The Benefits of Yoga for Adults With Type 2 Diabetes: A Review of the Evidence and Call for a Collaborative, Integrated Research Initiative

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Abstract

Type 2 diabetes (T2DM) is a global public health crisis. Research suggests that yoga holds promise for T2DM management. This article summarizes evidence regarding the efficacy of yoga for T2DM management and encourages the development of an integrated research agenda and a collaborative work group to test it. We present a brief overview of the global rise in T2DM and its consequences and costs, review the evidence regarding the potential benefits of yoga for T2DM management, outline limitations in the literature, discuss possible mechanisms underlying the effects of yoga on T2DM, and suggest how a collaborative, multinational effort by yoga therapist and research communities might contribute to research and inform clinical practice. Yoga protocols that serve T2DM patients and a research framework for creating an evidence base to support the use of yoga for T2DM management are clearly needed.

Key Words: yoga, diabetes, type 2 diabetes, blood pressure, obesity, lipids, glycemia, glucose tolerance, CVD, hypertension

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Nearly 350 million people in the world have diabetes, a complex metabolic disease for which there is no cure. Diabetes is associated with a 2- to 4.5-fold elevation in risk for cardiovascular disease (CVD; American Diabetes Association, 2004; Cosentino & Assenza, 2004; National Center for Chronic Disease Prevention and Health Promotion, 2005) and has been linked to increased risk for vascular events, including heart attack and stroke (Wilson & Kannel, 2002). CVD is the major cause of illness and mortality among individuals with diabetes and accounts for as many as 80% or more of deaths in this population (Karasik, 2005). Other major complications include blindness, lower limb amputation, and kidney disease (Centers for Disease Control, 2011; National Center for Chronic Disease Prevention and Health Promotion, 2005). The extant literature suggests some benefits of yoga for individuals with diabetes mellitus (e.g., see Innes & Vincent, 2007). This article explores the need for collaborative partnerships among yoga therapists and researchers and offers a framework for creating an evidence base to support the effectiveness of yoga for the management of this disease.

Type 2 diabetes (T2DM) accounts for more than 90% of all cases of diabetes. T2DM is characterized by the body's inability to use insulin effectively, which leads to high levels of blood glucose (Zimmet, Alberti, & Shaw, 2001). Other key related metabolic and hemodynamic abnormalities typifying T2DM and linked to insulin resistance or metabolic syndrome include dyslipidemia, elevated blood pressure, and chronic inflammation, as well as increased oxidative stress and hypercoagulation (Rana, Nieuwdorp, Jukema, & Kastelein, 2007; Wellen & Hotamisligil, 2005). T2DM is a largely preventable disorder, with obesity and physical inactivity comprising the major underlying causes (International Diabetes Federation, 2012); other contributing lifestyle-related factors include impaired sleep, depression, chronic stress, and smoking (e.g., Eriksson et al., 2008; Everson-Rose et al., 2004; Irwin et al., 2008; Musselman, Betan, Larsen, & Phillips, 2003; Suarez, 2008).

The global prevalence of T2DM has risen dramatically in the past three decades (Wild, Roglic, Green, Sicree, & King, 2004), coincident with the rapid and unprecedented aging of the population (United Nations Department of Economic and Social Affairs Population Division, 2005) and a growing pandemic of obesity and inactivity (Formiguera & Canton, 2004). Diabetes is now considered a global public health crisis, with a projected increase in prevalence of 54%, from 285 million to 439 million from 2010 to 2030 (Chen, Magliano, & Zimmet, 2012; Hu, 2011).

In 2010 T2DM was estimated to account for 12% of the world's health budget, or $376 billion, and is expected to reach $490 billion by 2030 (Zhang et al., 2010). Asian countries are now the epicenter of the epidemic (Hu, 2011); the countries with the largest number of people with T2DM are China, with an estimated 92.4 million adults affected (Yang et al., 2010), and India, with about 51 million (Anjana et al., 2011). The United States is third, with 25.8 million people (Centers for Disease Control, 2011). Diabetes prevalence continues to rise rapidly worldwide, with the largest increases projected to occur in Africa (98%), the Middle East (97%), Asia (91%), and Latin America (88%; Zimmet, Shaw, Murray, & Sicree, 2003).

The precipitous rise of T2DM in the developing world during the past 30 years may be largely attributable to the adoption of Western, high-energy diets and a sedentary lifestyle (Zimmet et al., 2003), and changes accelerated by ongoing globalization of world cultures and economies and advances in the transportation and telecommunications infrastructure (Hu, 2011). Undernutrition early in life increases the risk for developing T2DM in many developing countries (Norris et al., 2012; Whincup et al., 2008; Yajnik, 2004), as does lower socioeconomic status in the United States and other industrialized nations (Krishnan, Cozier, Rosenberg, & Palmer, 2010; Saydah & Lochner, 2010). Populations at highest risk for developing T2DM in the poor and developing countries tend to be wealthier, urban, and better educated (Corsi & Subramanian, 2012; Sierra, 2009). This trend appears to be changing, with T2DM increasingly affecting poorer, rural communities (Yoon et al., 2006). Despite differences between industrialized and developing nations, physical inactivity, central obesity, and associated chronic inflammation appear to be common risk factors across the globe (Chopra & Puoane, 2003; Kolb & Mandrup-Poulsen, 2010; Ramachandran, 2003; Zimmet et al., 2003).

Risk for the development and progression of T2DM also appears to be influenced by ethnic and racial factors, with Asians, non-Hispanic Blacks, Pacific Islanders, and American Indians being at risk for the disease (Boyle et al., 2001; Yoon et al., 2006; Zimmet et al., 2003). Although increasing age remains a strong risk factor for T2DM, prevalence has been rising rapidly among children and young adults in industrialized and in developing countries (Rosenbloom, Joe, Young, & Winter, 1999; Yoon et al., 2006; Zimmet et al., 2003).

Diabetes is the seventh leading cause of death in the United States (Centers for Disease Control, 2011) and is among the principal reasons for physician office visits (Centers for Disease Control, 2009). In 2007, direct medical costs for DM-related interventions totaled $116.5 million (American Diabetes Association, 2008; Herman, 2011). Those suffering from this serious chronic disorder pay heavy out-of-pocket health care expenses that averaged $1,600 a year as of 2007. These costs are particularly burdensome for the estimated 40% of T2DM-diagnosed adults who report an annual family income of less than $35,000 (Kunjumoideen, 2007). In New York City's low-income neighborhoods in Harlem, Bronx, and Brooklyn, diabetes treatment resulted in an estimated 20,000 hospitalizations (80% higher than the national rate), 3,000 amputations, 1,400 new cases of kidney failure, and 4,700 diabetes-related deaths, at a total cost of approximately $6.5 billion (The City of New York, 2007). The T2DM epidemic results in staggering financial, social, and health costs in other countries as well, placing an ever-growing demand on already struggling economies and dwindling resources (Yoon et al., 2006; Zhang et al., 2010).

The global epidemic of T2DM has implications for the international yoga therapist and research communities. With the development of educational standards by the International Association of Yoga Therapists (IAYT) and an expanding evidence base regarding yoga's health benefits, yoga therapy is rapidly gaining visibility and credibility as a potentially important therapeutic option for the prevention and treatment of T2DM. A growing number of studies suggest that yoga can be used to help manage many chronic conditions, including arthritis (Fishman & Saltonstall, 2008; Garfinkel, Schumacher, Husain, & Levy, 1994; Haaz & Bartlett, 2011; Hansen, 2010; Raub, 2002), lower back pain (Saper et al., 2009; Sherman, Cherkin, Erro, Miglioretti, & Deyo, 2005; Williams et al., 2009; Williams et al., 2005), high blood pressure (Bhavanani, Sanjay, & Madanmohan, 2011; Cade et al., 2010; Cohen et al., 2011; McCall, 2007; Okanta 2012; Yang, 2007), CVD (Innes, Bourguignon, & Taylor, 2005; Ross & Thomas, 2010), respiratory diseases (McCall, 2007; Pomidori, Campigotto, Amatya, Bernardi, & Coga, 2009; Raub, 2002; Woodyard, 2011), stroke (Bastille & Gill-Body, 2004; Garrett, Immink, & Hillier, 2011; Lynton, Kligler, & Shiflett, 2007; Schmid, van Puymbroeck, & Koceja, 2010), and osteoporosis (Fishman & Saltonstall, 2010). Yoga has likewise shown considerable promise for the management of T2DM, as detailed by leading investigators in recent IAYT and other international symposia on yoga research (Innes, 2011; Telles, 2010; Yang, 2010) and highlighted in recent reviews (Innes & Vincent, 2007; Sharma & Knowlden, 2012; Yang, 2007). In addition, yoga is a safe, inexpensive, highly portable therapy that has no appreciable side effects. It is relatively easy to learn, offers multiple collateral benefits, supports other beneficial lifestyle changes, and can be practiced even by unfit, elderly, ill, and disabled individuals (Innes, Selfe, & Taylor, 2008; Innes & Vincent, 2007). If confirmed to be effective in T2DM management, yoga would offer a sustainable and cost-effective approach to diabetes prevention and treatment that could significantly reduce not only individual out-of-pocket expenses, but health care costs and burdens, both nationally and internationally. However, standardized yoga protocols for T2DM have not yet been developed and empirically validated, and no study group exists that is specifically focused on this topic.

Although the need for rigorous research remains, collective findings to date warrant initiation of a collaborative and integrated research effort. This article reviews the published evidence regarding the potential benefits of yoga for the management of T2DM, outlines limitations in the literature, discusses possible mechanisms underlying these effects, and makes recommendations for future research. We close with a call for a collaborative effort by members of the international yoga therapist and research community to (a) develop integrated, multidisciplinary programs of research that address the gaps in the literature; (b) establish the efficacy of specific yoga programs and delivery systems for the management of T2DM in a range of populations, cultures, and settings; and (c) synthesize and disseminate findings to inform clinical practice. The goal is to establish yoga therapy as a low-cost option that is effective, safe, and sustainable for the prevention and management of T2DM.

Methods

English language peer-reviewed studies published between 2007 and 2012 regarding yoga and T2DM management were identified through a careful search of PubMed, MEDLINE, CINAHL Plus, Alt HealthWatch, and PsycINFO databases. Search terms included *yoga, yog*, pranayam,* and *diabetes*. Bibliographies of retrieved articles were also scanned. Excluded were cross-sectional studies and studies with a sample size fewer than 15 that targeted individuals less than age 18 years, examined changes over a single session, and/or that did not report quantitative data. The search yielded 11 original research articles. Both authors screened articles, identified eligible studies, and extracted data. Disagreements were resolved by discussion to achieve consensus.

Peer-reviewed studies regarding the effects of yoga on diabetes and diabetes risk published between 1970 and 2006 as detailed in two comprehensive, systematic review articles were also considered (Innes et al., 2005; Innes & Vincent, 2007) These include 25 trials regarding the effects of yoga in adults with diabetes (Innes & Vincent, 2007) and 52 studies regarding the effects of yoga on CVD risk in other populations, including chronically ill and healthy adults (Innes et al., 2005). Trials regarding the effects of yoga on CVD risk profiles were considered relevant because these indices, including elevated blood sugar, high blood pressure, dyslipidemia, obesity, and other factors, are strongly linked to T2DM. Because CVD is the major cause of illness and death in T2DM patients (American Diabetes Association, 2008; International Diabetes Federation, 2012), reducing CVD risk is a central priority in diabetes management.

Results

As illustrated in Table 1, the majority of studies published between 1970 and 2012 (>70%) were conducted in India. Fewer than 8% were conducted in the United States or Canada. Most trials were small, with 39% including fewer than 25 participants (see Table 1). Collectively, these studies evaluated the effects of yoga on a broad range of outcomes, reflecting the complex nature of T2DM and the now widely recognized importance of multifactorial T2DM management (e.g., American Diabetes Association, 2008; Hoerger & Ahmann, 2008; Holcomb, 2008; Marshall & Flyvbjerg, 2006; Taylor, 2008; Watson, 2007). Outcomes included insulin resistance, glucose intolerance, elevated blood pressure, dyslipidemia, excess body weight and central adiposity, elevated blood pressure, increased oxidative stress, and impaired coagulation. Each of these factors is strongly implicated in the development and progression of T2DM. Although the proportion of controlled trials has increased in the past 5 years, more than 40% of studies conducted to date were uncontrolled trials, and less than one third were randomized controlled trials (RCTs).

Trials, 1970–2006

With few exceptions, the studies published between 1970 and 2006 collectively document beneficial changes in risk profiles among yoga program participants (see Table 2). Of the 25 trials investigating the effects of yoga in adults with diabetes (Innes &Vincent, 2007), all reported positive changes in at least one outcome. Nineteen trials (76%) showed beneficial changes in two or more outcomes. Twenty-four of the 25 studies reported improvements in every outcome category assessed. As indicated in Table 2, 46 of the 52 studies (88.5%) of the effects of yoga on CVD risk in chronically ill and in healthy adults reported positive outcomes. Of those, 31 (67.4%) showed beneficial changes in two or more endpoints. Not surprisingly, 5 of the 6 studies reported no or nonsignificant improvement in physically healthy adults. (For a detailed discussion of findings, see Innes et al., 2005, and Innes & Vincent 2007.)

The studies summarized in Table 2 point to considerable variability in study design, clinical measures used to assess efficacy, target populations, and other factors that make comparisons across studies challenging. Factors including diversity and inconsistency of the populations studied, a broad range of disease profiles and co-occurring illnesses, considerable variability in the types of yoga interventions and their duration and intensity, inadequate descriptions of the protocols used, and lack of systematic data collection also rendered meta-analysis of pooled results infeasible, precluding the reliable quantification of benefits needed to guide clinical practice and policy. Innes and Vincent (2007) offered the following conclusion:

> Overall, these studies suggest beneficial changes in several risk indices, including glucose tolerance and insulin sensitivity, lipid profiles, anthropometric characteristics, blood pressure, oxidative stress, coagulation profiles, sympathetic activation and pulmonary function, as well as improvement in specific clinical outcomes. Yoga may improve risk profiles in adults with DM2 and may have promise for the prevention and management of cardiovascular complications in this population. However, the limitations characterizing most studies preclude drawing firm conclusions. Additional high-quality RCTs are needed to confirm and further elucidate the effect of standardized yoga programs in populations with DM2 (Innes & Vincent, 2007).

Recent Studies (2007–2012)

Eleven trials regarding the effects of yoga in adults with T2DM were published between 2007 and 2012 (see Table 3). These studies include five RCTs and four nonrandomized, controlled trials (NRCTs), and study samples tend to be large. Considerable heterogeneity across studies was found for study target populations, sample sizes, research designs, outcome measures, and yoga intervention protocols. Findings offer support for yoga as a potentially cost-effective therapeutic intervention for T2DM. In 9 of 11 studies, yoga program participants showed significant beneficial changes in clinical outcomes and/or risk indices, including improvements in glucose tolerance (e.g., Amita, Prabhakar, Manoj, Harminder, & Pavan, 2009; Kyizom, Singh, Singh, Tandon, & Kumar, 2010; Madanmohan, Bhavanani, Dayanidy, Sanjay, & Basavaraddi, 2012), lipid profiles (e.g., Gordon et al., 2008; Pardasany, Shenoy, & Sandhu, 2010; Vaishali, Kumar, Adhikari, & UnniKrishnan, 2012), blood pressure (Yang et al., 2011), body weight (e.g., Hegde et al., 2011; Kosuri & GR, 2009; Vaishali et al., 2012), and other outcomes (Sharma, Gupta, &Bijlani, 2008). An RCT that included adults with T2DM showed no significant changes in any major endpoints (Skoro-Kondza, Tai, Gadelrab, Drincevic, & Greenhalgh, 2009), however. This may have resulted from a yoga class attendance rate of 50%, with some participants attending no classes at all. Adherence to the home practice component was also very poor in this study (0%), limiting interpretation of findings. In addition, a small RCT involving U.S. adults at risk for diabetes (N = 23) demonstrated positive, although nonsignificant, changes in blood pressure, lipid profiles, and body mass index (BMI) and smaller, nonsignificant improvements in measures of glucose tolerance (Yang et al., 2011).

Table 1.
Characteristics of Eligible Studies Published in 1970–2012 Regarding Effects of Yoga-based Programs on CVD Risk Profiles in Adults

Articles	No. studies	Study design			Sample size				Location						Publication dates			
	Total	UCT	NRCT	RCT	<25	25-40	41-60	>61	India	U.S.	Canada	Europe	Asia/ Pacific	Caribbean	2000–2012	1990–1999	1980–1989	1970–1979
Innes et al. 2005	52*	20	13	19	22	13	9	8	36	2	1	11	2	–	12	15	14	11
Innes & Vincent 2007	25	15	6	4	10	5	3	7	19	3	–	3	–	–	11	7	6	1
Trials published 2007–2012	11	2	4	5	2	1	5	3	8	1	–	1	–	1	11	–	–	–
Totals (*N*)	88	37	23	28	34	19	17	18	63	6	1	15	2	1	34	22	20	12
Totals (%)	100	42.0	26.1	31.8	38.6	21.6	19.3	20.5	71.5	6.8	1.1	17.0	2.2	1.1	38.6	25.0	22.7	13.6

Note. *Adjusted total from an original article count of 70. To avoid counting trials twice, 10 studies included in the 2007 review article were excluded. Also excluded were an additional 8 studies that evaluated changes only over one or two yoga sessions (Innes et al. 2005).
CVD = cardiovascular disease; NRCT = nonrandomized, controlled trial; RCT = randomized, controlled trial; UCT = uncontrolled (pre-post) trial.

Table 2.
Summary of Clinical Outcomes Assessed and Results Reported in Trials Investigating the Effects of Yoga-based Programs on CVD Risk Profiles in Nondiabetic Adults (Innes, 2005) and in Adults With Diabetes (Innes & Vincent, 2007)

	Clinical outcome measured and findings reported (+ = significant improvement; – = no significant change)															
Review article, # trials included (1970–2006)	Insulin resistance/ glucose tolerance		Blood lipid profiles		Body size/ composition		Blood Pressure		Coagulation		Oxidative stress		SNS/PNS		Other clinical l outcomes	
	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–
Innes et al., 2005 (CVD risk): *N* = 52 trials																
Findings: total (+, –)	4	1	6	3*	9	3	24	7	1	0	4	0	28	4*	7	0
Trials assessing given outcome; *N* (% total)	5(9.6)		9(17.3)		12(23.1)		31(59.6)		1(1.9)		4(7.7)		32(61.5)		7(13.5)	
Innes & Vincent, 2007 (diabetes): *N* = 25 trials																
Findings: total (+, –)	10	0	11	0	11	0	5	1*	1	0	2	0	4	0	12	0
Trials assessing given outcome; *N* (% total)	19(76.0)		11(44.0)		11(44.0)		6(24.0)		1(4.0)		2(8.0)		4(16.0)		12(48.0)	

Note. *Adjusted total from an original total of 70 studies. To avoid counting trials twice, 10 studies in adults with diabetes (included in the 2007 review article) were excluded. Also excluded were an additional 8 studies that evaluated changes only during 1 or 2 yoga sessions (Innes et al., 2005); CVD = cardiovascular disease.

Summary of the Extant Research: RCTs (1970–2012)

Although uncontrolled trials (UCTs) and nonrandomized, controlled trials (NRCTs) can be informative, well-designed RCTs are believed to be highly rigorous, less vulnerable to bias and confounding, and offer the strongest evidence of causation relative to other research designs. Table 4 details the characteristics and findings of the nine RCTs published between 1970 and 2012 about the potential benefits of yoga in adults with T2DM.

The majority of these studies reported beneficial effects of yoga on glycemia and other risk indices in those with T2DM. Documented changes include significant improvements in glucose tolerance, blood pressure, body weight, BMI, and oxidative stress relative to usual care, education, and other comparators (see Table 2). These trials clearly demonstrate that implementation of yoga interventions is feasible in U.S. and other Western populations and provide support for the findings of previously discussed UCTs and NRCTs.

Substantial heterogeneity for a number of key factors renders cross-study comparisons difficult. The studies vary widely in sample size (ranging from 21 to 230), study population (from adults with uncomplicated, well-controlled T2DM to those with poorly controlled diabetes of varying etiology and with varying levels of complications), study duration (12 weeks to 12 months), intervention intensity (60- to 90-minute classes 1 to 6 times per week), and design (yoga alone vs. yoga that included additional interventions, such as medication, conventional exercise, and special diets). Although findings collectively suggest yoga to be a useful therapeutic intervention for T2DM, the considerable variability, even among the RCTs, precludes drawing firm conclusions and hinders the establishment of specific recommendations and clinical guidelines regarding yoga for T2DM management.

Discussion

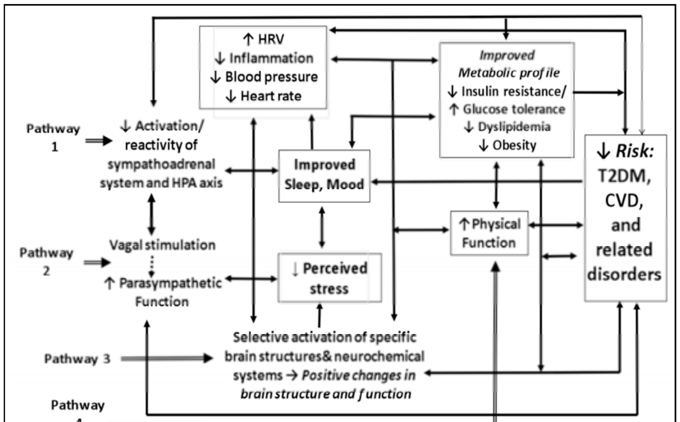
Although the number of yoga studies targeting adults with T2DM has grown dramatically, variability in study design and population, intervention and comparison condition, and outcome measures and assessment procedures render comparisons across studies difficult. The majority of studies suggest yoga to be beneficial for adults with T2DM; however, the limitations noted earlier preclude firm conclusions or recommendations. Given existing evidence regarding the potential significance of yoga as a therapeutic intervention for T2DM management and the pressing need to identify feasible, low-cost, and sustainable prevention and management strategies for those with and at risk for T2DM, additional rigorous research is clearly warranted.

Yoga and T2DM: Possible Underlying Mechanisms

Although the mechanisms underlying the putative beneficial effects of yoga therapy on cardiovascular and diabetes risk profiles are not yet well understood, mechanistic pathways are likely complex and interacting. The observed changes may occur through at least four pathways (see Figure 1).

As illustrated in Pathway 1 (Figure 1), yoga may alleviate the effects of stress and foster multiple positive downstream effects on sleep, neuroendocrine status, metabolic function, and related inflammatory and hemodynamic responses, and ultimately, lead to reduced risk for CVD and other vascular complications by reducing the activation and reactivity of the sympathoadrenal system and the hypothalamic pituitary adrenal (HPA) axis and promoting feelings of well-being (Innes, Vincent, & Taylor, 2007). Recent studies in both healthy populations and in adults with diabetes and other chronic conditions suggest yoga practice can lower cardiovascular response to stress, catecholamine and cortisol levels, blood pressure, and other indices of sympathetic activation and can decrease perceived stress and enhance mood during a single session and following short-term training programs (Innes et al., 2007; Khatri, Mathur, Gahlot, Jain, & Agrawal, 2007; Uebelacker et al., 2010). HPA dysregulation, sympathetic activation, and psychological distress have, in turn, been implicated in the development and exacerbation of several risk factors for T2DM (e.g., Golden, 2007; Innes et al., 2008; Kyrou, Chrousos, & Tsigos, 2006). These include insulin resistance and impaired glucose tolerance, central obesity, hypertension, dyslipidemia, proinflammatory and prothrombotic states, all shown to have adverse effects on neuroendocrine function and metabolic control and also to be strongly linked to increased risk for DM2 and for CVD and other vascular disorders.

Figure 1.
Hypothesized pathways by which yoga interventions may improve outcomes in individuals with and at risk for T2DM. Adapted from Innes and Vincent, 2007 and Innes and Selfe, 2012.



Abbreviations: CVD = cardiovascular disease; HPA = hypothalamic pituitary adrenal; HRV = heart rate variability; T2DM = Type 2 diabetes

Second, yoga may enhance parasympathetic output directly, possibly by stimulating the vagus nerve, and thereby shift the autonomic nervous system balance from primarily sympathetic to parasympathetic (Brown & Gerbarg, 2005; Innes et al., 2007; Singh, Kartik, Otsuka, Pella, & Pella, 2002), leading to positive changes in cardiovagal function; in related neuroendocrine, inflammatory, and hemodynamic profiles; in mood and sleep; and in associated downstream metabolic parameters (Figure 1, Pathway 2; e.g., Innes et al., 2005; Innes,et al., 2008). For example, recent controlled studies of healthy populations and of adults with hypertension, T2DM, CVD, and other chronic conditions have shown yoga breathing, meditative, and postural exercises to increase heart rate variability, enhance baroreflex sensitivity, and reduce resting heart rate, both acutely and following short-term (6–12 weeks) interventions (Innes et al., 2007; Khattab, Khattab, Ortak, Richardt, & Bonnemeier, 2007; McCaffrey, Ruknui, Hatthakit, & Kasetsomboon, 2005). Heart rate variability, baroreflex sensitivity, and resting heart rate are widely used markers of cardiovagal autonomic function, parasympathetic activation, and sympathovagal balance (e.g., Carnethon et al., 2006; De Meersman & Stein, 2007) and are thought to in part reflect vagal stimulation (Brown & Gerbarg, 2005; Innes et al., 2007; Singh et al., 2002). As detailed earlier, these parameters have been strongly related to insulin resistance syndrome and related conditions and associated with increased risk for T2DM and CVD (Innes et al., 2008; Innes et al., 2007; Thayer & Lane, 2007).

Third, findings of recent neuroimaging and neurophysiological studies (Kjaer et al., 2002; Newberg et al., 2010; Rubia, 2009; Wang et al., 2011) suggest that by selectively activating specific neurochemical systems and brain structures associated with positive mood and attention, yogic practices may likewise promote beneficial changes in sympathetic/parasympathetic balance, in neurological structure and function, in affect and memory, and in related metabolic and inflammatory responses (Figure 1, Pathway 3).

Finally, by increasing fitness, strength, and physical function, yoga may improve both metabolic and psychological risk profiles, enhance neuroendocrine function, promote weight loss (e.g., by increasing metabolic rate), improve body composition, and encourage increased physical activity (Figure 1, Pathway 4). Yoga may decrease CVD risk in other ways as well. For example, by reducing stress and leading to improved sleep and mood, yoga may also enhance CVD risk profiles indirectly by leading to enhanced self-care and healthier lifestyle choices. Although research to date has yielded inconsistent findings (Hartfiel, Havenhand, Khalsa, Clarke, & Krayer, 2011; Johnston, 2011; Noggle, Steiner, Minami, & Khalsa, 2012), yoga may also increase resilience to stress, a factor that has been linked to improved outcomes in T2DM (Steinhardt, Mamerow, Brown, & Jolly, 2009; Yi, Vitaliano, Smith, Yi, & Weinger, 2008). These pathways likely interact in a synergistic, bidirectional manner to reduce stress, blood sugar, blood pressure, and cholesterol; enhance mood and autonomic function; increase physical functioning; and improve other related risk markers and outcomes, and in this way lead to reduced risk for T2DM and related adverse sequelae.

Although these mechanisms remain speculative at present, they provide a conceptual framework that integrates possible mechanistic pathways and can help inform research and ultimately clinical interventions. Specifically, these potential mediating factors may offer critical endpoints to consider in future collaborative research initiatives regarding the efficacy of yoga in the multifactorial management of T2DM. In addition, the putative pathways outlined here may provide a rationale and foundation for the development of specific yoga protocols, including *asana*-, meditation-, and breath-based programs for populations with differing preferences, abilities, health status, and needs.

A Collaborative, Integrated Research Proposal

The overwhelming majority of studies to date suggest that yoga has therapeutic promise, yet high-quality RCTs are needed to clarify and establish the potential benefits of specific yoga programs for adults with T2DM. Although other study designs can be valuable for establishing feasibility and generalizability, RCTs are viewed as credible by the medical and scientific communities and are likely to critically inform clinical care and public health policy. The cost and logistic complexities of implementing such trials make it likely that smaller studies will continue to be conducted. Small, well-designed, and well-executed studies can provide essential data on which to base larger clinical trials. Moreover, provided that methodology is rigorous and consistent across studies, these smaller trials can collectively make important contributions to the evidence base.

It is imperative that yoga researchers and therapists collaborate to create a foundation for future research on T2DM. The collaborative development of standardized protocols to be tested in well-designed RCTs will provide the foundation for integrated research. This research has the potential to create a sound evidence base of sufficient rigor to ensure the incorporation of yoga into the standard care and management of T2DM, and the successful development of a broad-based, comprehensive, and rigorous program seems possible.

This process might begin with an amalgamation of the existing expertise and experience in T2DM research. Discussions might emphasize T2DM population variability and the outcome measurement of extant yoga protocols and explore the function of smaller pilot trials to clarify our understanding of yoga's effects on T2DM. The minimal components of a research program would include development of yoga protocols that (a) address the needs of active, ambulatory patients and those who must practice while seated; (b) include asana, pranayama, and mediation; and (c) involve tailored but increasingly challenging routines (with incorporation of props and pose modifications as appropriate) to enable all participants to safely increase strength and flexibility over time. It will be important to examine the use of cointerventions as confounds on the specific effects of yoga interventions on outcomes.

It will be necessary to develop a multistage research framework that (a) identifies characteristics of patients most likely to benefit from yoga interventions, (b) achieves consensus regarding basic components of trial design to allow comparisons across samples, (c) establishes specific clinical practice guidelines based on a strong evidence base, (d) documents processes and procedures for adapting standardized protocols for use in specific T2DM populations, and (e) identifies and coordinates sources of support for every stage of the project. The program would build an evidence base to elucidate the efficacy of specific yoga programs and delivery systems for the management of T2DM during the experimental and translational stages. Community engagement and input and partnership with local and regional public health agencies, health care organizations, research institutions, and national organizations will be needed ensure that these yoga programs are appropriate and sustainable. This program will maintain awareness that establishing and maintaining a permanent practice is difficult for many people (Alexander et al., 2012; Alexander, Taylor, Innes, Kilbock, &

Selfe, 2008; Skoro-Kondza et al., 2009) and seek to ascertain and understand which factors impede or facilitate consistent practice. All findings will be synthesized and disseminated to inform international clinical practice.

These goals do not aim to impose uniformity. Rather, the objective is to stimulate a productive conversation among interested professionals, with the goal of formulating a fruitful, comprehensive, collaborative, and consistent research agenda that will enable the yoga therapist community to understand the function of yoga for preventing and managing T2DM. Using a range of venues, including IAYT conferences and online communication, a collaborative effort among yoga therapists and researchers could yield high-impact research and a multifaceted, cost-effective approach to diabetes management and prevention.

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Table 3.
Characteristics, Measures, and Key Findings of Recent Trials (2007-2012) Investigating Effects of Yoga-based Programs in Adults With or at Risk for Type 2 Diabetes

Trial Characteristics						Clinical Measures and Findings				
Authors, year, location	Sample size yoga controls)	Duration	Study population	Comparison group/condition	Intervention	IR/GT indicies	Lipid profiles	Body size/ comp	BP	Key findings
Uncontrolled (pre–post) trials										
Kosuri et al., 2009 India	35	40 days	T2DM patients, no complications (24M/11F) 50.34 yrs +/- 8.38 yrs taking antidiabetic medication (5 were diet & exercise only, no meds)	Pre–post: subjects serve as own controls	Daily yoga (AS & PR), meals at home			X+		Yoga group: ↓BMI (26.5 +/- 3.45–25.8 +/- 3.4; $p < 0.001$). Significant ↑ in subjective well-being, ↓anxiety scores. Comments: duration of daily practice not given
Madanmohan et al., 2012 India	15	6 wks	Peri- and postmenopausal T2DM female patients	Pre–post: subjects serve as own controls	Yoga class 60 min. 3x/wk	X+	X+			Yoga group: ↓FBG and PPBG levels ($p < 0.01$); ↓LDL ($p < 0.01$), TC, TG, VLDL,↑ HDL ($p < 0.05$); all lipid ratios showed improvement: ↓TC/HDL & LDL/HDL ($p < 0.01$),↑ HDL/LDL ($p < 0.05$)
Nonrandomized, controlled trials										
Sharma et al., 2008 India	129 (89 [77 comp], 52)	10 days	Adults with HTN, CAD, DM &/or other conditions; either wishing to participate in yoga course (experimental group) or not (control)	(33M, 19F) healthy subjects uninterested in yoga program	8 days, 3-4 hrs/ day AS, PR, meditation, shavasana, stress management, principles of yoga & yogic techniques, nutrition education (meals at home)					Yoga group vs. control: subjective well-being scores for CAD patients and healthy individuals increased significantly. No significant changes in patients with DM, HTN, & chronic pain. Comments: did not describe recruitment; instrument validation not reported
Amita et al., 2009. India	41 (20, 21)	90 days	Middle-aged, T2DM patients on oral hypoglycemic meds	Usual care	Yoga nidra 30 min daily	X+				Yoga nidra vs. control: 21.3 mg/dl ↓in fasting blood glucose (159 ± 12.3 to 137.7 ± 23.15; $p < 0.0007$) 17.95 mg/dl ↓in PPBG (255.45 ± 16.85 to 237.5 ± 30.54, $p = 0.02$)
Hegde et al., 2011 India	123 (60 [54 comp], 63)	3 mos	T2DM patients (40–74 yrs) stratified according to micro- & macrovascular complications & peripheral neuropathy. Medications kept constant	Controls (57.5 ± 8.9 yr.) oral & written info about diet and exercise	Yoga class (AS & PR) at least 3x/wk	X+		X+	X–	Yoga vs. control: significant improvements in oxidative stress (malondialdehyde, glutathione, & vitamin C); no significant changes in vitamin E and superoxide dismutase
Kyizom et al., 2010 India	60 (30, 30)	45 days	T2DM patients (35–60 yrs) w/ no complications, taking conventional hypoglycemic meds	Controls (52.90 ± 6.87 yr.) receive only conventional meds	5-day yoga class (AS & PR) followed by daily home practice (?) with contact every 7 days to ensure supervision and compliance	X+				Yoga vs. control: significant ↓ in FBG & PPBG, improvements in cognition. Controls on meds alone: no significant changes

(Table 3 continued page 81)

(Table 3 continued)

Trial characteristics						Clinical measures and findings				
Authors, year, location	Sample size yoga controls)	Duration	Study population	Comparison group/condition	Intervention	IR/GT indicies	Lipid profiles	Body size/ comp	BP	Key findings
Randomized, controlled trials										
Gordon et al., 2008 Jamaica (Cuban hospital)	231 (77 yoga, 77 exercise, 77 usual care)	24 wks	T2DM patients w/ no complications or malnutrition, 40–70 yrs, trained in IDF recommendations for T2DM self-care, DM duration 1–10 yrs; no serious mental illness; all nonalcoholic, nonsmokers	(1) Usual care; (2) 2 h conventional (largely aerobic) exercise class/wk +1 h home practice 3–4 x/wk	Hatha yoga (PR, AS, SH) 2 h class/wk + 3–4 times/wk for 1 h home practice	X+	X+			Hatha yoga and conventional PT exercise groups vs. usual care: significant ↓FBG,TC, oxidative stress (↓malondialdehyde); significant ↑ superoxide dismutase from baseline in yoga and exercise groups. Yoga vs. exercise: no between-groups differences
Skoro-Kondza et al., 2009 UK	59 (29, 30)	12 wks	T2DM patients not taking insulin	Receive information on life style & exercise	90 min yoga class 2x/wk + home practice; also receive lifestyle and exercise information	X–	X–	X–	X–	Yoga vs. control: nonsignificant ↓ in HbA_{1c}, not sustained 6 mo later; no significant changes in other outcome measures. Comments: class attendance low (50%) & compliance w/ home practice very poor (0%)
Yang et al., 2009 USA	23 (12, 11)	12 wks	45–65 yrs w/family history of DM, sedentary, at least one cardio-metabolic risk factor: IGT, pre HTN, overweight/obese or high cholesterol	Receive health & T2DM education materials every 2 wks for 3 mos	1 h classes 2x/wk Vinyasa yoga + home practice	X+/–	X+/–	X+/–	X+/–	Yoga vs. controls: nonsignificant improvement in weight, systolic & diastolic BP, total cholesterol, triglycerides, exercise self–efficacy (effect sizes: 0.5–0.9); smaller, nonsignificant declines in FBG, insulin
Pardasany et al., 2010 India	45 (15 yoga, 15 tai chi, 15 usual care)	12 wks	T2DM adults 40–60 yrs; taking hypoglycemic medications, sedentary	(1) Usual care (no exercise): control; (2) tai chi chuan 3x/wk	3x/wk Hatha yoga	X+	X+			Hatha yoga vs. control: significant ↓ in cholesterol, LDL, FBG & PPBG Yoga: significant ↓in HbA_{1c} pre–post. Tai chi vs. yoga: no significant differences. Controls showed no significant improvements
Vaishali et al., 2012 India	60 enrolled 57 completed (27, 30)	12 wks	60 adults over 60 yrs, T2DM duration > 15 yrs	Controls received education materials + hypoglycemic medication	6x/wk yoga practice, 11 AS, 2 PR, SH + & hypoglycemia medication	X+	X+			Yoga group: significant ↓HbA_{1c}, FBG, TC, TG, LDL; ↑ HDL. Between-groups comparison shows significant beneficial changes in all outcome measures

Note. * *N*s for each group not given. + = improvement for 1 or more endpoints within a given outcome category; – = no beneficial changes reported; +/– = nonsignficant/marginally significant improvement; AS = yoga asanas or postures; BMI = body mass index; BP = blood pressure; CAD = coronary artery disease; comp = composition; h = hour; FBG = fasting blood glucose; IGT = impaired glucose tolerance; HbA_{1c} = glycosylated hemoglobin; HDL = high density lipoprotein; HTN = hypertension; IDF =International Diabetes Federation, IR = insulin resistance (markers of); LDL = low density lipoprotein; mos = months; med = medication; PPBG = postprandial blood glucose; PR = pranayama or yogic breathing exercises; SH = Shavasana or corpse pose, a traditional yoga relaxation pose; TC = total cholesterol; TG = triglyceride; T2DM = type 2 diabetes mellitus; VLDL = very low density lipoprotein; wk = week; yr = year.

Table 4.
Characteristics and Key Findings of Randomized, Controlled Trials (1992–2012) Investigating the Effects of Yoga-based Programs in Adults With or at Risk for Type 2 Diabetes

Trial characteristics						Clinical measures					
Reference, location	Sample size (enrolled/ completed)	Duration	Study population	Comparison group/condition	Intervention	IR/GT indicies	Lipids	Body size/ comp	Blood pressure	Oxidative stress	Other clinical outcomes
With and at risk for diabetes											
Monro, Power, et al., 1992; UK	21 (11,10)	12 wks	Uncomplicated T2DM controlled with meds (*N* = 13; 8 Yoga group) or diet (*N* = 8); 45-67 yrs, avg 53 (Y), 57 (C)	Usual care (continue on medication, diet)	Yoga classes (PR, AS, SH) + usual care, 2 classes/wk, + home, 90 min 1–5x/ wk	X+					X+
Kerr, Gillam, et al., 2002; UK	37*	16 wks	Poorly controlled insulin-treated DM (14 with DM 1) from Hospital DM clinic, avg 60–61 yrs	Education, simple exercise	Hatha yoga classes + education	X+	X+		X–		X+
Gordon et al., 2008; Jamaica, Cuban hospital	231 (77 yoga, 77 exercise, 77 usual care)	24 wks	T2DM patients w/ no complications or malnutrition, 40–70 yrs, trained in IDF recommendations for T2DM self-care, DM duration 1–10 yrs; no serious mental illness; all non-alcoholic, non-smokers	1) Usual care; 2) 2 h conventional (largely aerobic) exercise class/wk + 1 h home practice 3-4x/wk	Hatha yoga (PR, AS, SH) 2 hr. class/wk + 3–4 x/wk for 1hr home practice	X+	X+			X+	
Yang et al., 2011; USA	23 (12, 11)	12 wks	45–65 yrs w/family history of DM, sedentary, and at least one cardio-metabolic risk factor: IGT, pre–HTN, overweight/obese, or high cholesterol	Receive health and T2DM education materials every 2 weeks for 3 months	1 hr classes 2x/wk Vinyasa yoga + home practice	X+/–	X+/–	X+/–	X+/–		
Skoro-Kondza et al., 2009; UK	59 (29, 30)	12 wks	T2DM patients, not taking insulin	Receive information on life style and exercise	90 min yoga class 2x/wk + home practice; also receive lifestyle and exercise information	X–	X–	X–	X–		X–
Pardasany et al., 2010; India	45 (15 yoga, 15 tai chi, 15 usual care)	12 wks	T2DM adults 40–60 yrs; taking hypoglycemic medications, and sedentary	1) control, usual care (no exercise); 2) tai chi chuan 3x/wk	3x/wk Hatha yoga	X+	X+				

(Table 4 continued page 83)

(Table 4 continued)

Trial characteristics						Clinical measures					
Reference, location	Sample size (enrolled/ completed)	Duration	Study population	Comparison group/condition	Intervention	IR/GT indicies	Lipids	Body size/ comp	Blood pressure	Oxidative stress	Other clinical outcomes
With and at risk for diabetes											
Vaishali et al., 2012	60 enrolled 57 com- pleted (27, 30)	12 wks	60 adults over 60 yrs of age, T2DM duration greater than 15 yrs.	Controls received education materials + hypoglycemic medication	6x/wk yoga practice, 11 AS, 2 PR, SH + education materials and hypoglycemic medication	X+	X+				
Mixed clinical populations including adults Type 2 diabetes											
Fields, Walton et al., 2002; USA	57: 43 complete study (20 yoga; 9 exercise, 14 usual care); High risk Sx (6, 3, 6)	12 mos	Adults 65+ yrs, avg 74 yrs; overall healthy; 43 with complete, reliable data. 15 high risk, with at least 2 CHD risk factors, including DM (*N* not stated)	Exercise: walking 3x/wk (40–60 min), stretching/ isotonic exercises 2x/wk for 60 min (with video) Usual care	TM: 2x/d (20 min), daily yoga AS (20 min/d) + daily herbal supple- ments; 30 min/d walking; monthly meetings with instructor to check meditation and yoga training	X+	X+		X+		X+
Manchanda, Narang et al., 2000; India	42 (21, 21) (7 with left ventricular dys- function)	90 min daily for 1 yr	Men with CAD & chronic stable angina, 32–72 yrs. Yoga and control groups similar in age, weight, lesion severity; yoga group poorer fitness, cardiac health	Conventional program, including risk factor control and American Heart Association Step1 diet	Yoga: (PR, AS, KR, M) 90 min daily + diet, exercise		X+	X+			X+

Note. * *N*s for each group not given. + = positive (beneficial) findings for 1 or more endpoints within a given category; – = no beneficial effects demonstrated. AS = yoga asanas or postures; avg = average; CAD = coronary artery disease; comp = composition; CHD = coronary heart disease; d = day; DM = diabetes mellitus; GT = glucose tolerance; h = hour; HTN = hypertension; IDF = International Diabetes Foundation; IGT = impaired glucose tolerance; IR = insulin resistance; KR = kriyas or cleansing exercises; M = meditation; TM = transcendental meditation; mo = month; PR = pranayama or yogic breathing exercises; SH = shavasana or corpse pose, a traditional yoga relaxation pose; wk = week; yr = year; Y=yoga; C = control.