



Therapeutic Role of Yoga in Type 2 Diabetes

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Yoga originated in India more than 5,000 years ago and is a means of balancing and harmonizing the body, mind, and emotions. Yoga practice is useful in the management of various lifestyle diseases, including type 2 diabetes. Psycho-neuro-endocrine and immune mechanisms are involved in the beneficial effects of yoga on diabetes. Incorporation of yoga practice in daily life helps to attain glycaemic control and reduces the risk of complications in people with diabetes. In this review, we briefly describe the role of various yoga practices in the management of diabetes based on evidence from various clinical studies.

Keywords: Yoga; Diabetes mellitus; Yoga asana; Pranayama; Meditation

INTRODUCTION

Type 2 diabetes is a common lifestyle disorder caused by insulin resistance with relative or absolute insulin deficiency, resulting in chronic hyperglycaemia and various cardiovascular complications. Globally, according to the International Diabetes Federation diabetes atlas (eighth edition, 2017), in 2017 there were roughly 425 million people with diabetes, a figure that is projected to increase to 629 million by 2045 [1]. Sedentary habits and unhealthy dietary patterns are the major risk factors for the development of various lifestyle disorders, including diabetes. Psychological stress also increases the risk and severity of diabetes. Lack of physical activity was found to increase the risk of diabetes by 3 times and the risk of coronary artery disease by 2.4 times [2].

Dietary control and exercise are established treatment modalities in patients with type 2 diabetes and other lifestyle disorders, including obesity, hypertension, and dyslipidaemia. Urbanisation, the intake of calorie-rich food, use of various machines,

less open space for exercise, a busy modern lifestyle, and lack of motivation reduce the likelihood of adherence to dietary control and exercise as a management option in people with diabetes. Moreover, individuals with diabetes have a reduced capacity to engage in exercise because of overweight, physical unfitness, sedentary lifestyle, limited joint mobility, and other diabetes-related complications, including cardiovascular disease, peripheral neuropathy, and diabetic foot problems. Several studies have shown that poor adherence to diet and exercise programs were major limitations in the implementation of non-pharmacological treatments of diabetes.

Yoga, which originated in India more than 5,000 years ago, aims at balancing and harmonizing the body, mind, and emotions [3]. Increasing evidence suggests that yoga practice tackles the pathophysiologic mechanisms of diabetes and helps in controlling diabetes and its complications. In this short review, we briefly describe the role of various yoga practices in the management of diabetes based on evidence from various clinical studies.

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YOGA IN TYPE 2 DIABETES

Although yoga has been practised since ancient times, yoga as therapy is still a relatively new and emerging trend in the health-care field. Extensive research has explored changes in biochemical, electrophysiological, cellular, genetic, neuromuscular, and radiological parameters related to yoga practice. This has facilitated the practical application of yoga in various diseases, and it is now being recognized worldwide as a clinically viable treatment. Traditionally a mind-body practice with the ultimate goal of spiritual enlightenment, yoga is a science of health management, rather than a therapy for treating specific diseases [4].

Dietary management of diabetes with yoga

Yoga is also known to regulate eating patterns, and its potential utility in the management of eating disorders has been advocated. It is believed that the mind-body connection that stems from yoga practice provides opportunities for self-awareness, reflection, and change [5]. Yoga, *pranayama*, and *sudarshan kriya* were found to be beneficial in improving dietary practices and medication adherence.

Yoga practice and mindful eating

Yoga participation has been correlated with both fruit and vegetable intake, as well as improved eating habits and mindful eating practices [5]. Meditation and ability to heighten mindfulness may be beneficial in controlling binge-eating patterns. Mindful eating in diabetes has shown to facilitate improvements in dietary intake, modest weight loss, and glycaemic control [6].

Recommended practice based on evidence in diabetes

Yoga practice is a complex intervention with various components, including cleansing processes (*kriya*), postures (*asana*), controlled breathing (*pranayama*), meditation, relaxation, chanting mantras, yogic diet, code of conduct, philosophy, and spirituality.

Many yoga practices have been found to be beneficial in the management of type 2 diabetes; however, their judicious use is recommended after a careful assessment of a patient's overall health, individual requirements, associated risk factors, and contraindications (Table 1). By considering the person as a whole, including physical inactivity and poor health behaviours, yoga practices of high or low intensity may be prescribed [5].

Since most studies have evaluated the effects of yoga practices such as postures, *pranayama*, relaxation, and meditation, the effects of individual yoga postures or other practices are diffi-

cult to interpret. Below, information is presented regarding a subset of yoga practices that are known to have beneficial effects on type 2 diabetes, along with their possible mechanisms of action (Table 2).

Cleansing processes

The classical ancient texts *Hatha Yoga Pradipika* and *Gheranda Samhita* describe purification/cleansing practices known as *shatkarmas*. Of these, the practices of *vaman dhauti* (stomach cleansing with induced vomiting), *kapalbhati* (frontal brain purification, which is a breathing technique with forceful exhalations and automatic inhalations), and *shankhaprakshalana* (intestinal cleansing) help to increase the production of insulin and to control blood glucose levels. Regular internal cleansing enhances the functional capacity of the organs.

A study showed that *vaman dhauti* practice (emetic therapy) caused a marked reduction in fasting and postprandial blood sugar levels [7-9]. It is believed to increase glucose uptake, minimize insulin resistance, and promote the function of insulin by reducing levels of circulating free fatty acids in the body. The abdominal pressure created during exhalation in *kapalbhati* improves the efficiency of β -cells of the pancreas. *Shankhaprakshalana* is the process of cleansing the intestinal tract by practicing a set of yoga postures and drinking lukewarm water with salt in between. This sequence is repeated till only water is evacuated. The level of blood glucose falls significantly with this intestinal cleansing process. It has been claimed that this practice increases insulin production and helps in the control of diabetes [8]. *Agnisar kriya* (stimulation of the digestive fire) involves pulling the abdomen in (*uddiyan bandha*) and snapping it backwards and forwards while holding the breath. The 'vacuum' effect of this action massages the internal organs and increase blood flow to the area. It boosts metabolism and facilitates the proper functioning of the abdominal organs [9]. This practice is recommended for the management of diabetes [8].

Surya namaskar (sun salutation)

Surya namaskar involves a series of dynamic yoga postures performed in a specific sequence. A brisk *surya namaskar* performed in an energetic way increases cellular requirements for oxygen and glucose. To meet these requirements, insulin production is stimulated through brain signalling [8].

In a study, a yoga intervention consisting of 25 minutes of *surya namaskar* along with other yoga postures and a deep relaxation technique in perimenopausal women resulted in a significant decrease in diastolic blood pressure and hip circumfer-

Table 1. Some Yoga Practices Beneficial for the Management of Type 2 Diabetes Mellitus

Yoga technique	Approximate duration and remarks
Cleansing practices: <i>shuddhi kriya</i>	
<i>Kapalbhati</i> (frontal brain purification)	5 rounds, 120 strokes
<i>Agnisar kriya</i> (stimulating the digestive fire)	5 rounds
<i>Vaman dhauti</i> (stomach cleansing)	Once a week
Full <i>shankhprakashalana</i> (intestine cleansing)	Once a year
<i>Laghu shankhprakashalana</i> (short cleansing)	Every 40 days
Preparatory practices/warming up	5–10 minutes
<i>Surya namaskar</i>	Slow speed, 3–7 rounds according to an individual's capacity
Yoga postures: <i>asanas</i>	
Standing postures	
<i>Trikonasan</i> (triangle pose)	Recommended to hold the final pose for 15 seconds, gradually increasing the duration up to 1 minute
<i>Tadasan</i> (palm tree pose)	
<i>Tiryak tadasan</i> (bent palm tree pose)	
<i>Veerasan</i> (warrior pose)	
Seated poses	
<i>Vakrasan</i> (spinal twist)	Recommended to hold the final pose for 15 seconds, gradually increasing the duration up to 1 minute
<i>Ardhamatsyendrasan</i> (seated spinal twist)	
<i>Mandukasana</i> (frog pose)	
<i>Ushtrasan</i> (camel pose)	
<i>Paschimottanasan</i> (seated forward bend)	
<i>Yoga mudra</i> (forward bend)	
Prone poses	
<i>Bhujangasan</i> (cobra pose)	Recommended to hold the final pose for 15 seconds, gradually increasing the duration up to 1 minute
<i>Dhanurasan</i> (bow pose)	
<i>Naukasana</i> (boat pose)	Relaxation pose: 2–5 minutes as needed
<i>Makarasana</i> (crocodile pose)	
Supine poses	
<i>Pavanmuktasan</i> (wind releasing pose)	Recommended to hold the final pose for 15 seconds, gradually increasing the duration up to 1 minute
<i>Supta vajrasana</i> (supine thunderbolt pose)	
<i>Setubandhasana</i> (bridge pose)	
<i>Matsyasana</i> (fish pose)	Relaxation pose: 2–5 minutes as needed
<i>Shavasana</i> (corpse pose)	
Inversions	
<i>Sarvangasan</i> (shoulder stand)	Hold the final pose for 15 seconds, gradually increasing the duration up to 1 minute
<i>Halasan</i> (plough pose)	
Regulated breathing practices: <i>pranayama</i>	
<i>Anulom vilom</i> (alternate nostril breathing)	5–10 minutes
<i>Chandra bhedan</i> (left nostril breathing)	5 minutes
<i>Surya bhedan</i> (right nostril breathing)	5 minutes
<i>Bhastrika</i> (bellows breath)	3–5 minutes
<i>Bhramari</i> (humming bee breath)	5 rounds
<i>Sheetali/Sitkari</i> (cooling breath)	3–5 minutes
Lock: <i>bandha</i>	
<i>Uddiyan bandha</i> (abdominal lock)	5 rounds
Hand gestures: <i>mudras</i>	
<i>Linga mudra, surya mudra, prana mudra, apan mudra, gyan mudra</i>	15–45 minutes
Meditation	
Meditation on <i>manipur chakra</i> (solar plexus)	10 minutes
“Aum” chanting	5 minutes
Yogic relaxation: <i>yoga nidra</i>	30 minutes

Table 2. Some of the Beneficial Effects of Yoga Practices on Type 2 Diabetes Mellitus

Yoga practice	Effects
<i>Surya namaskar</i> sun salutation A series of dynamic yoga postures in a specific sequence	Stimulates insulin production through brain signalling [8] Significantly decreases hip circumference, exerting beneficial effects on glycaemic outcomes [10]
<i>Yoga asana</i> (yoga postures)	Rejuvenates of pancreatic cells through the alternating abdominal contractions and relaxations involved in yoga practice Improves blood supply to muscles Enhances insulin receptor expression in the muscles, causing increased glucose uptake by muscles [2] Has positive effects on glucose utilization and fat redistribution in type 2 diabetes [11]
Forward bend Backward bend Twisted poses Inversions	Massages and pressurizes the pancreas, stimulating insulin secretion Exerts stimulating and energizing effects Squeeze the intestines to prevent stagnation of colonic contents Improve blood circulation
<i>Shuddhi kriya</i> cleansing processes	
<i>Kapalbhati</i> (frontal brain purification): breathing technique with forceful exhalations and automatic inhalations	Abdominal pressure created during exhalation improves the efficiency of β -cells of the pancreas Helps in the production of insulin and controlling glucose levels in the blood
<i>Agnisar kriya</i> (stimulating the digestive fire): pulling the abdomen in (<i>uddiyan bandha</i>) and snapping it backwards and forwards while holding one's breath	The 'vacuum' effect of this action massages the internal organs and increase blood flow to the area Boosts metabolism and facilitates proper functioning of the abdominal organs [11]
<i>Vaman dhauti</i> (stomach cleansing with induced vomiting)	Increases glucose uptake, minimizes insulin resistance, and promotes the function of insulin by reducing levels of circulating free fatty acids in the body Marked reduction in fasting and post-prandial blood sugar levels
<i>Shankhprakashalana</i> (intestine cleansing)	Significantly reduces blood glucose levels Increases insulin production [8]
<i>Pranayama</i> (regulated breathing)	
Slow <i>pranayama</i> , <i>anulom vilom</i> , <i>chandrabhedan</i> , <i>sitkari</i> , and <i>bhramari</i>	Augment cerebral blood flow and oxygenation, improving neuronal activities in the brain centres, including those present in the limbic areas, hypothalamus, and medulla, and improve sympathovagal outflow [15]
<i>Anulom vilom</i> (alternate nostril breathing)	Improves components of health-related fitness, i.e., cardiorespiratory endurance, flexibility, and body fat percentage [16]
<i>Bhramari</i> (humming bee breath)	Soothing and calming effect on the mind, improves mental and physical health [17]
<i>Sheetali/Sitkari</i> (cooling breath)	Lowers blood pressure, cooling effect
<i>Chandra bhedan</i> (left nostril breathing)	Parasympathetic stimulation
<i>Surya bhedan</i> (right nostril breathing)	Sympathetic stimulating effect; may be recommended in people with diabetes [18]
<i>Bhastrika</i> (bellows breath)	Regulation of pineal, pituitary, and adrenaline glands, important role in the regulation of metabolism [19]
<i>Bandha</i> (lock)	
Constricts a certain part of the body	Re-directs the flow of blood and lymph to other body parts
<i>Uddiyan bandha</i> (abdominal lock): creation of negative pressure in abdomen and contraction of abdomen	Negative pressure created in the abdominal cavity may improve pancreatic function
<i>Hasta mudras</i> (hand gestures)	
<i>Apan mudra</i> , <i>gyan mudra</i> <i>Linga mudra</i> , <i>surya mudra</i> , <i>prana mudra</i>	Promote deep relaxation and eliminate stress Boost metabolic rates, promote weight loss, and reduce sugar levels
<i>Dhyan</i> (meditation)	Beneficial psychological effects, such as faster reactions to stimuli and being less prone to various forms of stress [24], anxiety reduction, and blood pressure control [25]
Meditation on the <i>manipur chakra</i> (solar plexus), visualization of pancreas during meditation	Positive effects on sugar levels
Mindfulness	Better sleep, greater relaxation, more accepting approaches to illness and the illness experience in people with diabetes and coronary heart disease [26]
"Aum" chanting	Stabilizes the brain, removes negative thoughts, increases energy, improves mind and body relaxation within minutes of practice [20] Chanting in the supine posture produces an integrated relaxation response [21]
<i>Yoga nidra</i> (yogic relaxation)	Improved symptom score, reduction of fasting blood glucose and postprandial blood glucose levels [27]

ence, and beneficial effects on glycaemic outcomes [10].

Asanas (yoga postures)

Asanas emphasize the relationship of body, mind, and awareness, focusing on the synchronization of breathing and movement. They involve stretching/twisting movements and relaxation. The key to performing a yoga posture is that it should be performed with stability and comfort. Seated postures such as *ardhamatsyendrasana*, *yoga mudra*, and *mandukasan* improve pancreatic function. *Asanas* with forward bends massage and pressurize the pancreas and stimulate the secretion of insulin. Twisting poses, such as *vakrasana* and *ardhamatsyendrasana* (seated spinal twist) squeeze the intestines and massage them to prevent the stagnation of colonic contents. For therapeutic benefits, the poses need to be maintained for approximately 30 seconds to 1 minute, depending on individual capacity, and the duration may be gradually increased. A study showed that yoga postures had a positive effect on glucose utilization and fat redistribution in individuals with type 2 diabetes [11]. In patients with diabetes, pancreatic cells may be rejuvenated and pancreatic β -cell sensitivity may be increased by the alternating abdominal contractions and relaxations involved in yoga practice. Improved blood supply to muscles may enhance insulin receptor expression in the muscles, causing increased glucose uptake [2].

In a study, it was observed that optimum control of diabetes was achieved by practicing *dhanurasana* and *ardhamatsyendrasana*. *Halasana*, *vajrasana*, *bhujangasana*, and *naukasana* were also found to be effective. However, *yoga mudra* and *shalabasana* worsened participants' diabetic status, for reasons that are not clearly understood [12].

A study evaluated the effects of four specific sets of *asanas*, *dhanurasana+matsyendrasana*, *halasana+vajrasana*, *naukasana+bhujangasana*, and *setubandhasana+pavanamuktasana*, on releasing insulin from the pancreas [13]. Increased sensitivity of the β -cells of the pancreas to the glucose signal was observed, which appeared to be a sustained change resulting from a progressive long-term effect of the *asanas*.

It was suggested that as little as 10 minutes of the yoga intervention combined with standard medical care could improve metabolic health significantly [14].

Pranayama (yogic breathing)

Pranayama is controlled or regulated yogic breathing practice. The slow breathing technique in *pranayama* causes comprehensive changes in body physiology by controlling the autonomic nervous system; it regularizes the rate and pattern of breathing

and regulates the heart rate and its variability [15].

Slow *pranayamas*, such as *anulom vilom* (alternate nostril breathing), *chandranadi* (left nostril breathing), *sitkari* (cooling breaths), and *bhramari* (humming bee breath) augment cerebral blood flow and oxygenation, thereby improving the neuronal activities of the brain centres, including those present in the limbic areas, hypothalamus, and medulla, as well as improving sympathovagal outflow [15]. *Anulom vilom pranayama* (alternate nostril breathing) has been shown to yield significant improvements in components of health-related fitness (i.e., cardio-respiratory endurance, flexibility, and percentage of body fat) [16]. The vibrations created in *bhramari pranayama* (humming bee breath) have a soothing and calming effect on the mind and could play a vital role in improving mental and physical health [17]. Right nostril breathing is believed to have a sympathetic stimulating effect and may be recommended in people with diabetes [18]. *Bhastrika pranayama* (bellow-breathing) is a powerful and energetic *pranayama* referred to as “the breath of fire.” It helps in the regulation of the pineal, pituitary, and adrenal glands, which play an important role in the regulation of metabolism [19].

Bandha (lock)

Bandha refers to a hold, tightening, or lock. It constricts a certain part of the body and re-directs the flow of blood and lymph to other parts. *Asanas* or *pranayama* may be combined with *bandhas*.

Uddiyan bandha (abdominal lock), which involves creating negative pressure in the abdomen and contracting the abdominal area, may have a therapeutic effect in the management of diabetes. It is believed that the negative pressure created in the abdominal cavity may improve pancreatic function.

Aum/Om chanting

Scientific analyses have shown that chanting “*Aum*” is based on the physics of sound, vibrations, and resonance, and has a positive influence on health. Chanting the “*Aum*” mantra results in stabilization of the brain, removal of negative thoughts, and increase of energy, and mental improvements and relaxation of the body take place within minutes of practice [20]. *Pranava pranayama* (chanting “*Aum*”) in the supine posture produces an integrated relaxation response, which may have clinical significance in the management of hypertension and diabetes [21].

Evaluation of the immediate effects of the mind-sound resonance technique in people with type 2 diabetes showed its potential role in enhancing cognitive function [22].

Sudarshan kriya

Sudarshan kriya is a specific breathing sequence involving “Aum” chanting, *ujjayi pranayama*, and *bhastrika pranayama* with rhythmic, cyclical breathing at slow, medium, and fast paces. In a study, significant improvements in physical, psychological, and social domains and total quality of life in diabetes patients were observed after the practice of *sudarshan kriya* yoga and *pranayama* in comparison to a group following standard treatment alone [23].

Dhyan (meditation)

Meditation has been shown to cause physiological changes in the brain. Meditators experience beneficial psychological effects, such as faster reactions to stimuli, and are less prone to various forms of stress [24]. The mental stability attained through the practice of meditation helps diabetes patients. A 6-week meditation and *sahaja yoga* meditation treatment showed improvements in quality of life, anxiety reduction, and blood pressure control [25]. Visualization and concentration on the pancreas during meditation has positive effects on sugar levels and is recommended in the management of diabetes. Mindfulness practice is advocated for better sleep, greater relaxation, and more accepting approaches to illness and the illness experience in people with diabetes and coronary heart disease [26].

Yogic relaxation technique, yoga nidra (yogic sleep)

Yoga nidra (conscious, dynamic, psychic sleep) is a comprehensive, profound relaxation technique for removing physical, mental, and emotional tensions. *Yoga nidra* practice in middle-age diabetes patients on oral medications led to improved symptom scores and reductions of fasting blood glucose and postprandial blood glucose levels [27].

Mudras (gestures)

Mudras are a combination of subtle physical movements that alter mood, attitude and perception, and deepen awareness and concentration [28]. Some *hasta mudras* (hand gestures), such as *linga mudra*, *surya mudra*, and *prana mudra*, are believed to be helpful for diabetes. Regular practice of these *mudras* boosts metabolic rates, promotes weight loss, and reduces sugar levels. Certain other *mudras*, such as *apan mudra* and *gyan mudra*, are recommended for diabetes patients for deep relaxation and eliminating stress. However, their individual effects have not been evaluated in scientific studies.

DURATION AND FREQUENCY OF YOGA PRACTICE

The recommended type, duration, and frequency of yoga practice have not been clearly defined, and studies have analysed various frequencies and durations of yoga practice. Durations of yoga practice ranging from 10 minutes [14], 25 to 35 minutes [23], and 60 minutes daily [10], 45- to 60-minute sessions 6 days a week [29], and three sessions of 75 minutes each per week [30], to 90-minute sessions twice weekly [9] have shown beneficial results. Many studies have reported beneficial effects after 3 months of the intervention [9,10,14,29,30], while in a few studies, interventions of 15 days [31], 40 days, and 6 months [23] were evaluated. Adherence to yoga practice was shown to have an impact on its beneficial effects [32].

Precautions and contraindications

Yoga should be learned under the guidance of a qualified yoga professional. There are many different styles of yoga, and while many are safe, some can be strenuous and may not be appropriate for everyone. Fast-paced yoga practice and vigorous exercises in extreme temperature conditions, as in hot or Bikram yoga, are not recommended for individuals with diabetes, cardiovascular disease, or who are at risk of complications. A relatively safe yoga style suitable for an individual's requirements should be practised. Beginners should avoid extreme practices. Patients taking medication to control diabetes should carefully monitor their bodies' reactions to any new fitness activity. Overlooking the warning signals of pain and discomfort while performing yoga practice may result in serious injury. Yoga practitioners should never push themselves beyond their physical capacity. Yoga practices are generally recommended on an empty stomach, but those taking treatments for diabetes may take light snacks to prevent hypoglycaemia. Inverted poses such as *sarvangasan* and *sheershasan* cause blood to rush or pool into the head and upper body, which may lead to a risk of retinal detachment or bleeding; such poses should be avoided in patients with diabetes or practiced with utmost care, only after an ophthalmic evaluation [33].

Balancing poses should be practiced carefully to avoid traumatic injuries. Yoga poses must be practiced slowly, without any sudden jerky movements and without pushing beyond one's limits. Complications of diabetes, such as autonomic neuropathy, may cause dizziness when sitting or standing abruptly because of a sudden drop in blood pressure. Individuals with diabetes are advised to enter and come out of poses slowly, pausing

for a breath or two if required while practicing the pose [34].

MECHANISM OF BENEFITS AND EVIDENCE FROM CLINICAL TRIALS

Yoga is based on the principle that the mind and body are intimately related. It improves flexibility, muscle strength, blood circulation, and oxygen uptake [23]. Yoga exhibits many health benefits, such as improving physical fitness, relaxation, and awareness of self. Various lifestyle disorders, including diabetes, can be effectively addressed by the practice of yoga, given acceptably high levels of adherence. Yoga practice improves an individual's discipline regarding food and exercise, thereby helping to modify patient-related reluctance that results in the underutilization of exercise as a treatment modality [35].

Diabetes is a chronic metabolic disease that adversely affects quality of life. Psychological stress and negative mood have a bidirectional effect in the control of diabetes [36]. Stress increases the risk and severity of diabetes by stimulating the hypothalamic-pituitary-adrenal (HPA) and sympathetic axes and parasympathetic withdrawal, resulting in increases in the levels of cortisol, epinephrine, norepinephrine, growth hormone, glucagon, catecholamines, prolactin, leptin, and neuropeptide Y [37]. Chronic activation of the HPA axis is associated with poor control of diabetes and complications such as diabetic neuropathy. An increased level of inflammatory cytokines results in insulin resistance in patients with type 2 diabetes. Chronic psychological stress can result in insulin resistance, hypertension, and an increased risk of cardiovascular events [38]. Yoga effectively reduces stress, thereby helping diabetes control [39]. Yoga practice in healthy volunteers was found to result in increases in wellness; reductions in stress, depression, and anxiety; improvements in the physical, psychological, and social domains and total quality of life; a feeling of balance; and a new outlook on life [25,39-41]. Yoga practice results in significant improvements in the scores of various psychological assessments, including satisfaction impact and worry [42]. Yoga also results in improvements in physical exercise, behavioural changes, and dietary practices, in addition to its effects on relaxation and stress management [35].

Abdominal stretching during yoga exercises is believed to result in the regeneration of pancreatic cells [2]. The various postures during yoga practice help to improve the sensitivity of β -cells to glucose, thereby improving insulin secretion, and increase the blood supply to the muscle and muscle relaxation, thereby improving glucose uptake. Improvements in hormonal

homeostasis also improve glycaemic control in people with diabetes mellitus [43]. Yoga therapy also results in immunomodulation by reducing proinflammatory responses and improving immune function [44].

The various health benefits of yoga therapy are related to changes in the level of various hormones and neurotransmitters: joy and euphoria during yoga therapy are due to an increase in β -endorphin, serotonin, and dopamine levels; improvements in arousal are due to increased arginine-vasopressin levels, which reduce the gamma-aminobutyric acid (GABA)-ergic inhibition of the supraoptic area of the hypothalamus; its calming effect is due to melatonin; the ecstatic and blissful feelings that arise during yoga are due to lateral hypothalamic stimulation; and the decrease in spatial orientation and out-of-body experiences during meditation are due to decreased levels of GABA and increased levels of N-acetylaspartylglutamate and 5-methoxydimethyl tryptamine (from pineal enzymes) [45].

Yoga practice is thought to have "beyond the drug action," which refers to the potential to induce stem cell trafficking from the bone marrow to the peripheral blood, which may lead to tissue regeneration by replacement and recruitment of cells differentiated from the stem cells [46]. However, this mechanism needs to be further explored.

Yoga asana also modulate gene expression and increase muscle activity, strength, endurance, flexibility, and balance, resulting in favourable effects on body weight, adiposity, dyslipidaemia, and insulin resistance [47].

Yoga reduces oxidative stress, as demonstrated by reductions in serum malondialdehyde, interleukin 6, and leptin levels, and improvements in adiponectin levels [44,48]. Yoga therapy increases the number of insulin receptors and increases the proportion of receptor binding in patients with diabetes [49]. It improves insulin kinetics by reducing fasting insulin levels, shifting the peak insulin level to the left, and by normalising the insulin-to-glucose ratio [50]. It also reduces levels of free fatty acids, indirectly indicating improved insulin sensitivity or reduced insulin resistance [51]. Yoga and various breathing exercises were found to lead to improvements on lung function tests [52]. Yoga improves cell-mediated immunity, as demonstrated by improvements in the lymphocyte migration test in people with type 2 diabetes [53].

Yoga also prevents the development of diabetes in high-risk individuals [54]. It was found to improve symptom scores in people with diabetes [55]. It also results in reduction of fasting blood sugar, postprandial blood sugar, haemoglobin A1c, and anti-diabetic drug requirements, suggesting improved glycae-

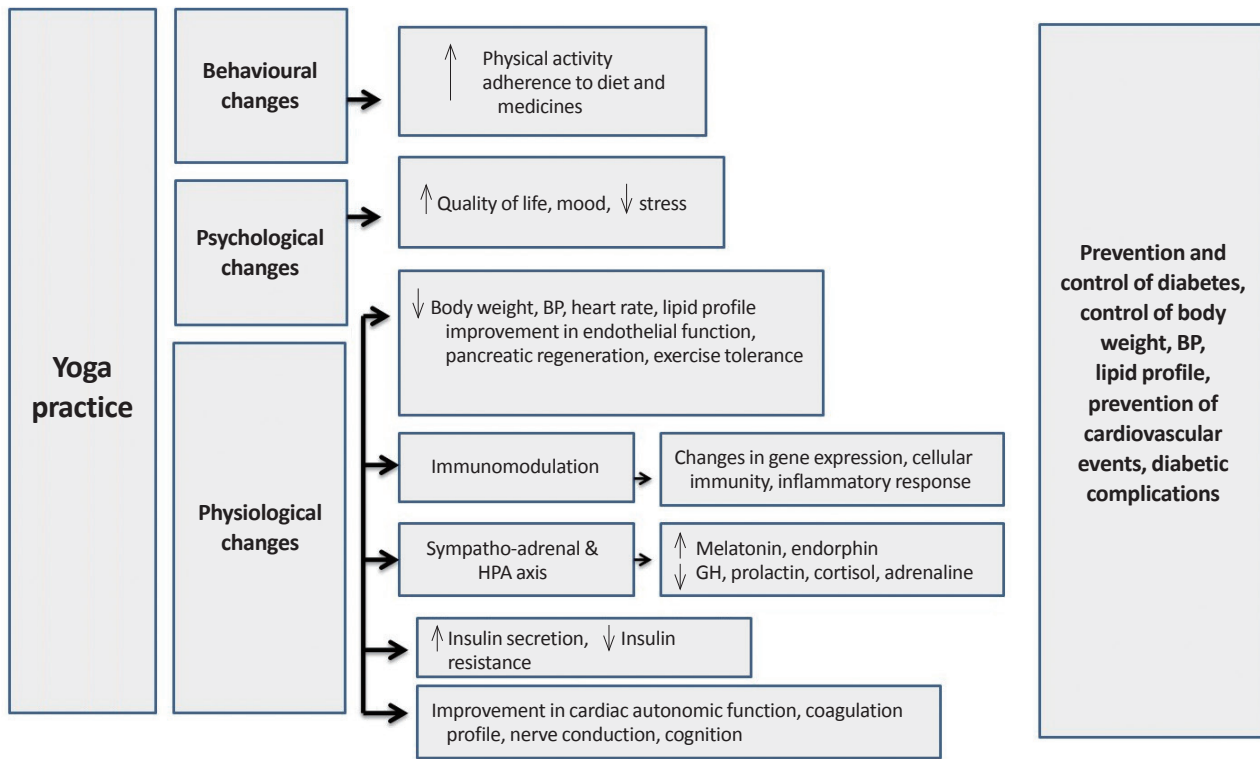


Fig. 1. Showing the mechanisms of benefits of yoga practice in type 2 diabetes. BP, blood pressure; HPA, hypothalamic-pituitary-adrenal; GH, growth hormone.

mic control. Yoga therapy results in a reduction in body weight, body mass index, the waist-to-hip ratio, body fat percentage, body fat mass, and skin fold thickness, thereby increasing lean body weight (Fig. 1).

Yoga reduces levels of triglycerides, low density lipoprotein cholesterol, and free fatty acids, and improves high density lipoprotein cholesterol levels [56]. It induces discipline regarding food and exercise [6]. The regular practice of yoga improves exercise tolerance, and it has been shown that yoga improved performance on the treadmill test from eight metabolic equivalents (METS) to 12 METS and resulted in the postponement of the anaerobic threshold [57]. Some studies have shown that there were reductions in both systolic and diastolic blood pressure in persons practicing yoga [58].

The regular practice of yoga reduces the risk of diabetes-related complications. Cardiac autonomic dysfunction is believed to be a cause of sudden death in patients with diabetes mellitus. Clinical studies have shown that regular yoga practice improved cardiac autonomic function independently of glycaemic control and reduced the risk of cardiovascular events [59]. Yoga therapy also stabilizes the coagulation profile, thereby improving nerve conduction and cognitive function in patients with diabetes [60].

In patients with type 2 diabetes, improvements in glycaemic control with up-titration of the insulin regimen or anti-diabetic medicines, without diet control or exercise, result in weight gain. In contrast, yoga improves glycaemic control without increasing body weight, and some studies have found it to reduce body weight [14].

The ease of use, safety, and multiple psychological benefits of yoga have led it to be more widely accepted in society, and it can now be considered a low-cost intervention to control various lifestyle disorders, including diabetes [35].

LIMITATIONS OF STUDIES ON YOGA

There are many lacunae in the clinical trials conducted to study the effects of yoga on health and various diseases. A lack of proper control groups, small numbers of patients, and short durations of the studies are the major limitations of the clinical trials that have investigated the therapeutic role of yoga in controlling diabetes. Additionally, some of the studies only considered blood sugar levels as outcomes, neglecting the other possible benefits of yoga. Selection bias, influence of confounding factors, lack of appropriate research methodology, inconsistency of

the baseline data, and a lack of appropriate statistical analysis all make the interpretation of studies on yoga difficult [61].

We can improve yoga research studies by improving the methodology of studies, reducing bias, studying long-term adherence to yoga practice (including home practice) to assess the long-term benefits of yoga, and analysing particular components of yoga therapy in order to obtain a clearer idea about particular types of yoga and the benefits thereof.

CONCLUSIONS

Yoga therapy is relevant for wellness, as well as for illness. The latest scientific evidence suggests the potential role of yoga-based lifestyle modifications in the management of type 2 diabetes and its associated risk factors. It is suggested that psychoneuro-endocrine and immune mechanisms have holistic effects in diabetes control. Parasympathetic activation and the associated anti-stress mechanisms improve patients' overall metabolic and psychological profiles, increase insulin sensitivity, and improve glucose tolerance and lipid metabolism. Yoga practices such as cleansing processes, *asanas*, *pranayama*, *mudras*, *bandha*, meditation, mindfulness, and relaxation are known to reduce blood glucose levels and to help in the management of comorbid disease conditions associated with type 2 diabetes mellitus, resulting in significant positive clinical outcomes.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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