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Review Article

Effects of yogic breath regulation: A narrative review of scientific evidence

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ABSTRACT

Pranayama or breath regulation is considered as an essential component of Yoga, which is said to influence the physiological systems. We present a comprehensive overview of scientific literature in the field of yogic breathing. We searched PubMed, PubMed Central and IndMed for citations for keywords "*Pranayama*" and "Yogic Breathing". The search yielded a total of 1400 references. Experimental papers, case studies and case series in English, revealing the effects of yogic breathing were included in the review. The preponderance of literature points to beneficial effects of yogic breathing techniques in both physiological and clinical setups. Advantageous effects of yogic breathing on the neurocognitive, psychophysiological, respiratory, biochemical and metabolic functions in healthy individuals were elicited. They were also found useful in management of various clinical conditions. Overall, yogic breathing could be considered safe, when practiced under guidance of a trained teacher. Considering the positive effects of yogic breathing, further large scale studies with rigorous designs to understand the mechanisms involved with yogic breathing are warranted.

1. Introduction

Yoga is a traditional practice from the ancient Indian culture and is considered to be the science of holistic living. Various practices involved in the tradition of Yoga include disciplined lifestyle (*Yama* and *Niyama*), cleansing procedures (*Kriya*), physical postures (*Asana*), breath regulation (*Pranayama*), concentration (*Dharana*) and meditation (*Dhyana*) [1,2]. In recent years, there has been greater interest in exploring the benefits of various practices described in Yoga [3,4]. There have been scientific studies on the effects of individual Yoga practices or their combinations on healthy individuals as well as in people suffering from various ailments [5]. *Pranayama* or breath regulation has been greatly emphasized in Yoga and has drawn special attention from the scientific community. Breath regulation includes modulation of the pace of breathing, viz. slowing down or pacing the breath, manipulation of nostrils, chanting of humming sounds, retention of breath etc. Various Yoga breathing practices described in classical text of *hathayoga* are enlisted in Table 1 [2]. The current review was undertaken with an objective of presenting an overview of the available scientific evidences on Yogic Breathing.

2. Methodology

The online database, PubMed, PubMed Central and IndMed were searched for citations for keywords "*Pranayama*" and "Yogic Breathing". The search yielded a total of 1400 references from the date of inception of the databases till July 2017. Experimental papers, case studies and case series in English, revealing the effects of yogic breathing were included in the review. The studies that had used yogic breathing in combination with other Yoga practices were excluded. Studies in languages other than English, and whose abstracts were unavailable were excluded from the review. After applying the inclusion and exclusion criteria and removing the duplicates, a total of 68 studies were selected for the final review.

The studies included in the review were classified into two major categories, physiological and clinical. They were subclassified based on the major findings of the study. The physiological measures assessed with various yogic breathing practices are the neurocognitive assessments, psychophysiological changes,

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Table 1
Procedures of various yogic breathing practices.

Name of the practice	Method of practice
Kapalabhati	Sitting with back and neck erect, one should inhale through both nostrils and exhale rapidly by flapping the abdomen during each exhalation at a pace of 60–120 breaths/min.
Bastrika (Bellow's breath)	One should inhale and exhale quickly and forcefully without straining by flapping the abdomen. This should be practiced for up to 100 breaths.
Nadishodhana/Nadishuddhi (Alternate nostril breathing)	With the right thumb, close the right nostril and inhale through left nostril. Closing the left nostril, exhale through right, following which inhalation should be done through right nostril. Closing the right nostril, breath out through left nostril. This is one round. The procedure is repeated for desired number of rounds.
Suryanuloma Viloma (Right uninostril breathing)	Closing the left nostril, both inhalation and exhalation should be done through right nostril, without altering the normal pace of breathing.
Chandranuloma Viloma (Left uninostril breathing)	Procedure similar to *Suryanuloma Viloma*, breathing is done through left nostril alone, by closing the right nostril.
Suryabhedana (Right nostril initiated breathing)	Closing the left nostril, inhalation should be done through right nostril. At the end of inhalation, close the right nostril and exhale through the left nostril. This is one round. The procedure is repeated for desired number of rounds.
Ujjayi (Psychic Breath)	Inhalation and exhalation are done through the nose at normal pace, with partial contraction of glottis, which produce light snoring sound. One should be aware of the passage of breath through the throat during the practice.
Bhramari (Female honeybee humming breath)	After a full inhalation, closing the ears using the index fingers, one should exhale making a soft humming sound similar to that of a female honeybee.

respiratory, biochemical and metabolic variables. Studies have also been conducted to understand the impact of yogic breathing in patients with hypertension, cardiac arrhythmias, bronchial asthma, pulmonary tuberculosis, cancer, diabetes mellitus, mental retardation, stroke rehabilitation, withdrawal from smoking, anxiety and pain.

3. Results

3.1. Neurocognitive effects of yogic breathing

Ancient Indian texts on Yoga describe, "As the breath moves, so does the mind, and mind ceases to move as the breath is stopped." [2] Thus, evaluating the impact of yogic breathing on neurocognitive abilities has sought special attention from the scientific community. An early review indicates that yogic breathing practices could influence the brain activity in different ways [6].

3.1.1. Changes due to pace of breathing

The earliest studies reported assessing the effects of yogic breathing on neurocognitive abilities evaluated the effect of 15 min of high frequency yogic breathing, described as *Kapalabhati* on EEG activity [7]. The study demonstrated increased alpha activity during the initial 5 min of *Kapalabhati*. Theta activity was observed to be enhanced, mostly in the occipital region during later stages of 15 min *Kapalabhati* compared to the pre-exercise period. Beta 1 activity increased during the first 10 min of *Kapalabhati* in occipital and to a lesser degree in parietal regions. Another study assessing the cognitive abilities demonstrated increase in the number of errors following 1 and 5 min of practice of *Kapalabhati*, in a letter cancellation task [8].

The impact of another rapid paced *Pranayama* called *Bhastrika*, described in *Hathayoga* as bellow's breath, on reaction time was studied by Telles et al. They found a reduction in anticipatory responses following 18 min of practice of *Bhastrika* [9]. Auditory (ART) and visual reaction time (VRT) reduced significantly in school children following just 9 rounds of *Mukha Bhastrika*, in 22 healthy school children [10]. This phenomenon was further exploited clinically in mentally challenged adolescents, who have higher reaction time. A study done by same authors has shown immediate reduction in VRT and ART among 34 mentally challenged adolescents [11]. A study comparing the effects of slow and fast paced *Pranayama* reported effects of 35 min/day of fast and slow *Pranayama* practiced for 10 weeks. Executive functions, perceived stress scale (PSS) and reaction time improved significantly in both fast and slow *Pranayama* groups, except reverse digit span, which showed an improvement only in fast *Pranayama* group [12].

3.1.2. Changes with Bhramari Pranayama

A form of yogic breathing called *Bhramari* (female honeybee humming breath), which is said to modify the brain responses through resonance produced by the humming sound, has shown to cause non-epileptic paroxysmal gamma waves in the EEG [13]. A study has shown that the practice of *Bhramari* for 10 min enhances inhibition and reaction time in the stop signal task that involves cognitive inhibition, in 31 healthy male individuals [14].

3.1.3. Changes due to manipulation of nostrils

Uninostril and alternate nostril breathing has been of special significance in Yoga, since the nostrils are said to represent the subtle energy channels known as *Nadis* [2,15]. Right nostril corresponds to *Pingala Nadi*, and the left to *Ida*, respectively. Breathing through a single specific nostril is said to affect the human system differently. A study involving 51 volunteers demonstrated that the performance in a spatial task was significantly enhanced during left nostril breathing in both males and females, whereas non-significant increase was noted in the verbal task performance [16]. Another study compared alternate nostril breathing with breath awareness. A significant increase was noted in the P300 peak amplitudes at different scalp sites along with a decrease in the peak latency at frontal scalp region, following alternate nostril Yoga breathing. Following breath awareness there was a significant increase in the peak amplitude of P300 at vertex region alone [17]. Healthy experienced Yoga practitioners demonstrated an increase in Na-wave amplitude and decrease in latency during the period of *Pranayama* practice, whereas no alterations were observed in the Pa-wave. The *Pranayama* practice in the study involved consciously controlled rhythmic breathing with breath holding [18]. A three arm randomized controlled trial done on patients with essential hypertension, comparing the effects of *Nadishuddhi Pranayama* and breath awareness with control session for 10 min elucidated reduction in systolic and diastolic blood pressure following *Nadishuddhi* and improvement in Purdue pegboard task performance with both hands and right hand. The Purdue pegboard task assesses manual dexterity and eye–hand co-ordination. Breath awareness group demonstrated reduction in systolic blood pressure when compared with control activity like reading magazine [19]. The practice of uninostril breathing was also used clinically in cases of stroke, where practice of uninostril breathing for 10 weeks reduced anxiety in 11 post stroke cases and improved language measures in individuals with aphasia due to stroke [20]. Another case series on the use of forced uninostril breathing along with speech therapy for post stroke aphasia showed improvement in correct information unit and word productivity [21].

Thus, most yogic breathing techniques are found to influence the neuro-cognitive abilities positively and some of which were even used in clinical settings with beneficial effects. The neuro-cognitive effects of yogic breathing are summarized in Table 2.

3.2. Psychophysiological effects of yogic breathing

Human respiration is the only physiological system that is under both autonomic and voluntary nervous control and thus it is also given special emphasis in yogic texts. The effects of yogic breath regulation on modulation of autonomic functions (AFT) have been studied extensively. The studies on yogic breathing assessing the AFT include various assessment measures like blood pressure (BP) – systolic (SBP) and diastolic (DBP), heart rate (HR), heart rate variability (HRV), respiratory rate (RR), galvanic skin resistance (GSR), pulse rate (PR), etc. Both short and long term effects of yogic breathing have been assessed using AFT.

3.2.1. Changes due to nostril manipulation

A study performed on 8 healthy volunteers demonstrated an increase in HR following right forced uninostril breathing (UNB) indicating the sympathetic activation following right UNB [22]. A three-arm RCT using HRV as the measure of autonomic activity, showed sympathetic arousal in the right UNB group, whereas indices representing parasympathetic activity were increased in left UNB group following 6-week nostril breathing [23]. A pilot RCT performed on 12 individuals found that 20 min of alternate nostril breathing increased GSR, which denotes parasympathetic activity. Though there was no significant change in the BP or pulmonary function tests, the study demonstrated efficacy of the yogic breathing in bringing a parasympathetic shift in the autonomic functions within a short span of one week [24]. Another study illustrating the ability of ANB in bringing the parasympathetic shift in the autonomic functions uses 30:15 ratio and expiration:inspiration ratio as measures of autonomic functions [25]. *Nadishuddhi Pranayama* at the rate of one breath per min was found to enhance sinus arrhythmia and reduction in low frequency component of HRV [26]. It also decreased the average breath rate, confirming the

Table 2
The neurocognitive effects of yogic breathing.

Sl No.	Author	Year	Sample size	Variables studied	Findings
1	Stancák et al.	1991	11	EEG	Alpha activity was increased during the initial 5 min of *Kapalabhati* (KPB). Theta activity was increased during later stages of 15 min KPB mostly in the occipital region, compared to the pre-exercise period. Beta 1 activity increased during the first 10 min of KPB in occipital and to a lesser degree in parietal regions.
2	Telles et al.	1993	11	Middle Latency Auditory Evoked Potential	Na-wave amplitude increased and latency decreased during the period of pranayamic practice, whereas the Pa-wave was not significantly altered.
3	Jella & Shannahoff-Khalsa	1993	51	Spatial and verbal task performance	Spatial task performance was significantly enhanced during left nostril breathing. Verbal task performance non-significantly increased during right nostril breathing.
4	Bhavanani et al.	2003	22	Visual reaction time (VRT) and auditory reaction time (ART)	VRT and ART reduced significantly in school children following 9 rounds of *Mukha Bhastrika.*
5	Vialatte et al.	2008	8	EEG	Non-epileptic paroxysmal gamma waves were generated during the practice of *Bhramari Pranayama*.
6	Bhavanani et al.	2012	34	VRT and ART	There was reduction in VRT and ART following 9 rounds of *Mukha Bhastrika* among mentally challenged children.
7	Telles et al.	2013	90	Blood pressure (BP) and Purdue pegboard task	There was reduction in systolic (SBP) and diastolic blood pressure (DBP) following *Nadishuddhi* and improvement in Purdue pegboard task performance with both hands and right hand. Breath awareness group demonstrated reduction in SBP.
8	Telles et al.	2013	20	P300	There was a significant increase in the P300 peak amplitudes at different scalp sites and a significant decrease in the peak latency at frontal scalp region, following alternate nostril Yoga breathing. Following breath awareness there was a significant increase in the peak amplitude of P300 at Vertex region.
9	Pradhan	2013	36	Digit Letter Substitution Task (DLST), Six Letter Cancellation Test (SLCT)	KPB practice for 1 and 5 min had no significant impact on SLCT and DLST scores, but there was increase in errors following the practice.
10	Telles et al.	2013	70	Reaction time	Following 18 min of *Bhastrika Pranayama* there was a statistically significant reduction in number of anticipatory responses compared to before the practice.
11	Rajesh et al.	2014	31	Stop Signal Task	Reduction in stop signal reaction time was found with 10 min of practice of *Bhramari Pranayama*. There was increase in go Reaction time in *Bhramari* group when compared to deep breathing group for equal duration.

parasympathetic shift of ANS. Another study demonstrated that *Nadishuddhi Pranayama* for 15 min/day for 4 weeks increased PEFR and pulse pressure and decrease in PR, RR, DBP in healthy subjects [27]. Training in *Nadishuddhi Pranayama* along with breath holding for 4 weeks elucidated reductions in baseline HR, SBP and DBP, which was attributed to increased vagal tone and reduced sympathetic discharge [28]. 6 variations of nostril breathings on cardiovascular parameters and reaction time in 20 experienced subjects demonstrated that 9 rounds of *Nadishuddhi*, left nostril breathing and left initiated breathing lead to reduction in BP and HR, whereas right nostril breathing and right initiated breathing showed an increase in the same. There were no changes found with normal breathing. The reaction time was lowered following the practice of right nostril breathing and right initiated breathing. The changes were attributed to the nostril used for inspiration than that for expiration [29].

3.2.2. Changes due to modulation of pace of breathing

The pace of breathing also modifies psychophysiological responses. A pilot study evaluating the effect of very slow breathing at 1 breath/min for 20 min on cardiovascular risk factors showed dramatic changes in hemodynamic variables like stroke index, HR, cardiac index, end diastolic index, peak flow, ejection fraction, thoracic fluid index, index of contractility, ejection ratio, systolic time ratio, acceleration index, and systolic, diastolic, and mean arterial pressures, left stroke work index and stroke systemic vascular resistance index. These changes indicate that breathing at a slow pace with internal breath hold could influence brainstem cardiorespiratory center regulating the Mayer wave patterns [30]. Another study done on 17 naïve subjects demonstrated an increase in baroreflex sensitivity (BRS) following slow breathing with or without *Ujjayi Pranayama*. The decrease in the BP and increase in the BRS was maximal when the subjects practiced slow breathing with equal inspiration and expiration at the rate of 6 breaths/minutes [31]. A study comparing the training in fast and slow *Pranayama* for 3 months elucidated increased parasympathetic activity and decreased sympathetic activity in the slow breathing group at the end of intervention period, whereas no significant change in autonomic functions was observed in the fast breathing group [32]. A three armed RCT involving 90 young healthcare students, which compared the effects of training in slow and fast *Pranayama* for 3 months, showed reduction in perceived stress in both fast and slow *Pranayama* group. The cardiovascular variables viz. HR, SBP and DBP reduced only in slow *Pranayama* group. The fast *Pranayama* group did not show significant changes in the cardiovascular variables [33]. Hand grip strength (HGS) and hand grip endurance (HGE) increased with the training of fast *Pranayama*, whereas only HGS increased following slow *Pranayama* training for 12 weeks [34]. Fast paced *Kapalabhati* was shown to increase the LF power and LF:HF ratio and lower the HF power in HRV, indicating the sympathetic arousal [35]. A concurrent result was found in another study that demonstrated an increase in HR, SBP and DBP following *Kapalabhati*. The study performed on 17 individuals also elucidated reduced BRS during practice of *Kapalabhati* [36]. A study demonstrating the effect of training in *Mukha Bhastrika*, involving rapid breathing for 12 weeks, reduced basal HR, increase in valsalva ratio and deep breathing difference in HR. It was also found to reduce the fall in BP on variation of posture. All the findings were indicative of increased parasympathetic activity following long term training in the practice of *Mukha Bhastrika* [37]. To understand the underlying pathways for the modulation of cardiovascular parameters following slow paced *Bhastrika Pranamayama*, a study compared the effect of 5 min of *Bhastrika* on HR and BP, with and without oral administration of hyoscine-N-butylbromide (Buscopan), a parasympathetic blocker drug. Fall in SBP, DBP and HR were noted in the group which practiced *Bhastrika* for 5 min without administration of the drug whereas subjects following the administration of the drug did not show significant changes in BP or HR. Thus the study concluded that the modulation of ANS due to practice of slow pace *Bhastrika* is attributed to the enhanced parasympathetic activity [38].

3.2.3. Changes due to other yogic breathing techniques

A recent study using HRV demonstrated parasympathetic withdrawal during the practice of *Bhramari Pranayama*, which reverted back to normalcy after the completion of practice [39]. Medical students showed reduced stress levels following practice of a combination of *Pranayama* practices for 1 h a day, 5 days per week for 2 months. HRV demonstrated reduction in VLF and LF and increase in HF component, indicative of a parasympathetic shift of the autonomic activity [38]. The relaxation attained through practice of *Pranayama* was exploited to ease the test anxiety and improve test scores in 107 postgraduate students. An RCT demonstrated that following the practice of *Pranayama* for a semester, only 33% participants experienced high test anxiety, compared to 66.67% among the control group. Participants in the *Pranayama* group also had higher scores in the test performance than controls [40].

We observed that, most yogic breathing techniques are found to have profound effects on autonomic functions. Most yogic breathing practices lead to parasympathetic shift of the ANS activity, except high frequency Yoga breathing (*Kapalabhati*) [41]. The effects of yogic breathing on psychophysiological variables are summarized in Table 3.

3.3. Effects of yogic breathing on respiratory system

The training in yogic breathing is found to be an effective means of enhancing the pulmonary functions. Slow breathing at 6 breaths/min showed an increase in vital capacity (VC) after 2 and 5 min, and increase in forced vital capacity after 2 min, and increase in forced inspiratory vital capacity and peak inspiratory flow rate after 2, 5 and 10 min [42]. Another study where the effects of 12 week training in slow and fast *Pranayama* on PFT were compared, revealed that slow *Pranayama* group, PEFR and FEV25 improved significantly, whereas in the fast *Pranayama* group, FEV1/FVC, PEFR, FEF25-75 improved significantly [43]. A recent study demonstrated beneficial effect of one month training in combination of yogic breathing on pulmonary functions in competitive swimmers [44]. Thus, the limited available evidence on effects of yogic breathing on respiratory system indicates a positive trend of change in the respiratory physiology.

3.4. Effects of yogic breathing on biochemical and metabolic variables

Curiosity of what causes the changes that are observed following the practice of yogic breathing, led to a study which examined the changes in arterial blood gas levels following the practice of *Pranayama*. No significant changes were observed in arterial blood oxygenation following *Pranayama*, thus speculating neural mechanisms for changes due to *Pranayama* [45]. Another study observed a decrease in blood urea, and an increase in creatinine and tyrosine after 1 min of *Kapalabhati*. It was attributed to decarboxylation and oxidation mechanisms, which may be responsible for a reduction in the activity of respiratory centers [46].

Table 3
Summary of the psychophysiological changes following yogic breathing.

Sl No.	Author	Year	Sample size	Variables studied	Findings
1	Stancák et al.	1991	17	BP, ECG and respiration	Increase of Heart rate (HR), SBP and DBP during *Kapalabhati*. BRS reduced during *Kapalabhati*.
2	Raghuraj et al.	1998	12	HRV	Increase in low frequency (LF) power and LF/HF ratio while high frequency (HF) power was significantly lower following KPB. There were no significant changes following *Nadishuddhi*.
3	Pal et al.	2004	60	Autonomic Function tests	The increased parasympathetic activity and decreased sympathetic activity were observed in slow breathing group after 3 months, whereas no significant change in autonomic functions was observed in the fast breathing group.
3	Shannahoff-Khalsa et al.	2004	4	Cardiovascular variables	Following breathing at 1 breath/min with ratio of 20:20:20 s, there are dramatic variations in hemodynamic variables.
4	Veerabhadrappa et al.	2011	50	Cardiovascular autonomic reactivity	*Mukh Bhastrika* training showed an increase in parasympathetic activity i.e., reduced basal HR, increase in Valsalva ratio and deep breathing difference in HR; and reduction in sympathetic activity i.e., reduction in fall of SBP on posture variation.
5	Bhimani et al.	2011	59	HRV, Stress questionnaire	There was reduction in stress levels with a combination of *Pranayama* practices. HRV demonstrated reduction in VLF and LF and increase in HF component.
6	Ghiya & Lee	2012	23	HRV	lnTP, lnLF and lnHF were greater during both post-Alternate Nostril Breathing and post-Paced Breathing compared to PRE. Mean Arterial Pressure (MAP) and lnLF/lnHF did not significantly differ between conditions
7	Mason et al.	2013	17	BRS	BRS increased with slow breathing techniques with or without expiratory *Ujjayi* except with inspiratory + expiratory *Ujjayi*. The maximal increase in BRS and decrease in blood pressure were found in slow breathing with equal inspiration and expiration.
8	Sinha et al.	2013	25	Expiration: inspiration ratio, 30:15 ratio	Alternate nostril breathing for 5 min/day, for 6 weeks increased parasympathetic tone.
9	Adhana et al.	2013	30	Electromyogram (EMG), GSR, Finger tip temperature (FTT), HR and RR. SBP and DBP	Slow yogic breathing lead to reduction in SBP and DBP. Significant modifications were also found in HR RR, EMG, GSR and rise in FTT.
10	Turankar et al.	2013	12	BP, Pulmonary function tests (PFT), GSR	Practice of *Anulom Vilom Pranayama* with breath holding was found to increase GSR in *Pranayama* group. No significant changes in BP or PFT were noted.
11	Sharma et al.	2013	90	Perceived stress scale (PSS), HR, BP	PSS scores reduced in both fast and slow *Pranayama* group, whereas HR, DBP and RPP reduced only in slow *Pranayama* group.
12	Pal et al.	2014	85	HRV	HRV indices representing sympathetic activity were increased in the Right nostril breathing group and indices representing parasympathetic activity were increased in Left Nostril Breathing group.
13	Bhavanani et al.	2014	20	Reaction time, HR, BP	BP reduced following *Chandara Nadi Pranayama, Chandrabhedana* and *Nadishuddhi* and increased following *Surya Nadi Pranayama* and *Suryabhedana*. Reduction in reaction time was observed with SN and SB.
14	Goyal et al.	2014	50	BP, HR, Rate pressure product	*Pranayama* along with antihypertensive medications reduced BP significantly compared to medications alone. RPP reduced significantly in the *Pranayama* group
15	Hakked et al.	2017	27	Spirometry	Training in Yogic Breathing for one month enhance lung functions in professional swimmers.
16	Nivethitha et al.	2017	16	HRV	HF component of HRV reduced during the practice of *Bhramari Pranayama* along with an increase in LF component and HR. The changes normalized after the conclusion of the practice.

3.4.1. Changes in oxygen consumption with yogic breathing

Oxygen consumption is used as a means to understand the metabolic activity of the body. A study exploring the effects of *Ujjayi Pranayama* along with short and prolonged *Kumbhaka* (breath hold) elucidated an increase in oxygen consumption with short *Kumbhaka* and reduction with prolonged breath hold [47]. Breathing through right nostril was observed to increase the oxygen consumption and thereby the overall metabolic status, when compared to the left nostril and alternate nostril breathing for the same duration [48,49]. These studies have indicated right nostril breathing in conditions with lower metabolic rates, like obesity, though caution must be taken, as the practice of right uninostril breathing was found to increase the BP [50].

3.4.2. Yogic breathing and oxidative stress

Yogic breathing was also found to be an effective means to combat oxidative stress. It was found to lower the free radical load and increase the superoxide dismutase (SOD) among healthy volunteers, when compared to a control population [51]. Athletes often suffer from fatigue due to oxidative stress following the bouts of exercise, therefore requiring antioxidant supply [52]. Yogic breathing for 1 h was found to effectively enhance the antioxidant defense status in athletes following an exhaustive exercise bout compared to control group who practiced quiet sitting. It was correlated to lower levels of cortisol and enhanced melatonin levels. The authors therefore suggest that rhythmic yogic breathing can protect the athletes from long term complications of free radicals [53].

3.4.3. Molecular changes with yogic breathing

The modifications in stress levels, physiological variables and cognition due to yogic breathing have been established through several studies quoted. The need for understanding the molecular biomarkers suggesting the pathways involved prompted a recent study, in which salivary proteomes were analyzed during 20 min of yogic breathing practice. The study revealed that the biomarkers called Deleted in Malignant Brain Tumor-1 (DMBT1) and Ig lambda-2 chain C region (IGLC2) were differentially expressed in yogic breathing group. DMBT1 was elevated in 7 of yogic breathing group by 10-fold and 11-fold at 10 and 15 min, respectively, whereas it was undetectable in the time-matched control group. IGLC2 also showed significant increase in the yogic breathing group when compared to controls [54]. This study was the first to indicate the feasibility of acute practice for the stimulation and detection of salivary protein biomarkers.

The studies indicate modulation of metabolism and modifications of biochemical markers with the practice of yogic breathing. These changes could be correlated to the traditional understanding of the flow of *Prana* (vital energy) controlling the physical functions in the body. Also, the studies confer the excitatory effect of right nostril breathing described in ancient Indian literature. Table 4 illustrates the biochemical and metabolic changes following yogic breathing.

3.5. Health benefits of yogic breath regulation

3.5.1. Yogic breathing in cardiovascular diseases

The physiological effects of yogic breathing practices observed through various experiments correlating with the traditional textual understanding, have been used in various clinical setups. Few studies were conducted to understand the immediate effect of yogic breathing techniques in hypertensive subjects. Following *Sukha Pranayama* for 5 min at 6 breaths per min, there was significant reduction in HR, SBP, pulse pressure, mean arterial pressure, rate-pressure product, and double product with an insignificant fall in diastolic pressure [55]. The practice of *Pranava Pranayama* demonstrated similar effects. Following 5 min of *Pranava Pranayama*, there was a reduction in SBP, HR and pulse pressure [56]. Another study showed immediate reduction in HR, SBP and pulse pressure in hypertensive patients following 27 rounds of left UNB [57]. A study showing the effect of 3 months regular practice of slow breathing for 5 min/day maintaining 2:1 ratio of exhalation:inhalation demonstrated significant reduction in SBP, DBP, HR, RR and increased fingertip temperature [58]. Another study involving 6 weeks training in *Pranayama* along with antihypertensive medications reduced BP significantly compared to medication alone. Rate pressure product reduced significantly in the *Pranayama* group [59]. A study demonstrated the beneficial effects of the practice of *Pranayama* in patients with cardiac arrhythmia, demonstrating improvement in QTd, QTc-d, JTd, and JTc-d in the ECG following the *Pranayama* session, indicating reduction in the indices of ventricular repolarization dispersion [60].

3.5.2. Yogic breathing in respiratory disorders

The effects of yogic breathing in respiratory disorders were also evaluated. A study assessed the effect of yogic breathing in asthmatics, in which patients were made to breathe through a Pink City Lung exerciser at 1:2 ratio of inhalation: exhalation for 2 weeks, 15 min/day. At the end of 2 weeks, mean forced expiratory volume in 1 s (FEV1), peak expiratory flow rate, symptom score, and inhaler use improved in the experimental group, when compared to controls who were breathing through a placebo device. As an indicator of airway reactivity, the dose of histamine needed to provoke a 20% reduction in FEV 1 (PD 20) was assessed, which increased significantly during *Pranayama* breathing but not with the placebo device [61]. Subsequent studies show stability [62,63] and improvement [64] of symptoms in patients with asthma. There was also

Table 4
Biochemical and metabolic changes following yogic breathing.

Sl No.	Author	Year	Sample size	Variables studied	Findings
1	Pratap et al.	1978	10	Arterial blood gas	No significance changes in arterial blood gases were noted after *Pranayama*. Possibility of mental effects of this practice was proposed due to neural mechanisms.
2	Desai & Gharote	1990	12	Blood Urea, Creatinine, tyrosine	Decrease in blood urea, increase in creatinine and tyrosine after 1 min of *Kapalabhati*
3	Telles & Desiraju	1991	10	Oxygen consumption	An increase in oxygen consumption was noted in Yoga breathing with short *kumbhaka* and a reduction with prolonged *kumbhaka*.
4	Telles et al.	1994	48	Oxygen consumption, GSR	Baseline oxygen consumption increased following right nostril breathing, which was more than alternate nostril breathing and increase with left nostril breathing. GSR increased with left nostril breathing.
5	Telles et al.	1996	12	Oxygen consumption, blood pressure, digit pulse volume, GSR	Following the right nostril breathing, there was an increase in oxygen consumption and SBP and reduction in digit pulse volume. Right nostril as well as normal breathing reduced GSR.
6	Bhattacharya et al.	2002	60	SOD, Free radicals	The free radicals were decreased significantly following practice of *Pranayama* but the SOD was increased insignificantly as compared to the control group.
7	Balasubramanian et al.	2015	20	Salivary Proteome –DMBT1 and IGLC2.	DMBT1 was elevated in yogic breathing group by 10-fold, whereas it was undetectable in the time-matched controls. IGLC2 also showed a significant increase in Yogic Breathing group.

improvement noted in FEV1 and peak expiratory flow rate (PEFR) in asthmatics [64]. A recent study also shows enhanced FEV1, FVC and FEV1:FVC ratio following 10 min practice of *Kapalabhati* in patients with asthma [65].

Pranayama was used to aid people trying to undergo cigarette withdrawal. Practice of 10 min of yogic breathing helped in reducing the craving measures than breathing video controls, viz. strength of urge, cigarette craving and desire to smoke. No effect was found on mood or physical symptoms [66]. A case reported beneficial changes in a patient with pulmonary tuberculosis (PTB), who performed *Bhramari Pranayama* for 45 min per day, 3 days a week for 8 weeks. There were significant improvements noted in the body weight, body mass index, symptom scores, pulmonary function and health related quality of life with conversion of positive to negative FME for acid fast bacilli [67].

3.5.3. Yogic breathing in diabetes mellitus

Diabetes is a major healthcare burden in recent years that causes loss of quality of life (QoL) and requires lifestyle modifications. There was significant improvement in the QoL and a non-significant trend toward improvement in glycemic control in the group practicing the comprehensive yogic breathing program

Table 5
Effects of yogic breathing in various clinical population.

Sl No.	Author	Year	Sample size	Disorder	Variables studied	Findings
1	Singh et al.	1990	18	Br. Asthma	Airway reactivity, airway caliber	Increase in the need of histamine for reduction in Forced expiratory volume in 1 s (FEV1) with *Pranayama* in ratio of 1:2 for inhalation: exhalation than control group.
2	Cooper et al.	2003	90	Br. Asthma	Symptom scores, FEV1	At 3rd and 6th month, symptoms remained stable in *Pranayama* group, whereas decrease in symptoms was noted in Buteyko breathing. No between group difference in FEV1 were noted.
3	Saxena & Saxena	2009	50	Br. Asthma	Peak Expiratory Flow Rate (PEFR), FEV1, Symptoms	A combination of slow breathing, *Bhramari* and *Omkara* significantly improved symptoms, FEV1 and PEFR in patients with Bronchial Asthma.
4	Prem et al.	2013	120	Br. Asthma	Asthma Quality of life, PFT	Buteyko breathing showed better trends of improvement in quality of life and asthma control than the group performing the *Pranayama*.
5	Raghavendra et al.	2016	60	Br. Asthma	FEV1, FVC, FEV1:FVC	10 min of practice of *Kapalabhati* enhances FEV1, FVC and FEV1:FVC ratio in patients with mild to moderate Asthma, when compared to control who performed deep breathing.
6	Dabhade et al.	2012	15	Cardiac Arrhythmias	ECG	In patients with cardiac arrthymias, there was improvement in QTd, QTc-d, JTd, and JTc-d following the *Pranayama* session, indicating reduction the indices of ventricular repolarization dispersion.
7	Dhruva et al.	2012	16	Cancer	Cancer related Symptoms, quality of life	Improved quality of sleep, quality of life and reduced anxiety following *Pranayama* between 2 chemotherapy sessions.
8	Chakrabarty et al.	2015	160	Cancer	Cancer related fatigue	Scores of Cancer related fatigue reduced following practice of *Pranayama* along with radiation therapy (RT) than RT alone.
9	Jyotsna et al.	2012	49	Type 2 Diabetes Mellitus	WHOQoL BREF, FBS, PPBS, HbA1C	There was significant improvement in the QOL and a non-significant trend toward improvement in glycemic control in the group practicing the yogic breathing program than standard treatment alone.
10	Jyotsna et al.	2013	64	Type 2 Diabetes Mellitus	Cardiac autonomic functions	*Pranayama* along with standard therapy improved sympathetic functions in diabetics than those who were on standard therapy alone.
11	Bhavanani et al.	2012	22	Hypertension	Heart rate, blood pressure	Immediate reduction in heart rate, systolic pressure, pulse pressure following *Chandra Nadi Pranayama* was noted
12	Bhavanani et al.	2012	29	Hypertension	Heart rate, blood pressure	Reduction in systolic pressure, pulse pressure and heart rate in hypertensive patients was observed following *Pranava Pranayama*.
13	Marshall et al.	2013	11	Stroke	Attention, language, spatial abilities, depression, and anxiety	Uninostril breathing practice reduced anxiety in post stroke cases and improved language measures in individuals with aphasia due to stroke.
14	Marshall et al.	2015	3	Stroke	Western Aphasia Battery-R (WAB-R) and Communication Abilities of Daily Living-2 (CADL-2)	In 2 out of 3 cases of stroke induced aphasia, Forced Uninostril breathing along with speech therapy showed improvement in correct information unit and word productivity.
15	Nemati.	2013	107	Test Anxiety	Sarason's test anxiety scale, test performance	Following practice of *Pranayama* for a semester, fewer participants experienced high test anxiety, compared to the control group. Participants in the *Pranayama* group also had higher scores in the test performance than controls.
16	Mooventhan et al.	2014	1	Pulmonary Tuberculosis	Weight, body mass index, symptom scores, pulmonary function and health related quality of life with conversion of positive to negative FME for acid fast bacilli	There were significant changes in weight, body mass index, symptom scores, pulmonary function and health related quality of life with conversion of positive to negative FME for acid fast bacilli, when the patient of Pulmonary Tuberculosis

compared with the group that was following standard treatment alone [68]. Diabetic patients also are known to have sympathovagal imbalance. Practice of *Pranayama* for 6 months along with standard therapy improved sympathetic functions in diabetics than those who were on standard therapy alone [69].

3.5.4. Yogic breathing in other diseases

A controlled study evaluating the effect of slow *Pranayama* breathing compared to normal breathing on pain perception demonstrated reduced ratings of pain intensity and unpleasantness, particularly for moderately versus mildly painful thermal stimuli with slow breathing [70]. A pilot RCT comparing effects of *Pranayama* as an ancillary technique to usual care for patients receiving chemotherapy demonstrated improved quality of sleep, QoL and reduced anxiety with the practice of *Pranayama* between 2 chemotherapy sessions [71]. An RCT involving 160 cancer patients undergoing radiotherapy demonstrated significant difference in protein thiols and serum glutathione in patients who practiced combination of *Nadishuddi*, *Bhramari* and *Shitali Pranayama* for 30 min/day, twice daily/5 days a week, when compared to controls who received radiotherapy alone [72]. *Pranayama* as an adjunct therapy to radiotherapy was also found to be beneficial to reduce the cancer related fatigue [73].

Table 5 summarizes the health benefits of yogic breath regulation in various clinical population.

3.6. Complications of yogic breathing

The practice of *Pranayama* is generally considered safe and we could find only one case report reporting an adverse effect of yogic breathing during our review of literature. A case of spontaneous pneumothorax caused due to a Yoga breathing technique called *Kapalabhati* was reported [74]. A review also denoted cases of rectus sheath hematoma and pneumomediastinum due to practice of unspecified *Pranayama* [75].

4. Conclusion

Pranayama or yogic breathing practices were found to influence the neurocognitive abilities, autonomic and pulmonary functions as well as the biochemical and metabolic activities in the body. The studies in the clinical populations, show the effects of yogic breathing in modulating cardiovascular variables in patients with hypertension and cardiac arrhythmias, relieving the symptoms and enhancing the pulmonary functions in bronchial asthma, as an ancillary aid to modify the body weight and symptoms of pulmonary tuberculosis, to enhance mood for patients withdrawing from cigarette smoking, to reduce the reaction time in specially abled children, to manage anxiety and stress in students, to modulate the pain perception, improve the QoL and sympathetic activity in patients with diabetes, reduce the cancer related symptoms and enhancing the antioxidant status of patients undergoing radiotherapy and chemotherapy for cancer. Thus the cost effective and safe practices of yogic breathing could aid in prevention and management of various non-communicable diseases. They may also play a role in management of communicable diseases such as pulmonary tuberculosis.

The limitations of the current review include limiting the search to free online databases, which might limit the access to actual research work done in the field. Also, the current review is limited to narration of the current available scientific literature on yogic breathing and no attempt was made to establish the statistical validity of the data presented in the literature.

Overall, we found the practice of yogic breathing safe, when practiced under guidance of a trained teacher. Though several studies are available elucidating the effects of yogic breathing, they lack methodological rigor. Considering the positive effects of yogic breathing, further large scale studies with better methodological designs to understand the mechanisms involved with yogic breathing are warranted.

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None.

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