovagal balance or imbalance. Resting tachycardia and decreased HRV are established cardiovascular (CV) risks. Practice of yoga, especially relaxation techniques and slow pranayamas has been known to ensure sympathovagal balance, improve HRV and reduce CV risks. In this review, we discuss the types of yoga, physiological basis of improvement of health in yoga practice, the concept and importance of HRV, attainment of sympathovagal balance and improvement of HRV through practice of yoga.

Key words: Autonomic balance, heart rate variability, relaxation therapy, slow pranayama, sympathovagal balance, sympathovagal imbalance, yoga

Received: 1st Feburary, 2015; ***Revised:*** 14th March, 2015; ***Accepted:*** 24th March, 2015

INTRODUCTION

Yoga means "union" with the universal Divine Consciousness. The objective of yoga is to unite with the Supreme (Divine) and manifest divine qualities in human life. In other words, it is a conscious effort to attain divinity and lead the divine life, which is achieved by a rapid evolution of human consciousness into divine consciousness.[1] Sri Aurobindo, the great seer, philosopher and spiritual guru of the world, has viewed "Yoga is a methodized effort towards self-perfection", and Swami Vivekananda has defined "Yoga is a means of compressing one's evolution into a single life, or even a shorter time than that."[1] Though at present in the society, yoga is represented mainly by perfunctory practice of asanas and pranayama. There are deeper spiritual aspects of yoga, without which yoga is not only imperfect, but also meaningless. Attainment of spirituality through yoga practice ensures a life full of bliss, free from stress and anxiety of ordinary living that provides the base for disease-free healthy life and retards the decay and degeneration of the physical body.

Access this article online	
Quick Response Code:	Website: www.ijcep.org
	DOI: 10.4103/2348-8093.155502

TYPES OF YOGA

There are several types of yoga practiced globally. However, the six are most popular and widely accepted ones. These are: Hatha yoga, raja yoga, bhakti yoga, karma yoga, tantra yoga and integral yoga.[1]

Hatha yoga

Hatha yoga includes practice of asanas, pranayamas and kriyas.[2] It aims at perfection of the body. A true hatha yogi not only achieves a healthy body and a greater longevity but also gains mastery over functions of the body.[2] However, in general, it neglects perfection of the mind. Therefore, hatha yoga by and large attains improvement of physical health, which may happen without full refinement of the mind. Practice of hatha yoga techniques such as asanas, pranayamas and kriyas has been reported to accomplish physical equanimity and autonomic balance.[3]

Raja yoga

Raja yoga basically aims at perfection of the mind. A controlled and quietened mind is the basic need for

Address for correspondence: Dr. Gopal Krushna Pal, Department of Physiology, Jawaharlal Institute of Post-graduate Medical Education and Research, Puducherry - 605 006, India. E-mail: drgkpal@gmail.com

practice of any yoga. Patanjali, the master of raja yoga, has advocated yoga into eight limbs.[1] Therefore, *Patanjali's yoga* is popularly known as *Ashtanga yoga* (yoga of eight limbs). Ashtanga yoga is considered to be the best of yogas as it has all the components of yoga. The eight limbs are: Yama, niyama, asana, pranayama, pratyahara, dharana, dhyana and samadhi.[4]

Yama

Yama consists of five principles. These are, ahimsa (nonviolence), satya (stick to truth only), asteya (nonstealing), brahmacharya (celibacy) and aparigraha (nonreceiving, or not being greedy).

Niyama

Niyama also consists of five principles: Shaucha (cleanliness, purification of body and mind), santosh (be satisfied with what you get), tapas (austerities, or disciplining our movements), swadhyaya (study of spiritual scriptures) and ishwar pranidhan (surrender to the Divine).

Asana

Asana is the practice of different body postures that are steady and comfortable. There are different asanas, and practice of each asana has the specific benefit. Like meditation is usually performed in padmasana, and relaxation of the body is performed in savasana. Refer a standard book on asanas for details,[4] as it is beyond the scope of this review to discuss them.

Pranayama

Pranayama is the control of movement of prana, the vital energy. This is performed by practice of controlled breathing exercises. Different pranayamas have different benefits. In general, they decrease sympathetic activity and improve parasympathetic activity.[4]

Pratyahara

Pratyahara is withdrawal of senses to free the mind. It is mainly the material withdrawal, the withdrawal from physical enjoyments.

Dharana

Dharana is the concentration of the mind on a particular point, which may be an object, a sound or an idea.

Dhyana

Dhyana is the meditation, in which mind is allowed to flow towards the point of concentration.

Samadhi

This is the state of super-consciousness. The individual enters into a transcendent consciousness, and withdraws from external objects.

Bhakti yoga

Bhakti means devotion. In bhakti yoga, the disciples unites with the God by devotion. Therefore, often in yoga the disciple is called as devotee. Bhakti is the expression of joy of the emotional being, which is attained by reciting the name of the God, praying the God, and surrendering to the God. In this yoga, the higher emotional being evolves and helps in union with the supreme consciousness. Bhakti yoga ensures relaxation of the mind and body.[1]

Karma yoga

Karma means work. In karma yoga, union with the Divine is achieved through the work. In this yoga, disciple does everything in his life for the sake of the divine, in a divine way. He performs everything for the divine realization. Karma yoga brings body-mind coordination.[1]

Tantra yoga

The tantra yoga is based on the principles that all creation is the divine manifestation and all worldly activities are divine play.[5] It does not reject the world as an illusion but considers it as a manifestation of the Divine. Therefore, one should wholeheartedly participate in the cosmic play and enjoy them without attachment. However, enjoyment has the danger of falling in the trap of attachment as the modern man has many requirements and the being is not purified internally. Therefore, this yoga was not accepted widely by others.[5]

Integral yoga

The "Gita" taught us the triple path of work, knowledge and devotion as the means of union with the divine. The yoga through knowledge (*jnana yoga*), yoga through devotion (*bhakti yoga)*, and yoga through works (*karma yoga)* are the triple paths of yoga. Integral yoga is the yoga envisaged by Sri Aurobindo.[1] Though it appears to be the synthesis of all the yoga as described above, it is much beyond the synthesis. It accepts the central principle of triple path of *yoga of the Gita*, but does not stop at union or salvation of the being with the divine. It proposes the transformation of the being into the complete divine consciousness, the transformation of the being as a whole, that is, the physical, the mental, the vital, and the psychic (the inner being). Therefore, this is also called yoga of integral transformation. Integral yoga of Sri Aurobindo is based on the concept of evolution, according to which as life has evolved from matter and mind from life, the mind is bound to be evolved into a state of supermind, the *Supramental Consciousness*. Therefore, his yoga is also called the Supramental Yoga.[1] Practice of integral yoga is based on the three fundamental principles: The *aspiration* for higher spiritual life, the *rejection* of lower qualities from human nature and the *surrender* to the Divine. Surrender to the Divine is the foremost condition in integral yoga. The true

surrender brings complete trust on the Divine, and also the spiritual realizations. Without spiritual experience, yoga is not possible. In essence, spiritual progress is not achieved by giving speeches, conducting seminars and workshops on yoga, and by mechanically practicing asanas and pranayamas. A true yoga practitioner does not speak much; he is eternally connected with the divine consciousness. Union with the Divine gives the confidence that the Divine takes care of everything, and there is nothing to worry for anything in the world. A truly surrendered and realized life makes the life stress-free and brings the true happiness.[6] To lead this stress-less and happy life is the best way to achieve stable homeostasis and prevent degeneration and aging. Thus, practice of yoga yields internal balance that improves all visceral and metabolic functions including improvement in cardiovascular (CV) autonomic functions[7] and heart rate and blood pressure variability.

HEART RATE VARIABILITY

Heart rate variability (HRV) is the beat to beat variation (variation in cardiac cycle length), a physiological phenomenon that mainly occurs due to variation in cardiac activities during the respiratory cycle (respiratory sinus arrhythmia [RSA]) at rest, though circadian rhythm and environmental factors also contribute to it.[8] The pacing of the heart and its beat-to-beat variations are dependent on the rate of discharge of the primary pacemaker, the sinu-atrial (SA) node, which is influenced by autonomic activities that are controlled in a complex array of factors such as visceral reflexes, central irradiations and cortical factors. As SA nodal discharge is largely controlled by parasympathetic (vagal) influence, and sinus arrhythmia is primarily due to alteration in vagal tone in inspiration and expiration, HRV is mainly influenced by vagal activity, though both the divisions of autonomic nervous system (ANS) influence it.[9] Recently, HRV has been proposed as the most sensitive indicator of autonomic functions, especially, for the assessment of sympathovagal balance, the balance between sympathetic and parasympathetic activity of the individual at any given time. The state of sympathovagal balance as detected by HRV analysis is used for prediction, diagnosis, management and prevention of many CV dysfunctions and other dysfunctions affecting CV system.[10]

Quantification of HRV

HRV can be quantified in time and frequency domains.[10] Time domain measures include the usual tools of assessment of variations, as done in statistics. Time domain is easier to assess but finer aspects of variations are not appreciated. Further, the variations in the instantaneous heart rate can be assessed spectrally. An RR tachogram is plotted using the RR intervals in the 5–10 min lead II electrocardiography (ECG) recording. The RR tachogram is considered as a nonperiodic signal, which is transformed to its frequency spectrum using fast-fourier transformation algorithm or autoregressive modeling. The biggest advantage of this complex mathematical transformation is that the distribution of magnitude of variations in different frequency bands corresponds to the activity of different physiological systems.

Frequency domain indices

The entire frequency spectrum 0–0.4 Hz is divided into 3 major components: A high frequency band (HF) 0.15–0.4 Hz, a low frequency band (LF) 0.04–0.15 Hz and a very low frequency band (VLF) 0–0.04 Hz.[8,10]

High frequency component

High frequency component is caused by vagal tone during the respiratory cycle. The inspiratory inhibition of vagal activity is evoked centrally in the CV center and explains why heart rate fluctuates with the respiratory frequency. In addition, peripheral reflexes arising from thoracic stretch receptors also contribute to this so-called RSA. RSA is clearly abolished by atropine or vagotomy and the power of the HF component has been used as an index of the vagal drive.[8,10]

Low frequency component

Low frequency component of HRV is usually characterized by an oscillatory pattern with a period of 10 s. This rhythm originates from self-oscillation in the vasomotor part (sympathetic component) of the baroreflex loop as a result of negative feedback and it is commonly associated with synchronous fluctuations in blood pressure, the so-called Mayer waves. Though there is a parasympathetic influence, LF component mainly reflects sympathetic cardiac drive.[8,10]

Very low-frequency component

Very low frequency component accounts for all other heart rate changes, including those associated with thermoregulation and humoral (especially, rennin-angiotensin mechanism) and local factors.[8,10]

The measurement of VLF, LF and HF power components is usually made in absolute values of power (milliseconds squared). All these components taken together is designated as total power (TP), which represents overall vagal modulation of cardiac functions. LF and HF may also be measured in normalized units, which represent the relative value of each power component in proportion to the TP minus the VLF component. The representation of LF and HF in normalized units (LFnu and HFnu) emphasizes the controlled and balanced behavior of the two branches of the ANS. Moreover, the normalization

tends to minimize the effect of the changes in TP on the values of LF and HF components. Nevertheless, normalized units should always be quoted with absolute values of LF and HF power in order to describe completely the distribution of power in spectral components. LF-HF ratio provides better indicator of spectral powers.[8,10]

Long-term HRV recordings

Spectral analysis also may be used to analyze the sequence of normal-to-normal (NN) intervals of the entire 24 h period. The result then includes an ultra-low frequency component, in addition to VLF, LF and HF components. The slope of the 24 h spectrum also can be assessed on a log-log scale by linear fitting the spectral values. Frequency domain measures are summarized below.[8,10]

Time domain indices

In a continuous ECG record, each QRS complex is detected, and the so-called NN intervals, that is, all intervals between adjacent QRS complexes resulting from sinus node depolarization or in the instantaneous heart rate are determined.[8] Simple time domain variables that can be calculated include the mean NN interval, the mean heart rate, the difference between the longest and shortest NN interval, the difference between night and day heart rate and so forth. The most commonly used measures derived from interval differences include, mean RR: Average heart rate; SDNN: Standard deviation of all NN intervals; RMSSD: The square root of the mean squared differences of successive NN intervals; NN50: The number of interval differences of successive NN intervals >50 ms; and pNN50: The proportion derived by dividing NN50 by the total number of NN intervals. All of these measurements of the short-term variation estimate HF variations in heart rate and thus are highly correlated.[8,10]

Physiological significance of HRV

HRV analysis is used to precisely assess the efficiency of cardiac vagal control of the individual, as it reflects the variation that occurs mainly due to sinus arrhythmia. Due to inspiratory inhibition of the vagal tone, the heart rate shows fluctuations with a frequency similar to the respiratory rate. The inspiratory inhibition is evoked primarily by central irradiation of impulses from the medullary respiratory center to the CV center. RSA can be abolished by atropine or vagotomy as it is parasympathetically mediated.[8,10]

HRV analysis as a tool of sympathovagal balance

HRV, that is, the amount of heart rate fluctuations around the mean heart rate, can be used as a mirror of the cardio-respiratory control system. It is a valuable tool to investigate the sympathetic and parasympathetic function of the ANS.[8] SA nodal activity at any particular time is determined by the balance between vagal activity, which slows it, and sympathetic activity, which accelerates it.[9] In general, if the rate is lower than the intrinsic rate of the pacemaker, it implies predominant vagal activity, whereas high heart rates are achieved by increased sympathetic drive. HF component of HRV indicates vagal tone of the individual. Increased HF power (or more specifically, increased HFnu) represents increased vagal activity and decreased HF power (decreased HFnu) represents decreased vagal activity.[8,10] LF component of HRV in general indicates sympathetic tone of the individual. Increased LF power (or more specifically, increased LFnu) represents increased sympathetic activity and decreased LF power (decreased LFnu) represents decreased sympathetic activity.[8,10] The sympathovagal balance is assessed by LF-HF ratio [Table 1]. Increased LF-HF ratio reflects increased sympathetic activity and decreased LF-HF ratio indicates increased parasympathetic activity.[8,10]

Table 1: Physiological correlation of FDI and TDI of HRV

	Physiological correlation
FDI of HRV	
TP (ms^2): Total power of HRV	Overall vagal potency of cardiac modulation
VLF (ms^2): Very-low frequency power of HRV	Integrity of renin-angiotensin system
LF (ms^2): Low frequency power of HRV	Mainly, cardiac sympathetic drive
LFnu: Normalized low frequency power	Cardiac sympathetic modulation, independent of other HRV powers
HF (ms^2): High frequency power of HRV	Cardiac parasympathetic drive
HFnu: Normalized high frequency power	Cardiac parasympathetic modulation independent of other powers of HRV
LF-HF ratio: Ratio of LF to HF power	Sympathovagal balance
TDI of HRV	
Mean-RR (ms): Mean of RR intervals	Average heart rate
RMSSD (ms): Square root of the mean squared differences of successive normal to normal (NN) intervals	Vagal modulation of cardiac functions on short-term basis
SDNN (ms): Standard deviation of NN interval	Overall vagal modulation of cardiac functions from beat to beat
NN50: The number of interval differences of successive NN intervals >50 ms	Short-term variability of vagal modulation
PNN50: The proportion derived by dividing NN50 by the total number of NN intervals	Short-term variability of vagal drive

FDI: Frequency domain indices, TDI: Time domain indices, HRV: Heart rate variability

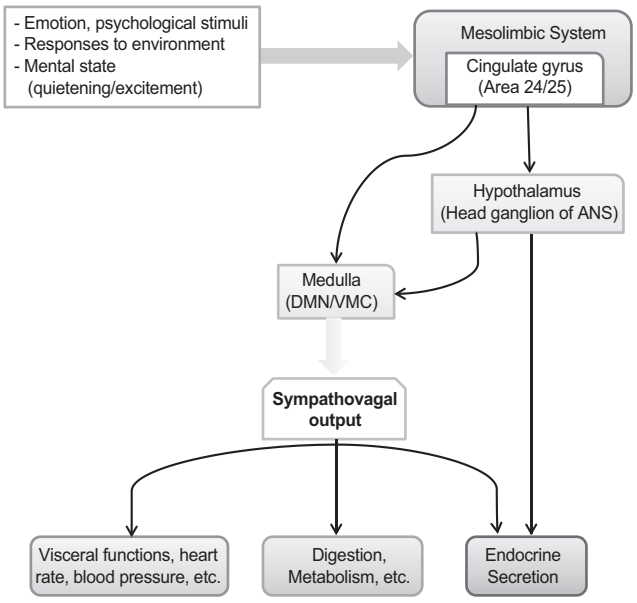

Figure 1: Limbic-hypothalamic-medullary axis of sympathovagal output. ANS: Autonomic nervous system; DMN: Dorsal motor nucleus of vagus nerve; VMC: Vasomotor center

The relationship between vagal stimulation frequency and the resulting change in heart rate is hyperbolic with changes in frequency at low heart rates having a much greater effect, which does not directly control heart rate, but rather it acts to regulate the interval between successive beats.[10] The effect of vagal stimulation is very rapid. The vagal stimulation releases the neurotransmitter acetylcholine, which has inhibitory effects on the pacemaker potentials. Sympathetic responses differ from vagal effects in that they develop slowly. Hence, responses with longer latencies are likely to be mainly sympathetic.[11]

Peripheral vascular resistance exhibits intrinsic oscillations with a LF presentation. These oscillations can be influenced by thermal skin stimulation and are thought to arise from thermoregulatory peripheral blood flow adjustments. The fluctuations in peripheral vascular resistance are accompanied by fluctuations with the same frequency in blood pressure and heart rate and are mediated by the sympathetic nervous system. Hence, analysis of HRV also indicates the tone of the sympathetic outflow and, therefore, reflects the individual's state of sympathetic functions and susceptibility to sympathetic dysfunctions.[11]

Clinical application of HRV

Though there is considerable discussion regarding the physiology of HRV, it is well correlated and studied in a number of clinical and pathological conditions.[12,13] Decreased HRV is observed in many CV disease conditions. Much before the onset of clinical symptoms of the CV disease, alterations are observed in HRV.[12] HRV is equally used as a prognostic tool in conditions like postmyocardial infarction and cardiac transplantation.[14] The most important application of HRV analysis is the surveillance of post-infarction, diabetic and hypertensive patients.[15,16] HRV gives information about the sympathetic-parasympathetic autonomic balance. As HRV analysis is useful to assess the state of sympathovagal balance of the individual, it can be used in determining the individual's susceptibility to develop autonomic dysfunctions like hypertension.[17] Decreased HRV is well correlated with risk for sudden cardiac death in heart disease patients.[18] Improvement in HRV is observed following interventions like exercise, yoga, relaxation exercises.[19]

The clinical applicability is still limited for the want of established normative data of HRV for different age, gender, ethnic groups and its demanding technical and mathematical comprehensibility. However, with increasing use of automation and computers in medicine, the clinical applicability of HRV is imminent.

ASSOCIATION OF YOGA WITH HRV

Heart rate and its variability at rest is primarily the parasympathetic function, which is more precisely the expression of the vagal tone. Variation in heart rate is the variation in interbeat interval during inspiration and expiration that principally occurs due to alteration in vagal influence during the phases of respiration. This oscillation in cardiac cycle length during respiration reflects the cardiac vagal drive of the person. Stable homeostasis in yoga practice is achieved physiologically by improving the vigor of sympathovagal balance, of which vagal tone is the major determinant.

Neurophysiological basis

Sympathetic and vagal output from the brain mainly occurs from the limbic-hypothalamic-medullary axis.[9] Vasomotor center and vagal nuclei (nucleus tractus solitarius, nucleus ambiguous and dorsal motor nucleus of the vagus nerve) in the medulla of the brain are the sympathetic and parasympathetic outflow nuclei respectively. Both these medullary centers are profoundly influenced by the influences from the medullary respiratory centers, mesolimbic nuclei (area 24 and 25 of anterior cingulate gyrus) and hypothalamic nuclei.[20] Due to intimate and intense connection and influence of hypothalamus with medullary sympathetic and parasympathetic centers, the hypothalamus is designated as the head ganglion of ANS. The anterior hypothalamus is the center for parasympathetic and posterior hypothalamus the center for the sympathetic system. This limbic-hypothalamic-medullary axis controls all the autonomic, visceral, endocrine and metabolic functions of the body.[20] In the practice of yoga, it has

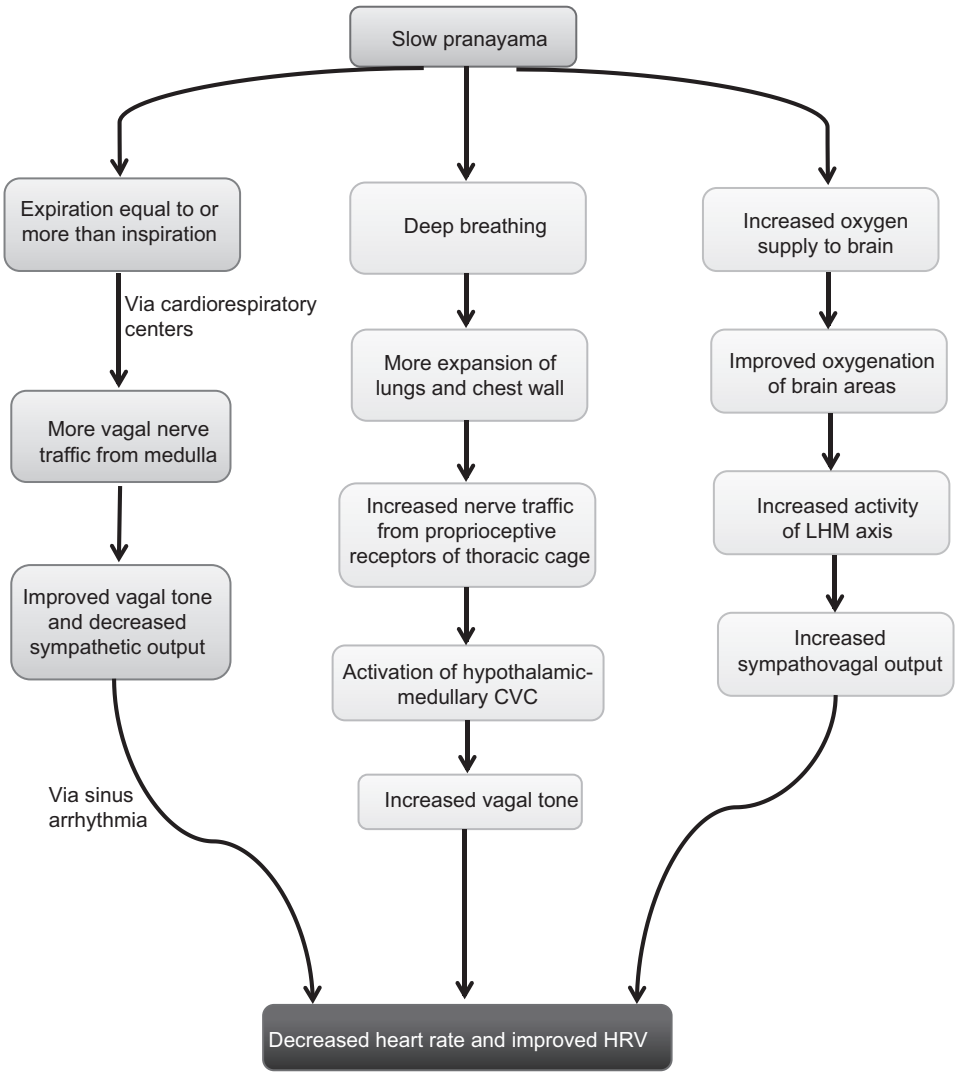

Figure 2: Mechanisms of improvement in heart rate variability by practice of slow pranayamas. CVC: Cardiovascular centers; LHM: Limbic-hypothalamic-medullary axis

been proposed that the refinement and tuning occur in neuronal activities of these limbic, hypothalamic and medullary centers [Figure 1]. However, detailed scientific investigations are needed to explore the neuro-physiological basis of achieving stable homeostasis in yoga practice.

Importance of relaxation techniques & pranayamas

In yoga relaxation techniques, the sympathetic discharge is inhibited and parasympathetic discharge is facilitated.[21] Thus, relaxation therapies in yoga (meditation, yoga nidra, concentration on devotional songs or spiritual music, and asanas for body relaxation such as shavasana) ensure sympathovagal homeostasis.[22] However, for achieving sympathovagal balance, emphasis is given more on pranayama (practice of controlled breathing exercises). Pranayama (prana + ayama) is the controlled breathing in which the practitioner regulates his breathing (ayama) and concentrates on imbibing cosmic energy (prana) from the atmosphere through breathings.[4] In normal breathing, inspiration is longer and duration of expiration may be less than half of the inspiration. During inspiration, heart rate is more due to less vagal tone and during expiration heart rate is less due to more vagal tone (sinus arrhythmia). Taking advantage of this physiological phenomenon of sinus arrhythmia, our ancient spiritual visionaries, rishies (seers) and yogis (yoga luminaries) had practiced pranayama as part of their natural living and lived healthily for centuries, and attained a kind of immortality.

Importance of slow pranayamas

Pranayama are classified into two categories: Fast pranayamas and slow pranayamas.[4] Fast pranayamas like kapalabhatti, bhastrika and bellows breathing, the respirations are faster but deep. In slow type of pranayamas, such as anulom-vilom (alternate nostril breathing), chandranadi (left nostril breathing), sitkari (cooling breaths), bhramari (breathing with

vibrations through ear), etc., respirations are slower, deeper and more prolonged with greater duration of expiration.[4] By reducing inspiration and lengthening expiration, the vagal nerve traffic is more strengthened. This improves the cardiac vagal modulation and increases vagal tone. Thus, heart rate is reduced and HRV is improved. It has also been explained that in slow pranayamas, gradual and graded increase in lung volume and rib cage increases nerve traffic from thoracic cage proprioceptors that strengthens vagal tone through the central limbic-hypothalamic influence of the sensory projections to thalamus and cortex.[23,24] Furthermore, it has been observed that such pranayamas augment cerebral blood flow and oxygenation that improves neuronal activities of the brain centers including those present in the limbic areas, hypothalamus, and medulla and improve sympathovagal outflow [Figure 2].

Importance of vagal tone and sympathovagal homeostasis

It has been reported recently that improvement in vagal tone is not only essential for stable CV health, but also for maintaining the fitness of the body as a whole, the integral health.[25] Slow pranayamic breathing has also been reported to reduce sympathetic activity and improve sympathovagal balance. Practice of fast pranayama and suryanadi pranayama (right nostril breathing) has been reported to increase sympathetic activity, and practice of chandranadi pranayama reported to decrease sympathetic activity.[26,27] Thus, pranayama is directly linked to autonomic activity, regulation of heart rate and HRV. Decrease in heart rate physiologically by practice of yoga or exercise, improves HRV. Though, resting heart rate can vary widely in normal healthy subjects ranging from 60 to 100 beats/min, tachycardia, especially heart rate >75/min, has been reported to decrease HRV, which is an established CV risk.[28]

CONCLUSION

Sympathovagal imbalance (SVI) and reduced HRV has been reported to be the pathophysiological basis of metabolic syndrome including obesity, hypertension, diabetes, dyslipidemia and heart diseases. SVI facilitates decay and degeneration and is the basis of all-cause morbidity and mortality. As metabolic syndrome is a global health burden, the long-term objective of the treatment of those patients should be aimed at improving their autonomic balance, which can be achieved by implementation of a healthy life-style that should include yoga. The practice of yoga (especially relaxation techniques and slow pranayamas) can not only reduce the CV risks, but also help achieve an integral health.

REFERENCES

1. Pal GK. Physiology of aging, oxidative stress, prevention of aging and physiology of yoga. In: Textbook of Medical Physiology. 2nd ed. New Delhi: Ahuja Publications; 2011. p. 1062-71.
2. Swami S. The Hatha Yoga Pradipika. New York: Yogavidya. Com Publications; 2002. p. 33-115.
3. Huang FJ, Chien DK, Chung UL. Effects of Hatha yoga on stress in middle-aged women. J Nurs Res 2013;21:59-66.
4. Saraswati SS. Introduction to yoga. In:. Asana, Pranayama, Mudra and Bandha. India: Yoga Publication Trust; Munger (India); 2012. p. 1-9.
5. Saraswati SS. A Systematic Course on Ancient Tantric Techniques of Yoga and Kriya. India: Yoga Publication Truest; Munger (India); 2013. p. 9-36.
6. Iyengar BKS. The Iyngar approach to yoga. In: Yoga the Path to Holistic Health. New York: D. K. Publications; 2014. p. 16-24.
7. Saraswati SK. Yogic Management of Common Diseases. Publication of Bihar School of Yoga, Munger (India); 1983. p. 23-67.
8. Pal GK, Pravati P. Spectral analysis of heart rate variability. In: Textbook of Practical Physiology. 3rd ed. Hyderabad (India): Universities Press; 2011. p. 291-7.
9. Pal GK. Sympathetic and parasympathetic systems. In: Textbook of Medical Physiology. New Delhi: Ahuja Publications; 2010. p. 2009-216.
10. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Heart rate variability: Standards of measurement, physiological interpretation and clinical use. Circulation 1996;93:1043-65.
11. Martens A, Greenberg J, Allen JJ. Self-esteem and autonomic physiology: Parallels between self-esteem and cardiac vagal tone as buffers of threat. Pers Soc Psychol Rev 2008;12:370-89.
12. Zhao YX, Li YP, Gao F, Ma HY, Wang ZJ, Han HY, *et al*. Heart rate distribution and predictors of resting heart rate after initiation of beta-blocker treatment in patients with coronary artery disease: Results of Sympathetic Evaluation and Research of China (RESEARCH) study. Chin Med J (Engl) 2013;126:3460-3.
13. Malliani A. Heart rate variability: From bench to bedside. Eur J Intern Med 2005;16:12-20.
14. Kleiger RE, Miller JP, Bigger JT Jr, Moss AJ. Decreased heart rate variability and its association with increased mortality after acute myocardial infarction. Am J Cardiol 1987;59:256-62.
15. La Rovere MT, Bigger JT Jr, Marcus FI, Mortara A, Schwartz PJ. Baroreflex sensitivity and heart-rate variability in prediction of total cardiac mortality after myocardial infarction. ATRAMI (Autonomic Tone and Reflexes after Myocardial Infarction) Investigators. Lancet 1998;351:478-84.
16. Camm AJ, Pratt CM, Schwartz PJ, Al-Khalidi HR, Spyte MJ, Karam R, *et al*. Mortality in patients after a recent myocardial infarction: A randomized, placebo-controlled trial of azimilide using heart rate variability for risk stratification. Circulation 2004;109:990-6.
17. Gerritsen J, Dekker JM, TenVoorde BJ, Kostense PJ, Heine RJ, Bouter LM, *et al.* Impaired autonomic function is associated with increased mortality, especially in subjects with diabetes, hypertension, or a history of cardiovascular disease: The Hoorn Study. Diabetes Care 2001;24:1793-8.
18. Kudaiberdieva G, Görenek B, Timuralp B. Heart rate variability as a predictor of sudden cardiac death. Anadolu Kardiyol Derg 2007;7 Suppl 1:68-70.
19. Papp ME, Lindfors P, Storck N, Wändell PE. Increased heart rate variability but no effect on blood pressure from 8 weeks of hatha yoga - A pilot study. BMC Res Notes 2013;6:59.
20. Baklavadzhian OG, Nersesian LB, Avetisian EA, Avetisian IN, Arshakian AV, Bagdasarian KG, *et al.* The

neuronal organization of the limbic (cingulo-)-visceral reflex arc. Usp Fiziol Nauk 2000;31:11-23.
21. Markil N, Whitehurst M, Jacobs PL, Zoeller RF. Yoga Nidra relaxation increases heart rate variability and is unaffected by a prior bout of Hatha yoga. J Altern Complement Med 2012;18:953-8.
22. Pal GK, Ganesh V, Karthik S, Nanda N, Pal P. The effects of short-term relaxation therapy on indices of heart rate variability and blood pressure in young adults. Am J Health Promot 2014;29:23-8.
23. Pal GK, Agarwal A, Karthik S, Pal P, Nanda N. Slow yogic breathing through right and left nostril influences sympathovagal balance, heart rate variability, and cardiovascular risks in young adults. N Am J Med Sci 2014;6:145-51.
24. Jerath R, Edry JW, Barnes VA, Jerath V. Physiology of long pranayamic breathing: Neural respiratory elements may provide a mechanism that explains how slow deep breathing shifts the autonomic nervous system. Med Hypotheses 2006;67:566-71.
25. Pal GK. Role of sympathovagal balance in achieving effective homeostasis. Biomedicine 2008;28:67-8.
26. Bhavanani AB, Madanmohan T, Sanjay Z. Immediate effect of Chandra Nadi pranayama (left unilateral forced nostril breathing) on cardiovascular parameters in hypertensive patients. Int J Yoga 2012;5:108-11.
27. Bhavanani AB, Ramanathan M, Balaji R, Pushpa D. Differential effects of uninostril and alternate nostril pranayamas on cardiovascular parameters and reaction time. Int J Yoga 2014;7:60-5.
28. Tsuji H, Venditti FJ Jr, Manders ES, Evans JC, Larson MG, Feldman CL, *et al*. Reduced heart rate variability and mortality risk in an elderly cohort. The Framingham Heart Study. Circulation 1994;90:878-83.

How to cite this article: Pal GK. Yoga and heart rate variability. Int J Clin Exp Physiol 2015;2:2-9.

Source of Support: Nil, **Conflict of Interest:** Nil.