Chapter 3

Review of Scientific Literature

3.0 REVIEW OF SCIENTIFIC LITERATURE

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" (Muktibodhananda, 2002). Thus, evaluating the impact of yogic Breathing on neurocognitive abilities has sought special attention from the scientific community. An early review indicates yogic breathing practices could influence the brain activity in different ways (Srinivasan, 1991).

Changes due to pace of breathing:

The earliest studies reported assessing the effects of YB on neurocognitive abilities evaluated the effect of 15 minutes of high frequency YB, described as *Kapalabhati* (KPB) on EEG activity (Stancák, Kuna, Srinivasan, Dostálek, & Vishnudevananda, 1991). The study demonstrated increased alpha activity during the initial five min of KPB. Theta activity was observed to be enhanced, mostly in the occipital region during later stages of 15 min KPB 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. Another study assessed the cognitive abilities following KPB demonstrated increase in the number of errors following 1 and 5 minutes of practice of KPB, in a letter cancellation task (Pradhan, 2013).

The impact of another rapid paced pranayama called *Bhastrika*, described in *Hathayoga* as bellow's breath, on reaction time was studied by Telles and colleagues. They found a reduction in anticipatory responses following 18 minutes of practice of *Bhastrika* (Telles, Yadav, Gupta, & Balkrishna, 2013). Auditory (ART) and visual reaction time (VRT) reduced significantly in school children following just 9 rounds of *Mukha Bhastrika*, in 22 healthy school children (Bhavanani, Madanmohan, & Udupa, 2003). 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 (Bhavanani, Ramanathan, & Harichandrakumar, 2012). A study comparing the effects of slow and fast paced *pranayama* reported effects of 35 minutes/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 (Sharma et al., 2014). A study assessing the cerebral hemodynamics in healthy volunteers demonstrated an increased peak systolic velocity, end-diastolic velocity with reduction in pulsatality index in the right middle-cerebral artery during the practice of *Kumbhaka.* Contrasting results were found with the practice of high frequency practice of *Bhastrika* (Nivethitha, Mooventhan, Manjunath, Bathala, & Sharma, 2017).

Changes with Bhramari Pranayama:

A form of YB called *Bhramari*, in which humming sound is produced and is said to modify the brain responses through the resonance produced, has shown to produce non epileptic paroxysmal gamma waves in the EEG (Vialatte, Bakardjian, Prasad, & Cichocki, 2009). A study has shown that the practice of *Bhramari* for 10 minutes enhances inhibition and reaction time in the stop signal task that involves cognitive inhibition, in 31 healthy male individuals (Rajesh, Ilavarasu, & Srinivasan, 2014).

Changes due 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* (Muktibodhananda, 2002; Nagendra, 2007). Right nostril corresponds to *Pingala Nadi*, and the left *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 (Jella & Shannahoff-Khalsa, 1993). 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 (Telles, Singh, & Puthige, 2013). 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 (Telles, Joseph, Venkatesh, & Desiraju, 1993). A three-arm randomized controlled trial done on patients with essential hypertension, comparing the effects of *nadisuddhi pranayama* and breath awareness with control session for 10 minutes elucidated reduction in SBP and DBP following *nadisuddhi* 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 (Telles et al., 2013). 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 (Marshall, Basilakos, Williams, & Love-Myers, 2014). 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 (Marshall, Laures-Gore, DuBay, Williams, & Bryant, 2015).

Thus, most yoga 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 neurocognitive effects of yogic breathing are summarized in table 2.

Sl No.	Author	Year	Sample size	Variables studied	Findings
1	Stancák, et al.	1991	11	EEG	Alpha activity was increased during the initial five 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 *pranayama* 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 was 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	VRTand 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 BP (DBP) following *Nadisuddhi* 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 minutes 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 *bhastrikapranayama* 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 minutes of practice of *Bhramari* pranayama. There was increase in go Reaction time in *Bhramari* group when compared to deep breathing group for equal duration.
12	Nivethitha, et al.	2017	15	Transcranial Doppler	Increased peak systolic velocity, end-diastolic velocity with reduction in pulsatality index in the right middle-cerebral artery during the practice of *Kumbhaka.* Contrasting results were found with the practice of high frequency practice of *Bhastrika*

Table 2: The Neurocognitive Effects of Yogic Breathing.

3.2 PSYCHOPHYSIOLOGICAL EFFECTS OF YOGIC BREATHING

Human respiration the only physiological system that is under both autonomic and voluntary nervous control. 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 YB 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), etc. Both Short and long-term effects of YB have been assessed using AFT.

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 (Shannahoff-Khalsa & Kennedy, 1993). A three-arm RCT using HRV as the measure of autonomic activity, showed sympathetic arousal in the right uninostril breathing group, whereas indices representing parasympathetic activity were increased in LNB group following 6-week nostril breathing (Pal, Agarwal, Karthik, Pal, & Nanda, 2014). In a pilot RCT performed on 12 individuals found that 20 minutes of alternate nostril breathing increased galvanic skin resistance (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 (Turankar et al., 2013). 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 (Sinha, Deepak, & Gusain, 2013).

Nadisuddhi Pranayama at the rate of one breath per min was found to enhance sinus arrhythmia and reduction in low frequency component of HRV (Jovanov, 2005). It also decreased the average breath rate, confirming the 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 (Dhungel, Malhotra, Sarkar, & Prajapati, 2008). 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 (Bhargava, Gogate, & Mascarenhas, 1988). Six variations of nostril breathings on cardiovascular parameters and reaction time in 20 experienced subjects demonstrated that 9 rounds of *Nadisuddhi*, 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 (sBhavanani, Ramanathan, Balaji, & Pushpa, 2014). A study examining the effect of nostril breathing on hand grip strength in school children demonstrated enhanced hand grip strength following training in left, right and alternate nostril breathing groups, without lateralizing effect (Raghuraj, Nagarathna, Nagendra, & Telles, 1997). A recent experiment demonstrated the role of slow paced breathing at the rate of 5 breaths per min associated with alternate nostril breathing and breath holding to enhance the HRV and Blood Pressure Variability (Bhagat, Kharya, Jaryal, & Deepak, 2017). This study also depicted the interaction of the branches of ANS due to such breathing.

Changes due to modulation of pace of breathing:

The pace of breathing also modifies the psychophysiological responses. A pilot study evaluating the effect of very slow breathing at 1 breath/min for 20 minutes on cardiovascular risk factors showed dramatic changes in hemodynamic variables like stroke index (SI), heart rate (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 (MAPs),left stroke work index (LSWI) and stroke systemic vascular resistance index (SSVRI). These changes indicate that breathing at a slow pace with internal breath hold could influence brainstem cardiorespiratory center regulating the Mayer wave patterns (Shannahoff-Khalsa, Sramek, Kennel, & Jamieson, 2004). 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 (Mason et al., 2013). 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 (Pal, Velkumary, & Madanmohan, 2004). 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 (Sharma et al., 2013). Training in slow deep breathing was found to enhance the cardio-respiratory coupling

(Dick, Mims, Hsieh, Morris, & Wehrwein, 2014). 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 (Thangavel et al., 2014). 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 (Raghuraj, Ramakrishnan, Nagendra, & Telles, 1998). A concurrent result was found in another study that demonstrated an increase in HR, SBP and DBP following KPB. The study performed on 17 individuals also elucidated reduced BRS during practice of KPB (Stancák, Kuna, Srinivasan, Vishnudevananda, & Dostálek, 1991). 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 also was 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* (Veerabhadrappa et al., 2011). To understand the underlying pathways for the modulation of cardiovascular parameters following slow paced *Bhastrika pranamayama*, a study compared the effect of 5 minutes 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 five 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* are attributed to the enhanced parasympathetic activity (Pramanik et al., 2009).

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 (Nivethitha, Manjunath, & Mooventhan, 2017). *Bhramari pranayama* was also found to reduce the HR, MAP, Pulse pressure, rate pressure product and double product, indicating the relaxation attained following the practice, when compared to control group (Kuppusamy, Kamaldeen, Pitani, & Amaldas, 2016). Medical students showed reduced stress levels following practice of a combination of *pranayama* practices for 1 hour 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 (Pramanik et al., 2009). 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 (Nemati, 2013).

We observed that, most Yogic breathing is found to have profound effects on autonomic functions. Most YB practices lead to parasympathetic shift of the ANS activity, except high frequency Yoga breathing (*Kapalabhati*) (Mohanty & Saoji, 2016).

Effects of Yogic Breathing on Respiratory system:

The training in YB 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 minutes, and increase in forced vital capacity after 2 minutes, and increase in forced inspiratory vital capacity and peak inspiratory flow rate following 2, 5 and 10 minutes of slow deep breathing practice (Sivakumar et al., 2011). 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 (Dinesh et al., 2015). *Bhramari pranayama* and Om chanting for 10 min/day for two weeks improve peak expiratory flow (PEF), forced expiratory flow (FEF)25% and maximal voluntary ventilation (MVV) along with a reduction in weight, when compared to the control group (Mooventhan & Khode, 2014). A recent study demonstrated beneficial effect of one month training in combination of YB on pulmonary functions in competetive smimmers (Hakked, Balakrishnan, & Krishnamurthy, 2017). Thus, the limited available evidence on effects of YB on respiratory systemindicate a positive trend of change in the respiratory physiology with YB.

The effects of yogic breathing on psychophysiological and respiratory variables are summarized in table 3.

Sl No.	Author	Year	Sample size	Variables studied	Findings
1	Bhargava, et al.	1988	20	Heart Rate (HR), Systolic (SBP) and Diastolic Blood Pressure(DBP), galvanic skin resistance (GSR)	Practice of *Nadisuddhi pranayama* with breath retention for a period of 4 weeks demonstrated a decrease in baseline HR, SBP and DBP. The results of GSR were not conclusive.
2	Stancák, et al.	1991	17	Blood pressure (BP), ECG and respiration	Increase of HR, SBP and DBP during *Kapalabhati* (KPB). Baroreflex sensitivity (BRS) reduced during KPB.
3	Raghuraj, et al.	1997	130	Hand Grip strength	Practice of *pranayama* was found to enhance hand grip strength without lateralizing effect of the nostril manipulation.

4	Raghuraj, et al.	1998	12	Heart rate variability (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 *Nadisuddhi*.
5	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.
6	Shannahoff-Khalsa, et al.	2004	4	Cardiovascular variables	Following breathing at 1 breath/min with ratio of 20:20:20 seconds, there are dramatic variations in hemodynamic variables.
7	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.

8	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.
9	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
10	Mason, et al.	2013	17	Baroreflex sensitivity (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.
11	Sinha, et al.	2013	25	Expiration: inspiration ratio, 30:15 ratio	Alternate nostril breathing for 5 minutes/day, for 6 weeks increased parasympathetic tone.

12	Adhana, et al.	2013	30	Electromyogram (EMG), Galvanic skin response (GSR), Finger tip temperature (FTT), HR and Respiratory rate(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.
13	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.
14	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.

15	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.
16	Bhavanani, et al.	2014	20	Reaction time, HR, BP	BP reduced following *Chandara Nadi pranayama*, *Chandrabhedana* and *Nadisuddhi* and increased following *Surya Nadi pranayama* and *Suryabhedana*. Reduction in reaction time was observed with SN and SB.
17	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

18	Mooventhan & khode	2014	82	Spirometry	*Bhramari pranayama* and Om chanting for 10 min/day for two weeks improve peak expiratory flow (PEF), forced expiratory flow (FEF) 25% and maximal voluntary ventilation (MVV) along with a reduction in weight, when compared to the control group.
19	Dick, et al.	2014	10	Cardio-respiratory coupling	Training in slow deep breathing could enhance the cardio-respiratory coupling.
20	Kuppusamy, et al.	2016	60	HR, MAP, pulse pressure (PP), Rate Pressure Product (RPP) and Double Product (DoP)	Practice of *bhramari pranayama* leads to relaxation as indicated by reduction in HR, MAP, PP, RPP and DoP, when compared with the control group.
21	Bhavanani, et al.	2016	52	Respiratory Sinus Arrhythmias (RSA)	Different methods of performing *pranayama* were assessed. The highest change in RSA was found following the practice of *Pranava pranayama*, in which the inspiration: expiration ratio was maintained at 1:3.

22	Hakked, et al.	2017	27	Spirometry	Training in Yogic Breathing for one month enhance lung functions in professional swimmers.
23	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.
24	Bhagat, et al.	2017	12	HRV, BPV, BRS	Increased in HRV and BPV was found following practice of alternate nostril breathing for five min along with retention of breath at the pace of 5 breaths/min.

Table 3: Psychophysiological and Respiratory Changes Following Yogic Breathing

3.3 EFFECTS OF YOGIC BREATHING ON BIOCHEMICAL AND METABOLIC VARIABLES:

Curiosity of what causes the changes that are observed following the practice of yogic breathing, a study examining the changes in arterial blood gas levels following the practice of *pranayama* was conducted. No significant changes were observed in arterial blood oxygenation following *pranayama*, thus speculating neural mechanisms for changes due to *pranayama* (Pratap, Berrettini, & Smith, 1978). Another study observed a decrease in blood urea, and an increase in creatinine and tyrosine after one minute of *Kapalabhati*. It was attribured to decarboxylation and oxidation mechanisms, which may be responsible for a reduction in the activity of respiratory centers (Desai & Gharote, 1990).

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* whereas reduction with prolonged breath hold (Telles & Desiraju, 1991). 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 (Telles, Nagarathna, & Nagendra, 1994; Telles, Nagarathna, & Nagendra, 1996). 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 (Raghuraj & Telles, 2008).

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 (Bhattacharya, Pandey, & Verma, 2002). Athletes often suffer from fatigue due to oxidative stress following the bouts of exercise, therefore requiring antioxidant supply (Marzatico, Pansarasa, Bertorelli, Somenzini, & Della Valle, 1997). The observations by Marzatico et al. were replicated in a study demonstrating the beneficial effects of diaphragmatic breathing on oxidative stress in athletes along with reduction in cortisol and increased melatonin (Martarelli, Cocchioni, Scuri, & Pompei, 2011). Yogic breathing for 1 hour 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 YB can protect the athletes from long term complications of free radicals (Martarelli et al., 2011).

Molecular changes with Yogic Breathing:

The variations in stress levels, physiological variables and cognition due to YB have been established through several studies quoted. The need for understanding the molecular biomarkers suggesting the pathways involved for such changes, prompted a recent study, in which Salivary Proteomes were analyzed during 20 minutes of YB 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 YB group. DMBT1 was elevated in 7 of YB group by 10-fold and 11-fold at 10 and 15 minutes, respectively, whereas it was undetectable in the time-matched control group. IGLC2 also showed significant increase in the YB group when compared to controls (Balasubramanian, Janech, & Warren, 2015). This study was the first to indicate the feasibility of acute YB practice for the stimulation and detection of salivary protein biomarkers. A study demonstrated reduction in pro-inflammatory markers, IL-1β, IL-8 and monocyte chemotactic protein -1 (MCP-1) immedietly following the practice of YB, when compared with attention control. The study, therefore indicated potential anti-inflammatory nature of YB practice (Twal, Wahlquist, & Balasubramanian, 2016).

The studies indicate modulation of metabolism and modifications of biochemical markers with the practice of YB. 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.

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 one minute 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, Galvanic skin resistance (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	Superoxide dismutase (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	Martarelli, et al.	2011	24	Antioxidant status, cortisol, melatonin	One hour of diaphragmatic breathing enhanced antioxidant defense status in athletes following the bout of exhaustive exercise. These effects correlate with the concomitant decrease in cortisol and the increase in melatonin
8	Balasubramanian, et al.	2015	20	Salivary Proteome - deleted in malignant brain tumor-1 (DMBT1) and Ig lambda-2 chain C region (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.

9	Twal, et al.	2016	20	Interleukin (IL)-1β, IL-8, IL-1RA, IL-6, IL-10, IL-17, IP-10, monocyte chemotactic protein -1 (MCP-1), MIP-1b, and Tumor Necrosis Factor-α (TNF-α).	The levels of IL-1β, IL-8 and MCP-1 were significantly reduced in yogic breathing group when compared with attention control group, indicating the potential role of yogic breathing in restricting inflammation.

Table 4: Biochemical and Metabolic Changes Following Yogic Breathing.

3.4 HEALTH BENEFITS OF YOGIC BREATH REGULATION

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 YB techniques in hypertensive subjects. Following *Sukha Pranayama* for 5 minutes 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 (Bhavanani, Sanjay, & Madanmohan, 2011). The practice of *Pranava pranayama* demonstrated similar effects. Following 5 minutes of *pranava Pranayama*, there was a reduction in SBP, HR and pulse pressure (Bhavanani, Madanmohan, Sanjay, & Basavaraddi, 2012). Another study showed immediate reduction in HR, SBP and pulse pressure in hypertensive patients following 27 rounds of left uninostril breathing (Bhavanani, Madanmohan, Sanjay, & Madanmohan, 2012). A study showing the effect of 3 months regular practice of slow breathing for 5 minutes/day maintaining 2:1 ratio of exhalation: inhalation demonstrated significant reduction in SBP, DBP, HR, RR and increased fingertip temperature (Adhana et al., 2013). 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 (Goyal, Lata, Walia, & Narula, 2014). 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 the indices of ventricular repolarization dispersion (Dabhade, Pawar, Ghunage, & Ghunage, 2012). Patients undergoing coronary angiography demonstrated reduced anxiety scores following the practice of *sukha pranayama,* performed at the pace of 10 breath/min for five min (Bidgoli, Taghadosi, Gilasi, & Farokhian, 2016).

Yogic Breathing in Respiratory Disorders:

The effects of YB in respiratory disorders are also evaluated. A study assessing the effect of YB in asthmatics, patients were made to breathe through a Pink City Lung exerciser at 1:2 ratio of inhalation: exhalation for 2 weeks, 15 minutes/day. At the end of 2 weeks, mean forced expiratory volume in 1 second (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 (Singh, Wisniewski, Britton, & Tattersfield, 1990). Subsequent studies show stability (Cooper et al., 2003; Prem, Sahoo, & Adhikari, 2012) and improvement (Saxena & Saxena, 2009) of symptoms in patients with asthma. There was also improvement noted in FEV1 and peak expiratory flow rate (PEFR) in asthmatics (Saxena & Saxena, 2009). A recent study also shows enhanced FEV1, FVC and FEV1:FVC ratio following 10 min practice of *Kapalabhati* in pateints with asthma (Raghavendra, Shetty, Shetty, Manjunath, & Saoji, 2016). Another study proved that daily practice of modified breathing incorporating yogic breathing improved the scores in Asthma Control test (Karam, Kaur, & Baptist, 2017).

Pranayama was used to aid people trying to undergo cigarette withdrawal. Practice of 10 minutes 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 (Shahab, Sarkar, & West, 2013). A study was designed to assess the effect of pranayama on the exercise tolerance in patients with chronic obstructive pulmonary disorders (COPD). The study reported enhanced performance in the six min walking distance following training in *pranayama*. The study also demonstrated improved symptoms, small improvements in inspiratory capacity and air trapping (Kaminsky et al., 2017). A case reported beneficial changes in a patient with pulmonary tuberculosis (PTB), who performed *bhramari pranayama* for 45 minutes 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 (Mooventhan & Khode, 2014).

Yogic Breathing in Diabetes Mellitus:

Diabetes is a major health care burden in recent years that causes loss of quality of life 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 compared with the group that was following standard treatment alone (Jyotsna et al., 2012). 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 (Jyotsna et al., 2013).

Yogic Breathing in other diseases:

A controlled study evaluating the effect of slow *pranayama* breathing comparing with normal breathing on pain perception demonstrated reduced ratings of pain intensity and unpleasantness, particularly for moderately versus mildly painful thermal stimuli with slow breathing (Zautra, Fasman, Davis, & Craig, 2010). A pilot RCT comparing effects of *pranayama* as an ancillary technique to usual care for patients receiving chemotherapy demonstrated improved quality of sleep, quality of life and reduced anxiety with the practice of *pranayama* between 2 chemotherapy sessions (Dhruva et al., 2012). An RCT involving 160 cancer patients undergoing radiotherapy demonstrated significant difference in protein thiols and serum glutathione in patients who practiced combination of *nadisuddi*, *bhramari* and *shitali pranayama* for 30 minutes/day, twice daily/5 days a week, when compared to controls who received radiotherapy alone (J Chakrabarty et al., 2013). *Pranayama* as an adjunct therapy to radiotherapy was also found to be beneficial to reduce the cancer related fatigue (Jyothi Chakrabarty et al., 2015) and negative emotions (Jyothi Chakrabarty, Vidyasagar, Fernandes, & Mayya, 2016). A recent study elicited a newer avenue of use of *pranayama* as an adjunct therapy for management of chronic periodontitis along with the Scaling and Root Planing. The results indicated demonstrated higher clinical attachment levels, along with reduction in the expression of Nuclear Factor-Kappa B (NF-κB) and increase in Peroxisome Proliferator-Activated Receptor Gamma (PPAR-γ) (Mahendra et al., 2017). Another specific area explored for the application of yogic breathing was post traumatic stress disorder (PTSD) in military veterans. A case series demonstrated beneficial effects of Sudarshana kriya yoga breathing techniques reduce the symptoms of PTSD (Walker & Pacik, 2017).

Table 5 summarizes the health benefits of yogic breath regulation 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 one sec (FEV1) with pranayama in ratio of1:2 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	Karam, et al.	2017	74	Br. Asthma	Asthma Control Test (ACT) and mini-Asthma Quality of Life Questionnaire (AQLQ)	10 min practice per day of modified breathing was found to be effective in improving the score in ACT.

7	Kaminsky, et al.	2017	43	COPD	6-min walk distance (6MWD), lung function, markers of oxidative stress and systemic inflammation	12 week training in *pranayama* improved the 6MWD, reduced symptoms, air trapping and improved inspiratory capacity
8	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.
9	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.

10	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.
11	Chakrabarty, et al.	2016	160	Breast Cancer	Negative emotions	Practice of *pranayama* as along with RT may reduce the negative emotions, thus emulating the role of *pranayama* as a supportive therapy along with RT.
12	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.
13	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.

14	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
15	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*.
16	Goyal, et al.	2014	50	Hypertension	BP, HR, RPP	Reduction in BP, HR and RPP were noted in both groups. The patients receiving *pranayama* along with antihypertensive medications showed significantly reduced BP and RPP when compared to antihypertensive medications alone.
17	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.

18	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.
19	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.
20	Mobini Bidgoli, et al.	2016	80	Pre-Coronary angiography anxiety	Spielberger State Anxiety Inventory	Practice of *sukha pranayama* for five minutes, breathing at rate of 10 breath/min reduce the pre-state anxiety significantly in patients prior to coronary angiography.

21	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
22	Walker & Pacik	2017	3	Post traumatic stress disorder (PTSD)	Subjective symptoms of PTSD	Military veterans demonstrated reduced symptoms of PTSD following the practice of sudarshan kriya yoga breathing regimen for 5 days/week.

23	Mahendra, et al.	2017	60	Chronic Periodontitis	Peroxisome Proliferator-Activated Receptor Gamma (PPAR-γ), Nuclear Factor-Kappa B (NF-κB) and Red Complex Microorganisms (RCM), Clinical attachment Level (CAL), Bleeding Index (BI) and Plaque Index (PI)	Practice of *pranayama* as an adjunct therapy along with Scaling and Root Planing demonstrated higher CAL, along with reduction in the expression of NF-κB and increase in PPAR-γ

Table 5: Effects of Yogic Breathing in Clinical Population

3.5 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 (Johnson, Tierney, & Sadighi, 2004). A review also denoted cases of rectus sheeth hematoma and pneumomediastinum due to practice of unspecified *pranayama* (Cramer, Krucoff, & Dobos, 2013).

3.6 SUMMARY

Pranayama or Yogic breathing practices were found to influence the neuro-cognitive 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 quality of life 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.