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Psychophysiologic Effects of Hatha Yoga on Musculoskeletal and Cardiopulmonary Function: A Literature Review

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ABSTRACT

Yoga has become increasingly popular in Western cultures as a means of exercise and fitness training; however, it is still depicted as trendy as evidenced by an April 2001 *Time* magazine cover story on "The Power of Yoga." There is a need to have yoga better recognized by the health care community as a complement to conventional medical care. Over the last 10 years, a growing number of research studies have shown that the practice of Hatha Yoga can improve strength and flexibility, and may help control such physiological variables as blood pressure, respiration and heart rate, and metabolic rate to improve overall exercise capacity. This review presents a summary of medically substantiated information about the health benefits of yoga for healthy people and for people compromised by musculoskeletal and cardiopulmonary disease.

INTRODUCTION

The word "yoga" comes from the Sanskrit root *yug*, which means "union." In the spiritual sense, yoga means union of the mind with the divine intelligence of the universe. Yoga aims through its practices to liberate a human being from the conflicts of duality (body–mind), which exists in every living thing, and from the influence of the *gunas*, the qualities of universal energy that are present in every physical thing. (Universal energy has three qualities, known as *gunas,* that exist together in equilibrium: *Sattva* [purity]; *Rajas* [activity, passion, the process of change]; and *Tamas* [darkness, inertia]). Put simply, the follower of yoga learns to work with the forces and processes of life as a partner—coupled, rather than in conflict and unease with their own nature.

One of the yoga practices, Hatha Yoga, is based on the knowledge, development, and balance of psychophysical energies in the body and can, therefore, be referred to as the "psychophysical yoga." The three main elements used in Hatha Yoga to attain its purposes are the body, the physical part of man; the mind, the subtle part; and the element that relates the body with the mind in a special way, the breath. Hatha Yoga offers special techniques for each one of these elements. For the physical part, or body, it offers the *asanas* ("postures"), techniques for physical conditioning, called *kriyas* ("actions"), *mudras* ("seals"), *bandhas* ("locks"), as well as techniques for total and conscious physical relaxation. Although a small part of the practice of yoga, the capacity of *kriyas, mudras,* and *bandhas* to deepen awareness and consciousness should not be over-

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looked. A *kriya* is an action or effort to direct movement of energy up and down the spine, transforming the meditator's state of being until spiritual realization occurs; a *mudra* is a gesture or a seal, a body movement to hold energy, or concentrate awareness; and a *bandha* is an energy lock, using muscular constriction to focus awareness. Each of these techniques are considered separately because of their discrete benefits. For the mental or subtle part, Hatha Yoga offers concentration in specific parts of the body, or in subtle forms or abstract ideas. Finally, for that link between the body and the mind, which is breathing, Hatha Yoga has developed a lot of specific techniques, called *pranayamas*. (*Pranayama* in a physiological sense involves breath control [inhalation, exhalation, and suspension] that strengthens the respiratory muscles and improves ventilation.) These are the techniques for activation of *prana* ("energy") that is contained in the breathing. In the practice of yoga, the whole life-energy of the universe is called *prana*. In Hatha Yoga, therefore, *prana* is absorbed by the breath, through the breathing. The manner in which we breathe sets off energy vibrations that influence our entire being. Understanding and controlling breathing will, in the practical sense of Hatha Yoga, control the energy flow. The mind, through its power of reflection, its discernment, and its will power, will supervise and control the whole process of purification. It is in this process that the performance of the pranayamas and asanas (Table 1) has an important physiologic role. They cause a beneficial influence on the four major systems of the human body: for locomotion, through the musculoskeletal system; for oxygen delivery, through the cardiopulmonary system; and for the nervous and the endocrine control systems. Thus, the combination of body, mind, and breath control forms a natural basis for the psychophysiologic effects of Hatha Yoga, as examined in this review of the published medical literature.

METHODS FOR SELECTION OF STUDIES

The published literature for this review was identified using a commercially indexed scientific database, MEDLINE®, which was accessed using two main search engines, PubMed and Medscape. Both of these browsers were searched frequently using the key words yoga or yogic, limiting the search to publication dates from 1985 to the present. Many of the retrieved articles had abstracts, making it easier to determine relevant literature. Selection was restricted to English language publications that reported objective physiological effects of yoga training, either through physical postures (*asanas*) or controlled breathing (*pranayamas*). Studies were eliminated if they evaluated effects of yogic cleansing exercises or more subjective measures of meditation (*dhyana*), such as neurobehavioral effects (e.g., dexterity skills, perceptual visual skills, memory skills, visual and auditory reaction time, flicker fusion, and maze learning), psychopharmacologic effects, or studies on psychotherapy. Some of these studies were discussed in previously published review articles (Arpita, 1990; Jevning et al., 1992; Murphy and Donovan, 1997). Except where noted, case studies or anecdotal reports also were eliminated from consideration.

Using the above criteria, approximately 120 published records were considered for the initial evaluation. A large number (approximately half) of the identified studies were published in the Indian literature, as would be expected on the basis of yoga alone. However, the contribution of Indian scientists in other areas of biomedical research and health care has been significant and conforms to international standards. Currently, 45 Indian medical journals are indexed in MEDLINE®. Unfortunately, MEDLINE® does not offer the full text of journals. These are only available from the Web sites of the individual journals, if and when the full texts of articles are placed on their sites. Indian medical journals have recognized the importance of an online presence and quite a few new Web sites have emerged in the last year. Online subscriptions are still hard to find, but many of them do offer free full text. In addition, the Indian MEDLARS Centre (www.indmed.nic.in) has designed and developed a bibliographic database (IndMED) of 75 prominent Indian journals from the Indian biomedical literature. The search application allows

Table 1. *ASANAS* (Postures) Basic to the Practice of Hatha Yoga*

Pose	*Name*	*Description/Comments*
Ankle-knee	*Badrasana*	Sitting, soles of feet together
Boat	*Ardha Navasana*	Angle pose, on back hands to knees
Bow	*Dhanurasana*	*Dhanur*, "bow" pose on abdomen
Bridge	*Setu Bandhasana*	Backbend, head on floor
Camel	*Ustrasana*	Backbend, hands to heels
Cat	*Vidalasana*	Alternate arching of back on all-fours
Chair	*Utkatasana*	Sitting on imaginary chair
Chest stretch	*Parsvottanasana*	Palms joined behind back
Cobra	*Bhujangasana*	Also called serpent or snake pose
Corpse	*Savasana*	Resting, restorative pose
Cow head	*Gomukhasana*	Sitting, legs crossed, hands clasped
Crocodile	*Nakrasana*	Strength pose on palms and toes
Crow	*Kakasana*	Balance pose on hands, legs in
Down-dog	*Adhomukha Svanasana*	Dog "stretch" pose, face down
Down cross-leg	*Adhomukha Swastikasana*	Downward facing, sitting pose
Eagle	*Garudasana*	Standing balance pose on one foot
Ear-knee	*Karna Peedasana*	Knees clasping ears, from plough
Fish	*Matsyasana*	*Matsya*, "fish" pose
Forward bend	*Uttanasana*	Standing in an intense forward bend
Four limbs	*Chaturanga Dandasana*	Push-up or dip pose
Frog	*Mandukasana*	Sitting between feet, knees apart
Half moon	*Ardha Chandrasana*	*Ardha*, "half" leg and arm balance
Hands-to-feet	*Padahastasana*	Standing on hands in forward bend
Head-to-knee	*Paschimottanasana*	Sitting in a forward bend
Headstand	*Sirsasana*	*Sirsa*, "head" inversion
Headstand, lotus	*Urdhva Padmasana*	Headstand inversion in lotus pose
Kneeling	*Vajrasana*	*Vajra*, "thunderbolt" pose
Leg-split	*Anjaneyasana*	Stretch pose on leg, knee up
Lion	*Simhasana*	*Stretch* of neck and facial muscles
Locust	*Salabhasana*	*Salab*, "locust" pose
Lotus	*Padmasana*	*Padma*, "lotus" sitting pose
Mountain	*Tadasana*	Standing, building block pose
Peacock	*Mayurasana*	*Mayura*, "peacock" balance pose
Perfect	*Siddhasana*	"Devine" or "adept" pose
Pigeon	*Eka Pada Rajakapotasana*	Stretch with bent leg under chest
Plough	*Halasana*	*Hala*, "plough" pose
Prayer	*Namaste*	Sitting pose, palms joined in front
Restrained angle	*Baddhakonasana*	Also called bound angle posture
Scorpion	*Vrischikasana*	Balance pose on forearms, legs up
Shoulderstand	*Sarvangasana*	*Sarva-anga*, "every part" or complete inversion
Side angle stretch	*Utthita Parsvakonasana*	*Utthita*, "stretch" in flank pose
Sitting	*Sukhasana*	Comfortable sitting pose; "easy" or "pleasant"
Sitting	*Samasana*	*Sama*, "wheel" pose
Spinal twist	*Ardha Matsyendrasana*	*Ardha*, "half" lateral twist
Spinal twist	*Marichyasana*	Intense twist in sitting pose
Staff	*Dandasana*	Sitting posture for forward bend
Sun salute	*Surya Namaskar*	Series of power stretch poses
Swinging	*Lolasana*	Combination of *Mayurasana* and *Padmasana*
Torso stretch	*Bharadvajasana*	Spinal rotation in cross-leg pose
Tree	*Vrksasana*	Standing, balance pose
Triangle	*Trikonasana*	*Trikona*, "triangle" pose
Up-bow	*Urdhva Dhanurasana*	Upward facing bow pose
Up-dog	*Urdhvamukha Svanasana*	Reverse dog stretch, face up
War-Lord	*Virabhadrasana*	Warrior, standing variations I, II, III
Warrior	*Virasana*	Also called Hero pose, sitting
Warrier, lying	*Supta Virasana*	Back lowered to floor
Wheel	*Chakrasana*	*Chakra*, "wheel" pose

Yoga *asanas* cover the basic positions of standing, sitting, forward bends, twists, inversions, backbends, and lying down. There are more than 840,000 poses, of which approximately 84 are important.

For more information and details on yoga asanas, see additional teaching tests (e.g., Iyengar BKS. Light on Yoga. New York, NY: Schocken Books, 1977 and Iyengar BKS. Yoga—The Path to Holistic Health. London, England: Dorling Kindersley Ltd., 2001) or Web sites (e.g., www.lifepositive.com/Body/yoga/yoga-asanas.asp).

you to search through the IndMed database like PubMed. More journals will be added to the list as their quality improves in coming years. IndMED will eventually cover the journals from 1985 to the present.

Similar search strategies were performed in IndMED to check for consistency with MEDLINE®, and in SCISEARCH to look exclusively for editorials or letters on yoga, as well as additional citations in the published literature by specific authors. On the basis of available information, a few studies were eliminated because abstracts were not presented or there was insufficient detail to determine any relevant variables. Full-text copies of the remaining papers were retrieved from journal Web sites, local academic libraries, or from the National Library of Medicine.

This review concentrated on studies published since 1990; however, earlier studies were not totally excluded if they were of historic or scientific value. For example, because of changes in journal editorial policies, studies with negative results were more likely to be published in the older literature. Negative studies often are difficult to find in the newer literature, but they are crucial, nonetheless, to any discussion on the topic. Studies were not eliminated because of the nature of their findings. Final studies selected for discussion, however, did have to exhibit at least most of the general attributes defined in Table 2.

RESULTS

Many of the studies considered for this discussion were published in international medical journals (e.g., *British Medical Journal, European Journal of Clinical Investigation, Journal of the American Medical Association, Journal of Hypertension, The Lancet, Preventive Cardiology*); the rest were published in the Indian medical literature which conforms to international standards (e.g., *Indian Journal of Physiology and Pharmacology, Indian Journal of Medical Research, Indian Heart Journal, Journal of the Association of Physicians of India*). The targeted readers were health professionals who generally practice conventional medicine, but also may be interested in complementary and alternative medicine. Unfortunately, only a few studies were published in the journals that target the latter (e.g., *Journal of Alternative and Complementary Medicine, Alternative Therapies in Health and Medicine*). The term conventional medicine refers to medicine as practiced by holders of M.D. (medical doctor) or D.O. (doctor of osteopathy) degrees, some of whom also may practice complementary and alternative medicine. Other terms for conventional medicine are allopathy, Western, regular, and mainstream medicine, and biomedicine (National Center for Complementary and Alternative Medicine, 2001).

Emphasis was placed on studies that evaluated musculoskeletal status, exercise perfor-

TABLE 2. GENERAL ATTRIBUTES OF STUDIES SELECTED FOR DISCUSSION

1. Focus	The work not only addresses the area of inquiry under consideration but also contributes to its understanding.
2. Verity	The work is either consistent with accepted knowledge and practice in the field or is well documented within the publication; the work fits within the context of the literature and is intellectually honest and authentic.
3. Integrity	The work is structurally sound and hangs together; the design or research rationale is logical and appropriate.
4. Rigor	The work is important, meaningful, and nontrivial relative to the field and exhibits sufficient depth of intellect rather than superficial or simplistic reasoning.
5. Utility	The work is useful and professionally relevant; it makes a contribution to the field in terms of the practitioner's understanding or decision-making on the topic.
6. Clarity	The writing is clear and the writing style is appropriate for the nature of the study.

mance, or cardiopulmonary function in response to the practice of yoga *asanas* and *pranayama.* The literature search identified 10 published studies on musculoskeletal status in subjects with back pain, carpal tunnel syndrome, or arthritis (rheumatoid or osteoarthritis), and an additional 20 studies on cardiopulmonary status (e.g., exercise capacity, cardiovascular endurance, aerobic/anaerobic power) in healthy subjects. The remaining studies selected for further evaluation reported the effects of yoga on cardiopulmonary function in subjects with asthma (11), chronic bronchitis (1), coronary artery disease (6), congestive heart failure (1) and hypertension (4), and the effects of yoga on chemoreflex responses to hypoxia (2). Studies (5) on glucose metabolism (e.g., diabetes, brain metabolism) and brain function (e.g., epilepsy, brain waves) were evaluated, but were eliminated from consideration in this review. Specific studies (14) on sympathetic neural activity and relationship to controlled-breathing techniques were evaluated and discussed in a separate manuscript (Raub, manuscript in preparation). Except where noted, results presented below were from studies that met most of the quality attributes presented in Table 2. No attempt was made, however, to combine results through a quantitative meta-analysis.

MUSCULOSKELETAL STATUS: EFFECTS OF HATHA YOGA ON OSTEOARTHRITIS OF THE HANDS AND SYMPTOMS OF CARPAL TUNNEL SYNDROME

Arthritis and other musculoskeletal disorders (e.g., spondylarthropathies, systemic lupus erythematosus, scleroderma, polymyalgia, fibromyalgia, and low-back pain) are the leading cause of disability among persons 65 years of age and older and a common cause of disability related to employment (Lawrence et al., 1998). Although most conditions are self-limited and respond to simple remedies, some patients have serious and complex problems for which timely intervention may be crucial for a successful outcome. In most cases, the nature of joint-associated pain, including the intensity, distribution, and point of origin of the pain, determines the course of subsequent treatment and follow-up. The following controlled studies investigated the use of Hatha Yoga as a treatment for musculoskeletal disorders of the hand and wrist.

Garfinkel et al. (1994) followed patients with osteoarthritis (OA) of the hands who were randomly assigned to receive either yoga techniques, supervised by the same instructor once per week for 8 weeks, or no therapy (control group). Variables assessed during the course of the study were pain and tenderness, strength, motion, joint circumference, and hand function. The yoga treated group improved significantly more than the control group in pain during activity, tenderness, and finger range of motion. Other improvement trends also favored the yoga techniques, thus providing relief in hand OA.

A similar yoga-based treatment regimen was assessed by Garfinkel et al. (1998) for relieving symptoms of carpal-tunnel syndrome. Forty-two (42) subjects, 24 to 77 years of age, were randomly assigned to receive treatment with yoga or treatment with a wrist splint to supplement their current treatment. The yoga intervention consisted of 11 yoga postures designed for strengthening, stretching, and balancing each joint in the upper body, along with relaxation, given twice weekly for 8 weeks. Changes in grip strength, pain intensity, sleep disturbance, Phalen maneuver and Tinel's sign, and in median nerve motor and sensory conduction time were followed from baseline. (Tinel's sign is the induction of an "electric-like" sensation in the hand and fingers by tapping over the site of the median nerve at the wrist. In Phalen's maneuver, these symptoms are reproduced by maximum flexion of the wrist for 60 seconds). The subjects receiving the yoga intervention had significant improvement in grip strength, Phalen sign, and pain reduction when compared to controls.

The yoga postures used by Garfinkel et al. (1994, 1998) for relieving symptoms of OA of the hands and carpal-tunnel syndrome consisted of the prayer position (*Namaste*, front and back), *Dandasana*, *Urdhva Hastasana*, *Parsvottanasana*, *Garudasana*, *Bharadvajasana*, *Tadasana*, half *Uttanasana*, *Virabhadrasana* (arms only), *Urdhvamukha Svanasana*, and *Savasana* (see Table 1 for details). They have been adapted for use by physical therapists to help improve the symptoms associated with recurrent, repetitive-motion. In a series of letters to the editor (Daniell et al., 1999; Sequeira, 1999) following publication of the latter article, the commentators noted some of the deficiencies of studies on carpal-tunnel syndrome. For example, they listed the small number of subjects per group, the questionable use of a splint as an adequate control intervention, the questionable clinical significance of "categorical data" (i.e., plus or minus for symptom presence), and the observation that simple improvement in standing and sitting posture may, by itself, relieve potential effects of repetitive motion. Despite these concerns, the commentators generally noted the interesting and promising nature of results from these studies and recommended the need for larger, multicenter studies utilizing more objective nerve conduction testing.

CARDIOPULMONARY STATUS: EFFECTS OF HATHA YOGA ON LUNG FUNCTION AND OVERALL CARDIOVASCULAR ENDURANCE IN HEALTHY ADULTS

Published studies have shown that the practice of Hatha Yoga improves baseline cardiopulmonary status in healthy, normal subjects. In the following series of studies, the investigators measured lung function by standardized spirometric techniques (American Thoracic Society, 1995) and compared yoga posture training in volunteers over time.

Early studies (Joshi et al., 1992; Makwana et al., 1988) reported improvement in some, but not all, measures of ventilation after breath control exercises alone. For example, Joshi et al. (1992) followed lung function in 75 males and females with an average age of 18.5 years during yoga breath-control exercises. After 6 weeks of practice, they reported significant increases in forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), peak expiratory flow rate (PEFR), maximum voluntary ventilation (MVV), as well as a significant decrease in breathing frequency (f_B), and prolongation of breath-holding time. Other studies reported similar improvement in lung function after practicing yoga postures alone or combined with other yoga techniques. Rai and Ram (1993) compared an active Hatha Yoga posture (*Virasana* or Warrior pose) to chair-sitting and to a resting, supine posture (*Savasana*) in 10 healthy men, 25 to 37 years of age. The active posture induced a hypermetabolic state, as indicated by increased minute ventilation, heart rate (HR), and oxygen consumption ($\dot{V}O_2$), compared to either the chair-sitting or resting posture. In a similar study, the same authors (Rai et al., 1994) compared an active sitting posture (*Siddhasana*) to chair-sitting and supine relaxation and found the same results, indicating that the yoga "activity" and not the body "posture" was important for cardiovascular "conditioning."

Telles et al. (2000) reported that a combination of yoga postures interspersed with relaxation improved measures of cardiopulmonary status in 40 male volunteers to a greater degree than relaxation alone. Cyclic meditation (stimulation plus calming), consisting of yoga postures and periods of supine relaxation, was better at decreasing $\dot{V}O_2$ and f_B, and increasing tidal volume than sessions of *Savasana* (calming) alone. Konar et al. (2000) reported that the practice of *Sarvangasana* (shoulder stand) twice daily for 2 weeks significantly reduced resting HR and left ventricular end-diastolic volume in 8 healthy male subjects. Birkel and Edgren (2000) reported that yoga postures, breath control, and relaxation techniques taught to 287 college students (89 men and 198 women) in two 50-minute class meetings for 15 weeks significantly improved FVC of the lungs measured by spirometry. In a similar study, 1 hour of yoga practice each day for 12 weeks significantly improved FVC, FEV_1, and PEFR in 60 healthy young women, 17 to 28 years of age (Yadav and Das, 2001).

Finally, a number of published studies (Bera and Rajapurkar, 1993; Pansare et al., 1989; Raju et al., 1986, 1994, 1997; Ray et al., 2001; Tran et al., 2001) have reported significant improvement in overall cardiovascular endurance of young subjects who were given varying periods of yoga training (months to years) and compared to a similar group who performed other types of exercise. In most cases, the physiological variables measured were oxygen consumption and other measures of endurance (e.g., work output, anaerobic threshold, blood lactate) during submaximal and maximal exercise tests. Maximum aerobic power, or maximum oxygen consumption ($\dot{V}O_2max$), is achieved when an individual's ability to deliver oxygen to exercising muscles reaches a plateau during step-wise progression to maximal exercise. Lactate starts to accumulate in active muscle when the oxygen supply is inadequate to support aerobic metabolism and passes into the bloodstream. Both are important determinants of endurance performance (Shephard and Åstrand, 2000).

The series of studies by Raju et al. (1986, 1994, 1997) evaluated work rates, $\dot{V}O_2$, and blood lactate levels in young adults (18 to 30 years of age) performing submaximal and maximal exercise tests on a motorized treadmill, using an acceptable exercise testing protocol (modified Balke). In the first study (Raju et al., 1986), an improvement in work rate and reduction in $\dot{V}O_2$ per unit work (i.e., a physical conditioning effect) was found for both the experimental group practicing yoga controlled-breathing techniques and in a comparable control group. However, after 2 years, the subjects who continued to practice controlled breathing achieved significantly higher work rates with reduced $\dot{V}O_2$ per unit work, and without increased blood lactate levels. The subjects in the first study were athletes; therefore, the second study (Raju et al., 1994) evaluated normal, healthy volunteers and found a similar physical conditioning effect after a shorter period of time (only 20 days). The second study was complicated, however, by adding yoga *asanas* to the yoga practices and conducting the study for only 3 months. Also, nonathletes have difficulty performing maximal exercise tests; therefore, performance evaluations were made at 80% of maximal. Similar enhancement in exercise performance was found only in males at the end of the study. A subsequent, case report (Raju et al., 1997) on six healthy female subjects found improved exercise performance after 4 weeks of intensive yoga training consisting of two 90-minute sessions per day (morning and evening).

Other studies have reported the benefits of yoga practice in untrained adolescent subjects (12 to 18 years of age). Bera and Rajapurkar (1993) reported that cardiovascular endurance was improved in male high school students who participated in a controlled yoga study for 1 year. Pansare et al. (1989) found that yoga training significantly increased serum lactate dehydrogenase (LDH) levels after only 6 weeks in 14 female and 6 male students. This glycolytic enzyme (LDH) provides energy to exercising muscle and normally increases about twofold after long-duration submaximal exercise, indicating that yoga can have an effect similar to endurance training.

Tran et al. (2001) reported that regular Hatha Yoga practice can improve overall physical fitness in untrained, young adult volunteers. Ten (10) healthy subjects, 18 to 27 years of age, were required to practice supervised sessions of pranayamas (10 minutes), warm-up exercises (15 minutes), and yoga postures (50 minutes) four times a week for 8 weeks. The yoga postures included spinal twists (e.g., *Vakrasana*), forward bends (e.g., *Pascimottanasana*), and standing and stretching poses (e.g., *Vrksasana*, *Virabhadrasana*, *Trikonasana*, *Eka Pada Rajakapotasana*). The health-related aspects of physical fitness, defined as isokinetic muscle strength and endurance, general flexibility, cardiopulmonary endurance, and body composition, as well as pulmonary function were evaluated before and after the 8 weeks of practice. Significant increases were found in all of the physical fitness variables except for body composition. There were no changes in pulmonary function. This study was well done and utilized direct measures of cardiopulmonary fitness; however, the sample size was small and predominantly female, the yoga training time was short, and the study lacked a control group.

Ray et al. (2001) studied 54 male and female trainees, 20 to 25 years of age, who were randomly divided into yoga ($n = 28$) and control ($n = 26$) groups during a longer, 10-month training period. For the first 5 months, the yoga group received intensive instruction in a combined yoga practice while the control group received no training at all. During the last 5 months, both groups performed the yoga practices. Various physiological and psychomotor measurements were made before training, after 5 months, and after 10 months. The authors noted significant improvements in submaximal exercise and in anaerobic threshold in the yoga group.

These studies are consistent in reporting significant improvement in most measures of cardiopulmonary status (e.g., exercise performance) in young, healthy subjects. Improvements in lung function, however, were not consistent and were subject to the length of yoga training, the type of yoga practice used (e.g., breathing exercises and yoga postures), and the type of subject followed over time (e.g., untrained versus elite athlete). The longer the period of yoga practice, the stronger the benefit in overall cardiopulmonary endurance.

OBSTRUCTIVE AIRWAY DISEASE: EFFECTS OF HATHA YOGA ON THE CLINICAL OUTCOME OF PATIENTS WITH DISEASES SUCH AS CHRONIC BRONCHITIS AND ASTHMA

The following series of studies on chronic bronchitis and asthma examined the effects of improved lung function and breathing training by Hatha Yoga on the clinical status of patients with these obstructive airway diseases.

Chronic bronchitis

Patients (n = 15) receiving yoga therapy, consisting of breath control and 8 types of *asanas* for a period of 4 weeks, were reported by Behera (1998) to show improvement in shortness of breath and improvement in some lung function parameters. The patients, ranging in age from 48 to 75 years (58.9 ± 11.1 years), had baseline assessment of their history of chronic bronchitis, including spirometry, medication strategy, and exercise tolerance. They were instructed in yoga techniques (e.g., *Vajrasana*, *Simhasana*, *Sarvangasana*, *Chakrasana*, *Matsyasana*), and in breathing techniques, for 1 week and were encouraged to practice daily with follow-up yoga sessions each subsequent week. All patients continued to take medication during the course of the study. Clinical status and pulmonary function were reevaluated after the second and fourth week of yoga exercises. By the second week, there were significant improvements in FEV_1 and PEFR. By the fourth week, there were significant improvements in VC and PEFR, and a patient-reported, perceptual decrease in shortness of breath. No changes were noted in the amount of medication taken. This was only a preliminary study, however, and few subjects were evaluated over a relatively short period of time. Unfortunately, no other studies examining the possible benefits of yoga have been published on chronic obstructive lung disease and it is difficult to draw any conclusions on the basis of only one published study in this patient population.

Asthma

The use of an integrated approach of yoga therapy has been shown previously in controlled clinical studies to be beneficial in the clinical management of asthma. A 65-minute daily practice of yoga for 2 weeks improved PEFR, medication use, and asthma attack frequency in 53 patients when compared to an age-, gender-, and clinically matched control group (Nagarathna and Nagendra, 1985). The daily routine consisted of *asanas* (yoga exercises and postures for 25 minutes), breath control (slow, deep breathing for 10 minutes), meditation (slow mental chanting for 15 minutes), and a devotional session. In a long-term, follow-up (3 to 54 months) prospective study (Nagendra and Nagarathna, 1986), 570 patients with asthma showed overall significant improvement in PEFR after a similar training program consisting of *asanas*, breath control, and meditation. The greatest improvement was found in patients with the highest frequency and intensity of yoga practice: approximately 70% of them were able to reduce asthma medication.

The effects of two *pranayama* yoga breathing exercises on lung function, airway reactivity, respiratory symptoms, and medication use were assessed in 18 patients with mild asthma in a randomized, double-blind, placebo-controlled, crossover trial (Singh et al., 1990). This study is unique to the health effects literature on possible benefits of yoga techniques because it is often difficult to perform a double-blind study. In this study, the subjects were taught *pranayama* breathing by using a breathing device called the Pink City lung (PCL; Pulmotech, Jaipur, India) exerciser that could be used with a matched placebo breathing device. The PCL device imposes slow breathing and a 1:2 inspiration-to-expiration ratio through the use of selected breathing apertures and a one-way valve; the placebo device had the same appearance, but with a concealed, unvalved aperture that did not impose restrictions on breathing. After a baseline assessment period, the subjects practiced slow deep breathing for 15 minutes, two times a day for two consecutive 2-week periods, randomly alternating the breathing devices for each practice period. Measured lung function variables (FEV_1, FVC, PEFR), symptom scores, and medication use improved with the PCL device, but the changes were small and not statistically significant. There was a statistically significant increase in the dose of histamine required to produce a 20% decrease in FEV_1, a provocative airway test commonly used to assess lung responsiveness to nonspecific bronchoconstrictors. The findings indicate that *pranyama*-like breathing may lead to an overall clinical improvement in mild asthma. In a subsequent letter to the editor, Stanescu (1990) commented on possible autonomic mechanisms suggested by Singh et al. (1990) that might lead to reduced airway responsiveness. Studies previously conducted by Stanescu et al. (1981) on healthy subjects showed that controlled yoga breathing techniques (i.e., slow, near VC maneuvers accompanied by apnea at end inspiration and end expiration) were effective in significantly lowering their ventilatory responsiveness to increased carbon dioxide. The potential effect of yoga breathing on autonomic cardiopulmonary control mechanisms is discussed further in Raub (manuscript in preparation).

The abililty to perform normal day-to-day exercise is an important issue for patients with asthma, but the outcome is more subjective in nature and difficult to evaluate quantitatively. Two early studies (Behera and Jindal, 1990; Jain and Talukdar, 1993) reported on these quality of life benefits provided by the effects of various yoga exercises. Behera and Jindal (1990) assessed the benefits of daily yoga exercises, consisting primarily of breath control and postures, over a 6- to 8-week period in 41 patients with documented asthma. Although the authors reported an overall subjective improvement in asthma symptoms, objective lung function measurements showed improvement in some, but not all of the patients, and some patients even showed a decline in function. Jain and Talukdar (1993) reported a similar overall effect of yoga therapy on exercise capacity in 46 patients with asthma. The patients improved in a 12-minute walking test, a modified Harvard step test, and a more subjective index of exercise tolerance. However, it was not clear if the improvements were due, in part, to a placebo response. For a discussion of the placebo effect in complex intervention comparison trials, see Walach (2001).

In the more recent literature (after 1995), breath-control and relaxation techniques in both children and adults with asthma have been reported to improve some, but not all, measures of lung function (e.g., PEFR, MVV, FEV_1, and FVC), decrease usage of medication, and increase exercise tolerance (Blanc-Gras et al., 1996; Khanam et al., 1996; Manocha et al., 2002; Sathyaprabha et al., 2001; Vedanthan et al., 1998). Large variability in the subject population, questionable compliance in the yoga treatment groups, and potentially adverse outcomes in some subjects further complicates interpretation of the effects specific to a particular relaxation technique (Ritz, 2001). More work is needed, therefore, to better understand the mechanisms of response to yoga intervention and to determine if it would be clinically valuable for patients with asthma.

CARDIOVASCULAR DISEASE: EFFECTS OF HATHA YOGA AS PART OF A PROGRAM OF LIFESTYLE CHANGES ON THE CLINICAL OUTCOME OF PATIENTS WITH HEART DISEASE

Cardiovascular disease (CVD) is the leading cause of death in the United States (American Heart Association, 2000; U.S. Centers for Disease Control and Prevention, 1997) and in many of the developed countries. Yoga has a potential benefit to patients with CVD, but the published literature is somewhat limited. Existing studies conducted outside the United States (Mahajan et al., 1999; Manchanda et al., 2000; Schmidt et al., 1997) suggest that changing to a yoga lifestyle can significantly reduce many of the risk factors for CVD, including increased body weight, altered blood lipid profile, and elevated blood pressure (BP). Significant lipid risk factors for CVD are increased levels of serum cholesterol and triglycerides, increased low-density lipoprotein (LDL) cholesterol, decreased high-density lipoprotein (HDL) cholesterol, and increased concentration of apoB-carrying lipoproteins.

Schmidt et al. (1997) reported that a 3-month residential training program of yoga, meditation, and vegetarian nutrition decreased body mass, total serum and LDL cholesterol, fibrinogen, and BP. Mahajan et al. (1999) reported a similar reduction in risk factors for patients with coronary artery disease (CAD). In this study, patients with documented angina (chest pain) and subjects with risk factors for CAD were randomly assigned to a yoga intervention group ($n = 52$) or a control group ($n = 41$). Both groups received lifestyle advice and the intervention group received additional yoga training. Serial evaluations at 4, 10, and 14 weeks showed a regular decrease in all lipid parameters, except for HDL, only in the patients with angina receiving yoga intervention.

The most impressive of these studies was a 1-year prospective, randomized, controlled trial of 42 men with angiographically documented CAD (Manchanda et al., 2000). A subgroup ($n = 21$) treated with an active program of risk factor and diet control along with yoga and moderate aerobic exercise showed significant reduction in angina, improved exercise capacity, and greater reductions in body weight, total cholesterol, LDL cholesterol, and triglyceride than the control group ($n = 21$) treated conventionally with risk factor control and the American Heart Association (AHA) Step I diet. Revascularization procedures also were less frequent in the yoga group and coronary angiography repeated at 1 year showed a significant regression of atherosclerotic lesions.

The lack of sufficient numbers of randomized, controlled, mind–body treatment studies of CVD, especially in comparison to the conventional practice of Western medicine, has made it difficult to assess the direct benefits of an integrated yoga practice on patients with CAD. A review of the literature on complementary and alternative treatments was conducted at Stanford University by Luskin et al. (1998). They reported that existing studies from the United States on mind–body therapies in elderly patients with cardiovascular disorders, including CAD, showed clinical efficacy, primarily as complementary treatment. More recent research in the United States has focused on total lifestyle changes. The Lifestyle Heart Trial (Ornish et al., 1998) demonstrated that intensive lifestyle changes could lead to regression of CAD after only 1 year of a 5-year program. Forty-eight (48) patients with moderate-to-severe CAD were randomized to an intensive lifestyle change group or to a usual-care group. The lifestyle changes consisted of a 10% fat whole–food vegetarian diet, aerobic exercise, stress management training (yoga and meditation), smoking cessation, and group psychologic support. Clinical status was followed by quantitative coronary angiography and frequency of cardiac events. Of the 35 patients completing the 5-year follow-up, 20 in the experimental group showed a 4.5% relative improvement in cardiovascular status after 1 year and a 7.9% relative improvement after 5 years. The control group had a relative worsening of cardiovascular status after 1 and 5 years (5.4% and 27.7%, respectively), and more than twice as many cardiac events. Intensive lifestyle changes, therefore, can cause a regression of CAD.

HYPERTENSION: EFFECTS OF HATHA YOGA ON THE CONTROL OF HIGH BLOOD PRESSURE

High BP is another major health problem in the United States and throughout other developed countries because of its high prevalence and its association with increased risk for cardiovascular diseases. Similar to the trials in patients with CAD, interventions including lifestyle modification and pharmacologic treatment, have been shown in clinical trials to produce major reductions in BP. Long-term benefits of BP control also have been demonstrated in the general population. For example, in the famous Framingham Heart Study (Kannel, 2000; Lloyd-Jones et al., 2000), increases in the rate of use of antihypertensive medications were associated with reductions in the prevalence of hypertension (defined as BP > 160/100 mm Hg). These findings suggest that the increasing use of antihypertensive medication may in part explain the major decline in mortality from CVD observed in the United States since the late 1960s. The goal of antihypertensive treatment is prevention of the major cardiovascular complications of high BP (e.g., CAD, stroke, congestive heart failure). Likewise, lifestyle changes, including proper exercise and relaxation, may help alone or in conjunction with pharmaceutical drugs.

Early studies on yoga intervention for hypertension investigated the value of total body relaxation postures, primarily *Savasana* (Chaudhary et al., 1988; Mogra and Singh, 1986). The authors reported reductions in BP that were similar to control by drug therapy or biofeedback; however, small numbers of subjects were utilized in the studies and there were no intervention control groups. The following, more recent studies were better controlled and conducted with sufficient numbers of subjects.

Yoga exercises twice a day for 11 weeks were found to be as effective as standard medical treatment in controlling measured variables of hypertension (Murugesan et al., 2000). In a randomized study, 33 patients with documented hypertension, 35 to 65 years of age, were assigned into three groups receiving yoga therapy, physician-provided medication, and no treatment (control group). Systolic and diastolic blood pressure, pulse rate, and body weight were recorded over the course of the study. Preanalysis/postanalysis revealed that both the treatment groups (i.e., yoga and drug) were effective in controlling hypertension.

Twenty (20) male patients with essential hypertension (EH) were treated for 3 weeks with postural tilt stimulus (tilt table) or with postural yoga *asanas* to restore normal baroreflex sensitivity (Selvamurthy et al., 1998). Progressive autonomic changes were assessed by cardiovascular responses to head-up tilt and cold pressor stimulus, electroencephalographic indices, blood catecholamines, and plasma renin activity. There was a significant reduction in blood pressure after 3 weeks in both treatment groups, indicating a gradual improvement in baroreflex sensitivity.

A similar improvement in baroreflex sensitivity, and significant reductions in systolic and diastolic blood pressure, were seen in 81 patients (58 ± 1 years of age) with stable chronic heart failure (CHF) who practiced slow and deep breathing (Bernardi et al., 2002). The same authors (Bernardi et al., 1998) previously reported that a slow rate of breathing in patients with CHF increases resting oxygen saturation, improves ventilation/perfusion mismatching, and improves exercise tolerance. These changes were obtained by simply modifying the breathing pattern, from a resting, spontaneous ventilation of approximately 15 breaths per minute to 6 breaths per minute, which seems to cause a relative increase in vagal activity and a decrease in sympathetic activity. The effects on baroreflex sensitivity were similar to those obtained with captopril treatment in patients with CHF (Osterziel et al., 1988). Captopril belongs to a group of drugs called angiotensin-converting enzyme (ACE) inhibitors that help to lower blood pressure and make the heart beat stronger. This medication is used to treat hypertension (high blood pressure) and heart failure.

CHEMOREFLEX RESPONSE TO HYPOXIA: EFFECTS OF HATHA YOGA CONTROLLED BREATHING ON TOLERANCE TO REDUCED OXYGENATION OF THE BLOOD

The slow breathing techniques associated with yoga postures have been shown to substantially reduce chemoreflex sensitivity to hypoxia (reduced oxygen delivery to tissues), especially after long-term practice (Röggla et al., 2001; Spicuzza et al., 2000; Stanescu et al., 1981). Increased sensitivity to hypoxia is thought to be responsible for the breathing difficulty (e.g., shortness of breath) experienced by patients with CHF or by healthy, high-altitude climbers. Breath control, as noted above, may be a useful technique for some people with chronic breathing problems to help improve exercise performance.

Chemoreflex sensitivity was evaluated in 10 healthy yoga trainees and compared to 12 healthy controls who had never practiced yoga (Spicuzza et al., 2000). A similar study was performed previously by Stanescu et al. (1981) using 8 subjects who were well advanced in the practice of Hatha Yoga (4 to 12 years) and compared to height-, age-, and gender-matched controls. The only difference between groups was that yoga subjects routinely practiced complete yoga breathing. Complete yoga breathing involves slow inhalation and exhalation accompanied by apnea (breath-hold) at end inspiration and end expiration. The goals are to decrease the breathing rate from a normal resting level of 12 breaths per minute to approximately 6 breaths per minute, achieve an approximate 1:2 ratio for the duration of inspiration and expiration, and achieve an end-inspiratory breath-hold of approximately two times the length of expiration. These breath maneuvers mobilize in sequence the abdominal muscles, diaphragm, the lower and upper intercostal muscles of the chest wall, and the sternocleidomastoid muscles from the sternum and collarbones to the neck. The back muscles also are activated (Gudmestad, 2002). All subjects randomly performed hypoxic-normocapnic and hypercapnic-normoxic rebreathing tests while spontaneously breathing or breathing at fixed frequencies of 6 and 12 breaths per minute. Rebreathing tests quantify the effect of normal (normoxic, normocapnic) inspired levels of oxygen (O_2) and carbon dioxide (CO_2), respectively, combined with either decreased O_2 (hypoxic) or increased CO_2 (hypercapnic) levels on peripheral and central chemoreceptors as a measure of the chemoreflex drive to breath (i.e., respiratory chemosensitivity to O_2 and CO_2). Ventilation variables were measured, along with end-tidal CO_2, BP, oxygen saturation, and heart rate. During spontaneous breathing, ventilatory responses to hypoxia and hypercapnia were substantially lower in yoga subjects compared to controls. The yoga subjects had lower respiration rates, lower minute ventilation, and higher end-tidal CO_2 before rebreathing, and minimal changes were measured when the subjects engaged in the rebreathing tests. A possible explanation provided by the authors was adaptation of chemoreceptors to chronic CO_2 retention resulting from the breath-control training of yoga. A subsequent letter to the editor (Röggla et al., 2001) challenged the explanation on the basis of high altitude (2600 m) studies with similar subjects, but significant differences in data interpretation were pointed out in a response by the authors of the study (Bernardi et al., 2001). The authors also noted that endurance training in athletes may produce a similar reduction in hypoxic ventilatory response.

DISCUSSION

Yoga is an ancient discipline of body, mind, and spirit that has been Westernized and practiced for its health benefits, similar to alternative medicinal (herbal) treatments, as a complement to more conventional medical therapy. Hatha Yoga, through holding static physical postures (*asanas*), uses stretching and improves muscular strength and flexibility (Tran et al., 2001) so that it would likely be beneficial for some musculoskeletal problems (Garfinkel and Schumacher, 2000; Luskin et al., 2000). In fact, two limited studies of yoga in osteoarthritis of the hand (Garfinkel et al., 1994) and carpal tunnel syndrome (Garfinkel et al., 1998) show greater improvement in pain than in control groups. In combination with breath control, which adds additional neuromuscular effects, Hatha Yoga has provided some limited benefit in other musculoskeletal-related pain management, especially back pain (Hudson, 1998; Nespor, 1989, 1991) and in the management of multiple sclerosis (Winterholler et al., 1997). These recent findings should not be surprising because yoga postures have been utilized in most athletic programs throughout Western societies for many years to both prevent and treat musculoskeletal injuries. Interestingly, anecdotal reports from non-Western societies (Tetley, 2000), where yoga posturing has been used instinctively by native populations for sitting and sleeping, find relatively few musculoskeletal problems (e.g., lower back pain and joint stiffness).

Through body- and breath-control, including relaxation techniques, Hatha Yoga clearly has additional benefits for cardiopulmonary endurance in healthy people (Birkel and Edgren, 2000; Konar et al., 2000; Ray et al., 2001; Telles et al., 2000; Tran et al., 2001; Yadav and Das, 2001), and possible benefits in some patients with cardiopulmonary disease (Behera, 1998; Blanc-Gras et al., 1996; Khanam et al., 1996; Manocha et al., 2002; Sathyaprabha et al., 2001; Vedanthan et al., 1998), and in patients with cardiovascular disease (Luskin et al., 1998; Mahajan et al., 1999; Manchanda et al., 2000; Murugesan et al., 2000; Ornish et al., 1998; Pandya et al., 1999; Schmidt et al., 1997). These benefits manifest clinically as improved lung capacity, increased oxygen delivery, decreased $\dot{V}O_2$ and respiration rate, and decreased resting heart rate, resulting in overall improved exercise capacity. Several physiological factors are involved.

The intense stretching and muscle conditioning associated with attaining and holding yoga postures increases skeletal muscle oxidative capacity and decreases glycogen utilization, possibly caused by increased vascularization, increased intramuscular oxygen and glycogen stores, increased oxidative enzymes, or by increased numbers of mitochondria (Shephard and Åstrand, 2000). In addition, passive muscle stretch in animal models for as little as 30 minutes per day has been associated with increased muscle growth and contractile strength (Frankeny et al., 1983; Holly et al., 1980).

The slow increase in lung capacity (e.g., FEV_1, FVC) associated with well-practiced yoga breathing recruits normally unventilated lung and helps to match ventilation to perfusion better, thereby increasing oxygen delivery to highly metabolic tissues (e.g., muscle). Intermittent deep lung inflations or sighs previously have been suggested as a possible method for lung volume recruitment, especially in patients with acute respiratory distress syndrome (Pelosi et al., 1999). Similar improvement in oxygenation also has been shown with variable tidal volume ventilation in animal models of acute lung injury (Arold et al., 2002).

The slow breathing rates associated with yoga breathing have been shown to substantially reduce chemoreflex response to hypoxia (Röggla et al., 2001; Spicuzza et al, 2000; Stanescu et al., 1981), probably through the improved oxygen delivery to tissues and possibly the result of acquired "tolerance" to hypoxia (e.g., increased CO_2) that is produced by a change in the chemoreflex threshold (Mahamed and Duffin, 2001). Yoga breathing while performing postures, especially relaxation postures (e.g., *Savasana*), also has been shown (Bera et al., 1998; Murugesan et al., 2000) to significantly reverse the physiologic effects of stress (i.e., increased HR, f_B, and BP). Some of these physiological benefits are possibly self-controlled (i.e., psychologic); however, there are data in healthy subjects (Bernardi et al., 2001, 2002; Bowman et al., 1997; Khanam et al., 1996: Raghuraj et al., 1998; Selvamurthy et al., 1998) showing that yoga breathing techniques have effects on the autonomic nervous system as well (Raub et al., in preparation).

It is likely that the yoga practices of controlling body, mind, and spirit combine to provide useful psychophysiological effects for healthy people and for people compromised by musculoskeletal and cardiopulmonary disease. No effects of yoga practices, on the other hand, have been shown convincingly for diseases such as chronic tinnitus (Kroner-Herwig et al., 1995) or epilepsy (Ramaratnam, 2001; Ramaratnam and Sridharan, 2000; Yardi, 2001) that do not have neuromuscular or neurovascular involvement. Further studies, therefore, are needed to confirm the cellular and psychophysiological effects of Hatha Yoga.

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