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Combined Diet and Physical Activity Promotion Programs to Prevent Type 2 Diabetes Among Persons at Increased Risk: A Systematic Review for the Community Preventive Services Task Force

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Background: Trials have shown efficacy of rigorous diet and physical activity promotion programs to reduce diabetes incidence and improve glycemic measures in adults at increased risk for type 2 diabetes.

Purpose: To evaluate diet and physical activity promotion programs for persons at increased risk for type 2 diabetes, primarily to reduce diabetes risk and decrease body weight and glycemia.

Data Sources: MEDLINE, the Cochrane Central Register of Controlled Trials, CAB Abstracts, Global Health, and Ovid HealthSTAR from 1991 through 27 February 2015, with no language restriction.

Study Selection: 8 researchers screened articles for single-group or comparative studies of combined diet and physical activity promotion programs with at least 2 sessions over at least 3 months in participants at increased risk for type 2 diabetes.

Data Extraction: 7 researchers extracted data on study design; participant, intervention, and outcome descriptions; and results and assessed study quality.

Data Synthesis: Fifty-three studies (30 of diet and physical activity promotion programs vs. usual care, 12 of more intensive vs. less intensive programs, and 13 of single programs) evaluated 66 programs. Compared with usual care, diet and physical activity promotion programs reduced type 2 diabetes incidence (risk ratio [RR], 0.59 [95% CI, 0.51 to 0.66]) (16 studies), decreased body weight (net change, −2.2% [CI, −2.9% to −1.4%]) (24 studies) and fasting blood glucose level (net change, −0.12 mmol/L [−2.2 mg/dL] [CI, −0.20 to −0.05 mmol/L {−3.6 to −0.9 mg/dL}]) (17 studies), and improved other cardiometabolic risk factors. Evidence for clinical events was limited. More intensive programs were more effective.

Limitations: Wide variation in diet and physical activity promotion programs limited identification of features most relevant to effectiveness. Evidence on clinical outcomes and in children was sparse.

Conclusion: Combined diet and physical activity promotion programs are effective at decreasing diabetes incidence and improving cardiometabolic risk factors in persons at increased risk. More intensive programs are more effective.

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Diabetes is a large and growing medical problem, and the costs to society are high and escalating. According to the latest figures from the Centers for Disease Control and Prevention (CDC), 29.1 million persons (9.3% of the U.S. population) have diabetes, and 1.7 million new cases are diagnosed annually (1). Worldwide, an estimated 387 million adults are living with diabetes, and this number is projected to increase to 592 million by 2035 (2). Prevalence of diabetes and related costs are expected to more than double in the next 25 years (3), given that more than 86 million Americans (37% of the adult population) are at risk for the disease (1). Effective prevention strategies are, therefore, critically important to slow the diabetes tide and its associated burden.

Nearly 9 out of 10 new diabetes cases are type 2 diabetes, which has a natural history characterized by a gradual increase in glycemia. Identification of persons at increased risk can enable the implementation of interventions to decrease the risk for progression to clinical diabetes. The American Diabetes Association has defined prediabetes as a high-risk category based on a glycemic level that does not meet criteria for diabetes but is too high to be considered normal (4). Persons with prediabetes progress to type 2 diabetes at a rate of about 5% to 10% per year without intervention (5). Three large clinical trials from the United States (6), Finland (7), and China (8) have shown that the primary components of diabetes prevention in adults are weight loss and increased physical activity. In these trials, among persons at risk for type 2 diabetes, rigorous application of combined diet and physical activity promotion programs, with the goals of weight loss and increased physical activity, reduced risk for diabetes by 50% to 60% during the active intervention period (3 to 6 years). Although attenuated, the effect of the intervention can persist in the long term (9–11). The results of these trials are well-known; however, wide-scale implementation of combined diet and physical activity promotion programs in clinical and community-based settings has only recently begun and requires further expansion (12).

See also:

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Combined diet and physical activity promotion programs aim to prevent type 2 diabetes among persons who are at increased risk for the disease. These programs actively encourage persons to improve their diet and increase their physical activity by using trained providers in various settings who work with clients for at least 3 months, providing some combination of counseling, coaching, and extended support in multiple sessions (delivered in person or by other methods) related to diet and physical activity. Programs may also include many other features, including specialized counselors; a range of number and frequency of sessions; different session types; and different diet, weight-loss, or exercise goals.

The purpose of this review was to assess the effectiveness of diet and physical activity promotion programs implemented in a wide range of clinical or community settings to reduce risk for new-onset diabetes among adults and children at risk for type 2 diabetes. The Community Preventive Services Task Force (Task Force) (www.thecommunityguide.org) used this review to update its guidance on diabetes prevention and to identify gaps in the evidence to inform future research. Potential effect modifiers, such as intensity and specificity of the programs, settings, and implementers, were evaluated. Furthermore, the potential benefit of the diabetes prevention programs extending to other cardiometabolic risk factors, such as overweight, high cholesterol level, and high blood pressure, was also assessed.

METHODS

This review was conducted in accordance with the methods of the Task Force (13, 14) and the highest standards for conducting systematic reviews (15, 16). We convened a panel of domain experts and stakeholders (Coordination Team) that, together with our Community Guide Technical Monitor and Task Force members, provided input on the protocol, feedback on the findings, conclusions, and evidence gaps.

Data Sources

We searched MEDLINE, the Cochrane Central Register of Controlled Trials, CAB Abstracts, Global Health, and Ovid HealthSTAR from 1991 through 27 February 2015 with no language restrictions. Table 1 of the Supplement (available at www.annals.org) shows the search strategy. We also screened reference lists of related systematic and narrative reviews and suggestions from the expert panel.

Study Selection

We included randomized, controlled trials and prospective nonrandomized comparative studies with at least 30 participants per group, as well as prospective single-group intervention studies with at least 100 participants. The population of interest was adults or children at increased risk for type 2 diabetes (that is, with prediabetes) as determined by glycemic measures or diabetes risk assessment tools. We included studies of participants with the metabolic syndrome (who are at increased risk for *both* diabetes and cardiovascular disease) and studies with participants who were chosen because they were at risk for *either* type 2 diabetes or cardiovascular disease. However, we excluded studies of participants with established type 2 diabetes or whose only risk factor was obesity or increased risk for cardiovascular disease (without explicit inclusion of participants with prediabetes). The implied or explicit intent of the diet and physical activity promotion programs had to be to prevent diabetes, and the programs had to include at least 2 contact sessions (in-person or virtual) over at least 3 months. Programs had to include both dietary and increased physical activity components and could be conducted in any outpatient setting. We allowed any type of advice to improve diet and increase physical activity (except for single-food or supplement dietary changes, such as addition of fish oil). We excluded interventions that included antidiabetic medications. The comparative studies had to include a usual care group (no active diet and physical activity promotion program) or a lower-intensity diet and physical activity promotion program (for example, one with fewer contact sessions or a more liberal diet). We required at least 6 months of follow-up for any of the following outcomes: incident diabetes, reversion to normoglycemia, body weight, glycemic measures (fasting glucose level, 2-hour glucose level after a 75-g oral glucose tolerance test, or hemoglobin A_{1c} [HbA_{1c}] level), all-cause death, diabetes-related clinical outcomes (such as cardiovascular events, end-stage renal disease, nephropathy, amputation, retinopathy, neuropathy, skin ulcers, or periodontitis), blood pressure (BP), and lipid levels (total, low-density lipoprotein [LDL], and high-density lipoprotein [HDL] cholesterol and triglycerides).

Data Extraction and Quality Assessment

We screened titles and abstracts using Abstrackr (17). Eight researchers double-screened the abstracts after iterative training of all reviewers on the same batches of abstracts. Discordant decisions and queries were resolved at group meetings. Full-text articles were retrieved for all potentially relevant abstracts and rescreened by the same researchers.

Data from each study were extracted by 1 of 7 experienced methodologists and confirmed by a senior methodologist; the same methodologists assessed study quality. Data extraction was conducted in the Systematic Review Data Repository (18) and included elements for study design, including eligibility criteria, population characteristics, detailed descriptions of the diet and physical activity promotion programs and comparison interventions, outcomes, and results. We assessed the quality of each study by using 12 Community Guide quality-of-execution questions (see the footnotes of Table 2 of the Supplement, available at www.annals.org) (14, 19). Per Community Guide protocol, we excluded studies with "limited quality of execution," defined as those with at least 5 major limitations.

Data Synthesis and Analysis

All extracted data were placed into summary evidence tables (available in the supporting materials at www.thecommunityguide.org/diabetes/combineddietandpa.html). Two studies that were conducted in children were not included in the meta-analyses and are reported separately. For outcomes with data from at least 3 comparative studies of diet and physical activity promotion versus usual care, we performed meta-analysis of the risk ratio (RR) or net change (20) using a profile likelihood random-effects model. For nonrandomized studies, we preferentially used results of adjusted analyses. Meta-analyses were conducted with the metaan package in Stata 13.1 (StataCorp). For the overall meta-analyses of incident diabetes and reversion to normoglycemia, we used data from the longest reported follow-up. For continuous outcomes, we used data closest to 1 year of follow-up, data restricted to less than 2 years of follow-up, and data from the longest follow-up. We evaluated differences in effect (for incident diabetes and weight only) using direct comparisons of different diet and physical activity promotion programs within studies, reported within-study subgroup analyses, and across-study metaregression (based on predetermined study setting and program features and using a random-effects model) across all programs. Incident diabetes and weight change were chosen for metaregression because of their relative importance in determining the effectiveness of diet and physical activity promotion programs. Metaregressions were conducted with the metareg package in Stata and were considered potentially significant if the *P* value was less than 0.10. For each outcome with at least 10 studies, we examined the possibility of publication bias with funnel plots and the Harbord test (for diabetes incidence) or the Egger test (for continuous outcomes) using the metabias and metafunnel packages in Stata (21).

Role of the Funding Source

One member of the Coordination Team and our Technical Monitor are employed by the CDC; none of the Task Force members are. The Coordination Team, the Technical Monitor, and members of the Task Force participated in the formulation of the study questions and the development of the protocol but did not participate in the literature search, the determination of study eligibility criteria, or data analysis or interpretation. The Coordination Team, the Technical Monitor, and CDC personnel were given an opportunity to provide feedback on the manuscript and the decision to submit the manuscript for publication, but the research team retained final determination of the content and the decision to publish the manuscript.

RESULTS

Appendix Figure 1 (available at www.annals.org) summarizes the search yield. Of 11 317 citations (plus articles from existing systematic reviews and suggestions from domain experts), 53 studies described 66 diet and physical activity promotion programs in 104 articles (6–11, 22–119). One additional study with 6 major limitations was excluded because of limited quality of execution (120). The included studies described 26 randomized and 4 nonrandomized comparisons of diet and physical activity promotion programs versus usual care, 11 randomized and 1 nonrandomized comparisons of 2 or more diet and physical activity promotion programs (3 of which also had usual care groups), and 13 single-group evaluations of diet and physical activity promotion programs. Thirty-three studies were of good quality (0 or 1 limitation), and 20 were of fair quality (2 to 4 limitations) (**Table 2** of the **Supplement**). The most common limitations were poor descriptions of the study populations or intervention programs, problems with data measurement or interpretation, and high dropout rates. Although half of the studies (*n* = 27) analyzed all enrolled participants, 9 had rates of dropout or loss to follow-up greater than 20%.

The characteristics of the diet and physical activity promotion programs are summarized in **Table 1**, and details are provided in **Tables 3** to **5** of the **Supplement** (available at www.annals.org). All but 5 programs (in 4 studies) lasted at least 6 months. Programs offered a wide range of number of contact sessions (0 [virtual contacts only] to 72; median, 15), and most included both a core period (with frequent contact sessions) and a maintenance period (with less frequent contact). Except for 7 programs that were delivered entirely over the Internet or by video, telephone, or e-mail, programs used in-person individual or group sessions (or both) on diet or exercise (or both). Sessions were led by different combinations of trained diet counselors, including dietitians or nutritionists (among others); trained exercise counselors, including physical trainers (among others); nurses; physicians or psychologists; or trained laypersons. Many programs included specific weight-loss, diet, or physical activity goals (**Table 1**). Some included individually tailored plans for diet and physical activity.

Table 2 summarizes the participant characteristics, with details provided in **Table 6** of the **Supplement** (available at www.annals.org). Thirty (57%) studies were restricted to participants with prediabetes, of which 21 used standard diagnostic criteria; 12 (23%) studies included only participants at increased risk for diabetes on the basis of a risk score. More than three quarters of the studies included mostly overweight or obese participants, and most study participants were female and at least middle-aged. Two studies were conducted in adolescents at increased risk for type 2 diabetes; these studies were analyzed separately. None of the studies reported any long-term harms directly related to the diet and physical activity promotion programs.

Incident Diabetes

Sixteen studies that compared diet and physical activity promotion programs versus usual care reported new-onset diabetes (6–9, 22–33); 2 studies each compared 2 programs with usual care. All but 3 were randomized trials (9, 22, 26). Incident diabetes was re-

Table 1. Characteristics of Combined Diet and Physical Activity Promotion Programs

Characteristic, by Category	Value
Median sessions (66 programs) (IQI; range), *n*	
Core	10 (6–16; 0*–72)
Maintenance†	6 (1.5–12; 0*–24)
Total	15 (6.5–24.5; 0*–72)
Median program duration (66 programs) (IQI; range), *mo*	
Core	6 (5–12; 1–60)
Maintenance†	12 (7–18; 4–68)
Total	12 (10–27; 3–72)
Program design (66 programs), *n (%)*‡	
Nominally based on DPP or DPS	27 (41)
Weight-loss goal (66 programs), *n (%)*‡	42 (64)
Diet intervention (66 programs), *n (%)*‡	
Individual sessions	40 (61)
Group sessions	41 (62)
Individual and group sessions	24 (36)
Individually tailored diet plan	16 (24)
Diet goal	19 (29)
Diet counselor	29 (44)
Physical activity intervention (67 programs), *n (%)*‡	
Individual sessions	41 (62)
Group sessions	39 (59)
Individual and group sessions	24 (36)
Individually tailored exercise plan	23 (35)
Exercise goal	32 (48)
Exercise counselor	18 (27)
Counselors (51 programs), *n (%)*‡	
Dietitian	37 (73)
Exercise therapist	26 (51)
Nurse	15 (29)
Layperson	13 (25)
Physician	8 (16)
Diabetes educator	3 (6)
Country (53 studies), *n (%)*	
United States/Canada	22 (42)
Western Europe/Australia	22 (42)
Japan	3 (6)
Middle-income§	6 (11)
Setting (41 studies), *n (%)*	
Community	12 (29)
Health care system	25 (61)
Worksite	0 (0)
Multiple	4 (10)
Location (53 studies), *n (%)*	
Urban	25 (47)
Regional	21 (40)
Suburban	2 (4)
Rural	1 (2)
Mixed	4 (8)

DPP = Diabetes Prevention Program; DPS = Diabetes Prevention Study; IQI = interquartile interval.
* In some programs, the contacts were by telephone, e-mail, Internet, or video only.
† 28 programs.
‡ Likely underestimated because of inadequate or unclear reporting in articles.
§ India (*n* = 3), Brazil (*n* = 1), China (*n* = 1), and Pakistan (*n* = 1).

Table 2. Characteristics of Study Participants

Characteristic, by Category	Value
Studies meeting eligibility criteria (53 studies), *n (%)*	
Prediabetes, IGT, or IFG	30 (57)
By ADA/WHO criteria	21 (40)
At increased risk for diabetes (by risk score)	12 (23)
Prediabetes or at increased risk for diabetes	4 (8)
Prediabetes or at increased risk for cardiovascular disease	4 (8)
Metabolic syndrome, with or without prediabetes	3 (6)
Body weight (47 studies)	
Median of mean BMI (IQI; range), *kg/m²*	31.2 (28.1–33.6; 23.8–39.7)
Hypertension (4 studies)	
Median participants (range), %	34.5 (30.6–50)
Female sex (39 studies)	
Median participants (IQI; range), %	65.3 (50.3–73.9; 13.5–90.5)
Age (39 studies)*	
Median of mean age (IQI; range), *y*	53.6 (48–57; 43.1–65.0)
Median ethnicity, %†	
White (13 studies) (range)	74 (18–89)
Black/African American (10 studies) (range)	18 (12–39)
Hispanic/Latino (8 studies) (range)	13 (3–38)
East Asian (5 studies)	100
Southeast Asian (6 studies)	100
Asian/Pacific Islander (4 studies)	4, 5, 15, and 17‡
Native American (4 studies)	1, 3, 6, and 100‡
Median education level, %	
Less than high school or equivalent (9 studies) (IQI; range)	14 (11–33; 5–64)
High school or some college (20 studies) (IQI; range)	30 (21–48; 10–69)
Bachelor's degree or equivalent (11 studies) (IQI; range)	28 (20–37; 14–52)
Graduate degree or equivalent (4 studies)	13, 15, 16, and 35‡

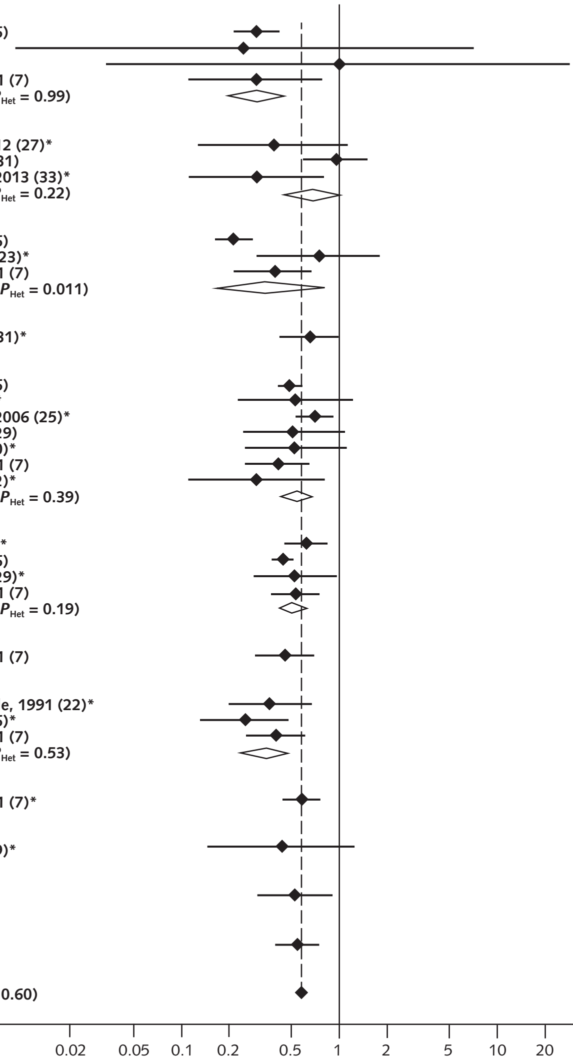
ADA = American Diabetes Association; BMI = body mass index; IFG = impaired fasting glucose; IGT = impaired glucose tolerance; IQI = interquartile interval; WHO = World Health Organization.
* Excludes 2 studies in adolescents.
† Excludes studies with 0% of an ethnicity.
‡ Percentages among relevant studies.

ported between 1 and 23 years from the start of the programs (**Figure 1**). Across studies, 0% (at 1 year) to 73% (at 23 years) of program participants developed diabetes. At all time points, program participants were less likely to develop diabetes. Across all studies, the summary RR for incident diabetes was 0.59 (95% CI, 0.51 to 0.66), with no statistical heterogeneity. The median risk difference across studies was −11 percentage points (interquartile interval, −16 to −5 percentage points). Funnel plot analysis did not find different effects between larger and smaller studies (Harbord test *P* = 0.27).

Both the U.S. DPP (Diabetes Prevention Program) study (6) and the Finnish DPS (Diabetes Prevention Study) (7) found statistically significantly larger effects in older participants, but although the latter found a non-

Figure 1. Random-effects model meta-analysis of RR of incident diabetes in at-risk participants in combined diet and physical activity promotion programs vs. usual care.

Study, Year (Reference)	RR (95% CI)	Rate, n/N (%): Diet and Physical Activity Promotion	Rate, n/N (%): Usual Care	RD (95% CI), *percentage points*
1 y				
Knowler et al, 2002 (6)	0.31 (0.22 to 0.43)	43/1079 (4)	141/1082 (13)	−9 (−11 to −7)
Ma et al, 2013 (28)*	0.25 (0.01 to 7.39)	0/81 (0)	1/81 (1)	−1 (−4 to 1)
Ma et al, 2013 (28)†	1.03 (0.03 to 31.2)	1/79 (1)	1/81 (1)	0 (−3 to 3)
Tuomilehto et al, 2001 (7)	0.30 (0.11 to 0.82)	5/265 (2)	16/257 (6)	−4 (−8 to −1)
Subtotal (I^2 = 0%; P_{Het} = 0.99)	0.31 (0.20 to 0.46)			
1.5 y				
Iqbal Hydrie et al, 2012 (27)*	039 (0.13 to 1.16)	ND/107	ND/82	ND
Vermunt et al, 2011 (31)	0.96 (0.60 to 1.53)	179/543 (7)	167/522 (7)	0 (−4 to 3)
Ramachandran et al, 2013 (33)*	0.64 (0.45 to 0.92)	50/271 (18)	73/266 (27)	−9 (−16 to −2)
Subtotal (I^2 = 0%; P_{Het} = 0.22)	0.71 (0.44 to 1.05)			
2 y				
Knowler et al, 2002 (6)	0.22 (0.16 to 0.29)	54/1079 (5)	249/1082 (23)	−18 (−21 to −15)
Oldroyd et al, 2006 (23)*	0.76 (0.31 to 1.86)	7/37 (19)	8/32 (25)	−6 (−26 to 14)
Tuomilehto et al, 2001 (7)	0.39 (0.22 to 0.70)	15/265 (6)	37/257 (14)	−9 (−14 to −4)
Subtotal (I^2 = 65%; P_{Het} = 0.011)	0.34 (0.17 to 0.85)			
2.5 y				
Vermunt et al, 2011 (31)*	0.67 (0.44 to 1.02)	223/543 (7)	240/522 (10)	−3 (−7 to 0)
3 y				
Knowler et al, 2002 (6)	0.50 (0.42 to 0.59)	155/1079 (14)	313/1082 (29)	−15 (−18 to −11)
Penn et al, 2009 (24)*	0.54 (0.23 to 1.24)	7/51 (14)	13/51 (25)	−12 (−27 to 3)
Ramachandran et al, 2006 (25)*	0.71 (0.54 to 0.94)	47/120 (39)	73/133 (55)	−16 (−28 to −4)
Roumen et al, 2008 (29)	0.52 (0.25 to 1.09)	11/61 (18)	19/60 (32)	−14 (−29 to 2)
Sakane et al, 2011 (30)*	0.53 (0.25 to 1.13)	9/103 (9)	18/110 (16)	−8 (−16 to 1)
Tuomilehto et al, 2001 (7)	0.42 (0.26 to 0.67)	22/265 (8)	51/257 (20)	−12 (−17 to −6)
Bhopal et al, 2014 (32)*	0.68 (0.27 to 1.69)	12/81 (15)	17/82 (21)	−6 (−18 to −6)
Subtotal (I^2 = 19%; P_{Het} = 0.39)	0.55 (0.44 to 0.68)			
4 y				
Costa et al, 2012 (26)*	0.64 (0.47 to 0.87)	61/333 (18)	63/219 (29)	−10 (−18 to −3)
Knowler et al, 2002 (6)	0.45 (0.39 to 0.51)	227/1079 (21)	508/1082 (47)	−26 (−30 to −22)
Roumen et al, 2008 (29)*	0.53 (0.29 to 0.97)	16/52 (31)	30/54 (56)	−25 (−43 to −7)
Tuomilehto et al, 2001 (7)	0.54 (0.37 to 0.78)	24/265 (9)	53/257 (21)	−12 (−18 to −6)
Subtotal (I^2 = 25%; P_{Het} = 0.19)	0.50 (0.42 to 0.66)			
5 y				
Tuomilehto et al, 2001 (7)	0.46 (0.30 to 0.70)	27/265 (10)	57/257 (22)	−12 (−18 to −6)
6 y				
Eriksson and Lindgärde, 1991 (22)*	0.37 (0.20 to 0.68)	17/161 (11)	16/56 (29)	−18 (−31 to −5)
Knowler et al, 2002 (6)*	0.26 (0.13 to 0.49)	11/1079 (1)	43/1082 (4)	−3 (−4 to −2)
Tuomilehto et al, 2001 (7)	0.40 (0.26 to 0.61)	27/265 (10)	59/257 (23)	−13 (−19 to −6)
Subtotal (I^2 = 0%; P_{Het} = 0.53)	0.36 (0.24 to 0.49)			
7 y				
Tuomilehto et al, 2001 (7)*	0.57 (0.43 to 0.76)	75/265 (28)	110/257 (43)	−14 (−23 to −6)
10 y				
Knowler et al, 2009 (9)*	0.44 (0.15 to 1.27)	4.8/100 PY (*n* = 1079)	11.0/100 PY (*n* = 1082)	−1 (−1 to 0)
20 y				
Pan et al, 1997 (8)	0.53 (0.30 to 0.93)	324/407 (77)	125/135 (90)	−13 (−20 to −5)
23 y				
Pan et al, 1997 (8)*	0.55 (0.40 to 0.76)	312/430 (73)	124/138 (90)	−17 (−24 to −11)
Overall (I^2 = 0%; P_{Het} = 0.60)	0.59 (0.51 to 0.66)			



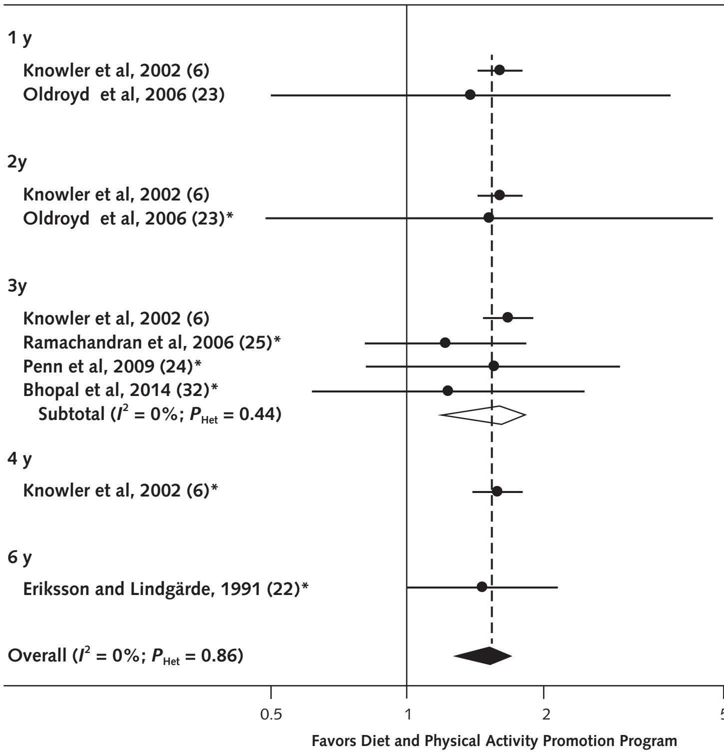
The meta-analysis of the overall RR (*black diamond*) used data from the longest follow-up from each study, as indicated by the asterisks. Subgroup meta-analyses by follow-up time (*open diamonds*) were conducted for time points with data from ≥3 studies. ND = no data; P_{Het} = chi-square *P* value of heterogeneity; PY = person-year; RD = risk difference; RR = risk ratio.
* Included in overall meta-analysis.
† To avoid biased meta-analyses due to inclusion of correlated analyses, this comparison between the lower-intensity intervention and control was excluded.

significant effect in the youngest age group (<51 years), the former found statistically significant effects in all age groups. Neither study found differences by sex. The DPP found no difference by race or ethnicity, and the DPS found no difference by educational attainment. The JDPP (Japan Diabetes Prevention Program) study reported a significant effect of diet and physical activity promotion programs among participants with baseline HbA_{1c} levels of at least 5.7% compared with those with lower levels, but it did not provide a statistical analysis of the difference between subgroups (34).

No significant differences across studies were found by setting; number of sessions; program duration; whether the program was based on the DPP or DPS approach; or inclusion of a weight-loss goal, individual or group diet or exercise sessions (analyzed separately), individually tailored diet plans, or diet or exercise counselors (analyzed separately). The 11 programs that included an individually tailored exercise plan (RR, 0.53 [CI, 0.45 to 0.63]) may have had a greater effect than the 5 that did not (RR, 0.67 [CI, 0.55 to 0.81]) (*P* = 0.070 for interaction).

Figure 2. Random-effects model meta-analysis of RR of reversion to normoglycemia in at-risk participants in combined diet and physical activity promotion programs vs. usual care.

Study, Year (Reference)	RR (95% CI)	Rate, *n/N* (%): Diet and Physical Activity Promotion	Rate, *n/N* (%): Usual Care	RD (95% CI), *percentage points*
1 y				
Knowler et al, 2002 (6)	1.59 (1.44 to 1.77)	550/1079 (51)	346/1082 (32)	19 (15 to 23)
Oldroyd et al, 2006 (23)	1.38 (0.50 to 3.81)	8/37 (22)	5/32 (17)	6 (−12 to 24)
2y				
Knowler et al, 2002 (6)	1.60 (1.43 to 1.78)	518/1079 (48)	325/1082 (30)	18 (14 to 22)
Oldroyd et al, 2006 (23)*	1.51 (0.49 to 4.70)	7/37 (20)	4/32 (13)	6 (−11 to 23)
3y				
Knowler et al, 2002 (6)	1.67 (1.46 to 1.89)	432/1079 (40)	260/1082 (24)	16 (12 to 20)
Ramachandran et al, 2006 (25)*	1.21 (0.80 to 1.83)	35/120 (29)	32/133 (24)	5 (−6 to 16)
Penn et al, 2009 (24)*	1.55 (0.81 to 2.97)	17/51 (33)	11/51 (22)	12 (−5 to 29)
Bhopal et al, 2014 (32)*	1.23 (0.62 to 2.46)	36/81 (44)	32/82 (39)	5 (−10 to 21)
Subtotal (I^2 = 0%; P_{Het} = 0.44)	1.60 (1.19 to 1.82)			
4 y				
Knowler et al, 2002 (6)*	1.58 (1.39 to 1.80)	470/1079 (38)	260/1082 (24)	14 (10 to 18)
6 y				
Eriksson and Lindgärde, 1991 (22)*	1.46 (1.00 to 2.14)	84/161 (52)	20/56 (36)	16 (2 to 31)
Overall (I^2 = 0%; P_{Het} = 0.86)	1.53 (1.26 to 1.71)			



The meta-analysis of the overall RR (*black diamond*) used data from the longest follow-up from each study, as indicated by the asterisks. Subgroup meta-analysis by follow-up time (*open diamond*) was conducted for the time point with data from >3 studies. P_{Het} = chi-square *P* value of heterogeneity; RD = risk difference; RR = risk ratio.
* Included in overall meta-analysis.

Six studies directly compared more intensive versus less intensive diet and physical activity promotion programs (28, 45, 47, 48, 50, 56). Compared with less intensive programs, more intensive programs had more sessions (4 studies); weight-loss, diet, or exercise goals (3 studies); or a maintenance phase, more intensive diet and exercise plans, an exercise physiologist, individual contact sessions, or in-person (vs. DVD) sessions (1 study each). All 5 studies that reported at least 1 case of incident diabetes found lower incidence with a more intensive program (RR, 0.28 to 0.56), but this was statistically significant in only 1 study (50) (**Appendix Figure 2**, available at www.annals.org).

Reversion to Normoglycemia

Six studies (5 trials and 1 nonrandomized study) that compared diet and physical activity promotion programs versus usual care reported reversion to normoglycemia as early as 1 year from the start of the intervention (**Figure 2**) (6, 22–25, 32). Across studies, between 20% (at 2 years) and 52% (at 6 years) of program participants reverted to normoglycemia. At 3 years (4 studies) and across time points, the summary RRs for achievement of normoglycemia were statistically significant, with an overall summary RR of 1.53 (CI, 1.26 to 1.71) and no statistical heterogeneity. The median risk difference across studies was 12 percentage points (interquartile interval, 6 to 14 percentage points). No within-study subgroup differences were reported, and no between-study subgroup differences were found. Three studies that directly compared more intensive versus less intensive programs (45, 47, 48) found effects favoring more intensive programs (RR, 1.58 to 2.11), 2 of which were statistically significant (47, 48) (**Appendix Figure 3**, available at www.annals.org).

Clinical Events

Three long-term studies reported all-cause mortality, 2 of which also reported cardiovascular mortality with no consistent pattern of results. The Da Qing study reported lower risk for all-cause death (hazard ratio [HR], 0.71 [CI, 0.51 to 0.99]) with diet and physical activity promotion after 23 years (10), but this effect was restricted to women and was not significant at earlier time points (HRs, 1.33 at 6 years and 0.96 at 20 years) (8). Knowler and colleagues (DPP study) (6) found no effect at 3 years (risk difference, −0.6 per 1000 person-years), and Uusitupa and coworkers (DPS) found no effect at 10 years (HR, 0.57 [CI, 0.21 to 1.58]) (105). Similar results were found for cardiovascular death, with significantly lower risk in the Da Qing study (HR, 0.59 [CI, 0.36 to 0.96]) at 23 years (10); this effect also was restricted to women and was not significant at earlier time points. The DPS found no significant effect on cardiovascular death at 3 years (RR, 0.50 [CI, 0.09 to 2.73]) (105). The Da Qing study reported a reduction in severe retinopathy at the 20-year follow-up (HR, 0.53 [CI, 0.29 to 0.99]) (71). Limited evidence suggested no significant effects on other clinical outcomes, including cardiovascular events (78, 95, 105), nephropathy (71), and neuropathy (71), often due to a lack of power.

Body Weight and Glycemia

The 24 studies that compared diet and physical activity promotion programs versus usual care and reported weight change all found net weight loss with diet and physical activity promotion (6, 7, 9, 22–24, 27–33, 35–41, 52–55), ranging from −0.2% to −10.5% of initial body weight (summary net change, −2.2% [CI, −2.9% to −1.4%]); however, the studies had high statistical heterogeneity (I^2 = 89%; P < 0.001) (**Figure 3**). Funnel plot analysis did not find different effects between larger and smaller studies (Egger test P = 0.51). We used metaregression to test the same covariables examined for incident diabetes, and the only variable for which effects differed across studies was whether programs were based on the DPP or the DPS approach. The 12 programs based on either approach yielded a net change of −3.0% (CI, −4.1% to −1.9%) compared with −1.6% (CI, −2.5% to −0.6%) for the 13 other programs (P = 0.051 for interaction). However, heterogeneity across studies remained high (residual I^2 = 95%). Across all 42 programs (not compared with usual care) (6, 7, 22, 23, 27–33, 35–51, 54–58), none of the factors explored by metaregression yielded statistically significant differences across studies. In contrast to the across-study analysis, 6 of the 10 studies that directly compared more intensive versus less intensive programs found statistically significantly greater weight loss with the more intensive programs (28, 35, 44, 45, 47–50, 56, 58) (**Appendix Figure 4**, available at www.annals.org).

Eighteen studies that compared diet and physical activity promotion programs versus usual care reported glycemic outcomes (6–9, 23, 28–32, 35–40, 52, 53). Overall, such programs improved measures of glycemia. Across studies, at follow-up durations closest to 1 year, fasting glucose level had a summary net change of −0.12 mmol/L (−2.2 mg/dL) (CI, −0.20 to −0.05 mmol/L [−3.6 to −0.9 mg/dL]) (17 studies; I^2 = 77%), 2-hour glucose level improved by −0.48 mmol/L (−8.6 mg/dL) (CI, −0.86 to −0.17 mmol/L [−15.5 to −3.1 mg/dL]) (11 studies; I^2 = 87%), and HbA_{1c} level improved by −0.08% (CI, −0.12% to −0.04%) (8 studies; I^2 = 0%) (**Table 7** of the **Supplement**, available at www.annals.org). Funnel plot analysis found no significant small-study effect for fasting glucose level (Egger test P = 0.54), but smaller studies were more likely to have large net reductions in 2-hour glucose level (P = 0.003). However, studies reporting significant effects on fasting glucose level were no more likely to report 2-hour glucose results than those with nonsignificant effects (P = 0.21). Across 8 studies that compared more intensive versus less intensive programs (28, 43–45, 48–50, 56) (**Table 8** of the **Supplement**, available at www.annals.org), the median net change in fasting glucose level was −0.11 mmol/L (−2.0 mg/dL) (range, −0.20 to 0.17 mmol/L [−3.6 to 3.0 mg/dL]), favoring more intensive programs; however, the difference was statistically significant in only 1 study (56). Among 4 studies (44, 45, 48, 50), the median net change in 2-hour glucose level was −0.37 mmol/L (−6.7 mg/dL) (range, −0.6 to −0.2 mmol/L [−11 to −3.6 mg/dL]), favoring more intensive programs; the difference was significant in 2 studies (48, 50). None of these studies reported on HbA_{1c} level.

Across the 31 diet and physical activity promotion programs (not compared with usual care) in 24 studies that reported on fasting glucose level (6–9, 23, 28–32, 36–39, 43–46, 48–50, 52, 53, 56), results differed on the basis of whether individual diet sessions and diet counselors were included. After adjustment for follow-up duration, programs with individual diet sessions (n = 25 of 31) or diet counselors (n = 22 of 31) yielded larger decrements in fasting glucose level (individual sessions: −0.24 vs. −0.02 mmol/L [−4.3 vs. −0.4 mg/dL] [P = 0.020]; counselors: −0.25 vs. −0.07 mmol/L [−4.5 vs. −1.3 mg/dL] [P = 0.034]).

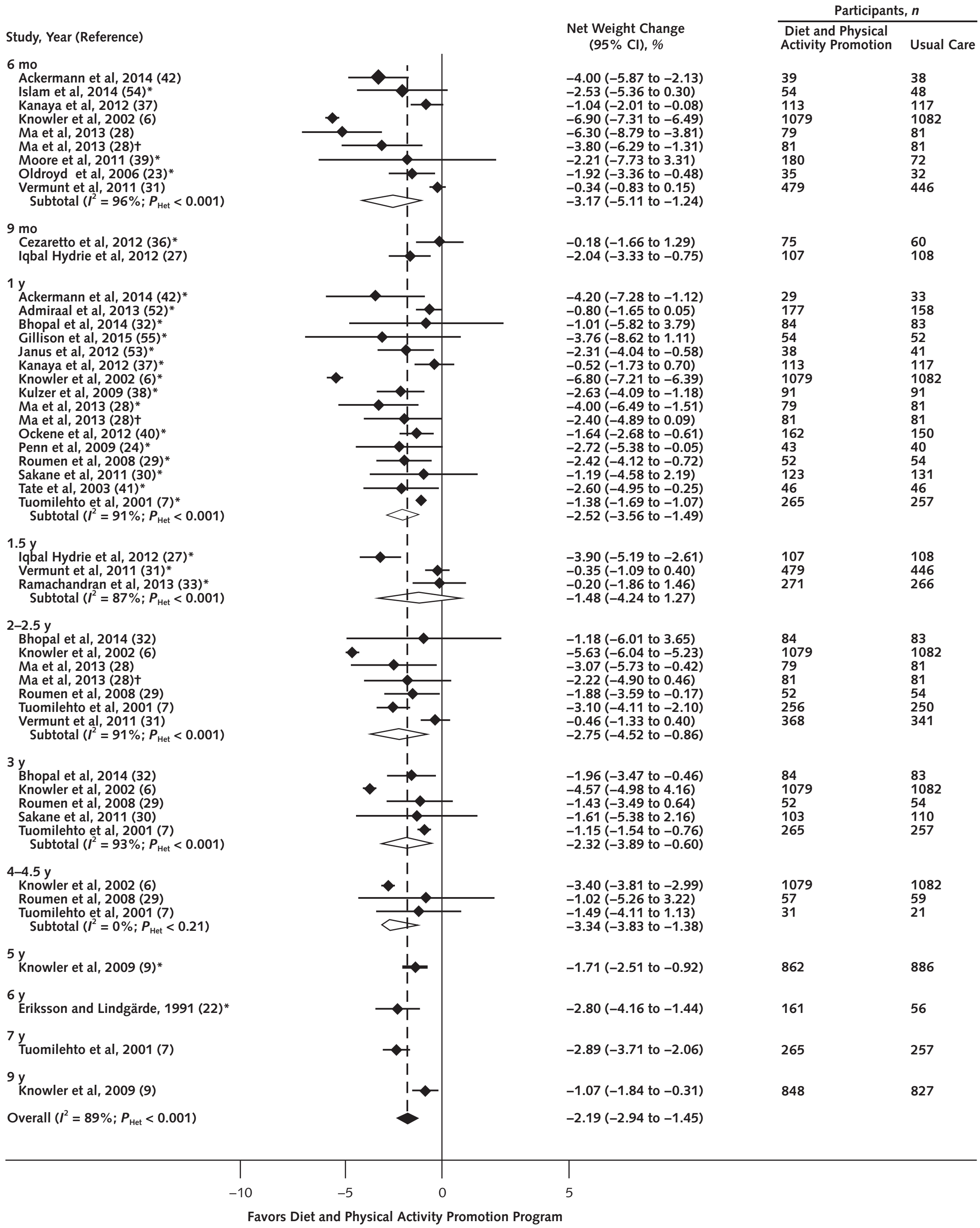
Blood Pressure and Lipid Levels

Across 17 studies comparing diet and physical activity promotion programs versus usual care (6, 7, 9, 22, 23, 28, 29, 32, 33, 35–39, 52–54), at follow-up durations closest to 1 year, the programs improved systolic BP (net change, −1.6 mm Hg [CI, −2.7 to −0.5 mm Hg]; I^2 = 45%) and diastolic BP (net change, −1.6 mm Hg [CI, −2.5 to −0.8 mm Hg]; I^2 = 73%) (**Table 9** of the **Supplement**, available at www.annals.org). We found no evidence of small-study effects (Egger test P = 0.51 for systolic BP and 0.83 for diastolic BP). Across 14 studies (7, 9, 22, 23, 28, 29, 33, 35–39, 52, 53), the programs also statistically significantly improved total cholesterol levels (net change, −0.05 mmol/L [−1.8 mg/dL] [CI, −0.12 to −0.002 mmol/L {−4.6 to −0.1 mg/dL}]) (12 studies; I^2 = 0%), LDL cholesterol levels (net change, −0.09 mmol/L [−3.3 mg/dL] [CI, −0.17 to −0.01 mmol/L {−6.4 to −0.3 mg/dL}]) (8 studies; I^2 = 0%), HDL cholesterol levels (net change, 0.03 mmol/L [1.2 mg/dL] [CI, 0.02 to 0.05 mmol/L {0.7 to 1.7 mg/dL}]) (12 studies; I^2 = 0%), and triglyceride levels (net change, −0.07 mmol/L [−6.5 mg/dL] [CI, −0.14 to −0.02 mmol/L {−12.7 to −1.8 mg/dL}]) (13 studies; I^2 = 38%) (**Table 10** of the **Supplement**, available at www.annals.org). No evidence of small-study effects was found (Egger test P = 0.17 for total cholesterol level, 0.75 for HDL cholesterol level, and 0.12 for triglyceride level).

Virtual Programs

Five studies evaluated programs that were conducted via Web tools, social networking, e-mail, text messaging, video, or a combination of these, with no

Figure 3. Random-effects model meta-analysis of net percentage of change in weight (from baseline) in at-risk participants in combined diet and physical activity promotion programs vs. usual care.



The meta-analysis of the overall net percentage of change in weight (*black diamond*) used data from follow-up durations closest to 1 y, as indicated by the asterisks. Subgroup meta-analyses by follow-up time (*open diamonds*) were conducted for time points with data from ≥3 studies. P_{Het} = chi-square *P* value of heterogeneity; RR = risk ratio.
* Included in overall meta-analysis.
† To avoid biased meta-analyses due to inclusion of correlated analyses, this comparison between the lower-intensity intervention and control was excluded.

in-person sessions (28, 33, 41, 42, 88). One study (28) found smaller but still significant improvements from baseline in weight (−5% vs. −7%) and fasting glucose level (−0.15 vs. −0.23 mmol/L [−2.7 vs. −4.2 mg/dL]) with a DVD compared with an in-person program. Two studies (41, 42) found effects on weight loss similar to those in studies with in-person sessions (−3% to −5% from baseline). One study in India (33) found that an intervention relying on text messages was effective compared with usual care, with lower diabetes incidence over 2 years (18% vs. 27%; HR, 0.64 [CI, 0.45 to 0.92]) and statistically significant net differences in HDL cholesterol and triglyceride levels but not weight, BP, or total cholesterol level. However, the fifth study (88), which was done in adolescents, found no effect on weight, although this was also true for a similar program with group sessions.

Programs in Adolescents

Two studies were conducted in adolescents. In the study by Savoye and associates (102), adolescents who participated in twice-weekly group sessions were significantly more likely to revert to normoglycemia, lose weight, and have lower fasting glucose levels and BP compared with a control group, but there was no change in lipid profile, except triglyceride levels. None developed diabetes during the 6-month follow-up. The study by Patrick and colleagues (88) evaluated 3 programs (Web, Web and text message, and Web and group session programs) and reported no difference in weight loss compared with a control group or between the more intensive and less intensive interventions after 6 and 12 months. The study did not report incident diabetes or fasting glucose outcomes.

DISCUSSION

Across a wide spectrum of diet and physical activity promotion programs, there is strong evidence of effectiveness in reducing new-onset diabetes. Among 16 studies, participants in these programs were consistently about 40% less likely to develop diabetes, but this outcome was evaluated in a minority (30%) of studies. Such programs also increase the likelihood of reversion to normoglycemia and improve diabetes and cardiometabolic risk factors, including overweight, high blood glucose level, high BP, and abnormal lipid profile. The effectiveness of these programs in reducing cardiovascular disease, diabetes-related complications, and death is yet to be determined because few studies reported these outcomes.

During protocol development, we searched MEDLINE and the Cochrane Database of Systematic Reviews for pertinent systematic reviews; none was found that was sufficiently up-to-date and that evaluated the breadth of outcomes and range of analyses evaluated in the current review. The most comprehensive review was a health technology assessment by Gillett and coworkers (121), whose search was conducted in 2011 but also included diet or exercise interventions (not in combination); 9 randomized trials were included. An updated search found 3 similar but more restrictive reviews published since 2013, which focused on narrower subsets of studies in adults. Schellenberg and associates (122) included 9 randomized trials of diet and physical activity promotion programs that had at least 1 other component. Dunkley and colleagues (123) included 25 studies (11 randomized trials) of programs that explicitly translated previous efficacy trials into community settings, but they also included studies of a broader population (such as obese or sedentary persons). Aguiar and coworkers (124) included only 8 studies (5 randomized trials) of diet and physical activity promotion interventions that included both aerobic and resistance training. The latter 2 reviews found effects on weight loss similar to those in our review (123, 124), and Aguiar and coworkers also found effects on fasting glucose levels similar to those in our review. In metaregression, Dunkley and colleagues found larger changes in weight with better alignment with lifestyle intervention attributes (123).

Evidence suggests that higher-intensity programs lead to greater weight loss and reduction in new-onset diabetes. Although the evaluated programs differed from each other too much to draw firm conclusions about the unique contributions of specific components, results from 12 studies that directly compared programs showed that persons who participated in more intensive programs (based on such features as number of sessions, individual sessions, and additional personnel) lost more weight and were less likely to develop diabetes. Effects on diabetes risk were similar across studies that compared programs with control groups; therefore, no differences based on differences in their programs could be ascertained. However, across all studies, programs that provided individual (vs. group) diet sessions resulted in greater reductions in fasting glucose levels, as did programs that used diet counselors (vs. no diet counselors). Programs based on the DPP study or the DPS (which were more intensive than many other programs) resulted in greater weight loss. More information on virtual delivery will be useful to increase the reach of effective programs.

On the basis of evidence from 2 of the larger studies (the U.S. DPP study and the Finnish DPS), findings seem to be applicable to wide populations (in Western countries) across race and ethnicity, socioeconomic status, risk factor status, and other demographic features. Except in 2 studies, all programs were conducted in adults; therefore, our results may not apply to children and adolescents. However, the benefit of diet and physical activity promotion programs is probably applicable to younger persons at risk for type 2 diabetes because adults and children share the mechanisms of the disease. Although most diabetes cases in children are type 1 diabetes, nearly all cases that develop from prediabetes are type 2 diabetes. Key aspects of the pathophysiology of type 2 diabetes are similar in persons of all ages; thus, the programs are likely to be effective regardless of age, assuming that they are effective at changing children's diet and physical activity. The one in-person program conducted in adolescents had effectiveness similar to that in programs conducted in adults; however, the other study of various virtual programs in adolescents found no effect on weight.

Additional studies comparing diet and physical activity promotion programs versus usual care (no program) will probably not change the overall conclusion about the effectiveness of such programs, except those in children and adolescents and, possibly, in specific populations or settings with gaps in data. However, several areas would benefit from future research. Because the available programs were highly heterogeneous and included many features, all of which likely interacted with each other, we were unable to explain the observed heterogeneity by whether programs included specific features. Furthermore, despite often protracted descriptions of the interventions, articles often did not clearly identify who led them or what the goals were or provide other details so that the intervention could be reproduced. Future studies that compare specific program features are needed to clarify which features (for example, individual vs. group sessions, few vs. many sessions, or differently trained counselors) optimize the effectiveness of the programs and which are less critical. The most effective way to structure the maintenance phase to help program participants maintain their improvements is also unclear. In addition, with the proliferation of mobile devices and applications, the effectiveness of virtual programs needs to be investigated further. Of note, long-term follow-up of existing community-based programs is needed to evaluate the durability of the programs' effects and their effects on clinical outcomes. Although this review did not specifically address participant attrition, a better understanding of typical attrition rates is needed to understand the reasons program participants drop out and to develop methods to retain them.

In conclusion, combined diet and physical activity promotion programs are effective in reducing new-onset diabetes, increasing reversion to normoglycemia, and improving diabetes and cardiometabolic risk factors in persons at increased risk for type 2 diabetes. Programs are effective across a wide range of features, but more intensive interventions seem to be more effective. Further research is needed to discern which specific program features are most important.

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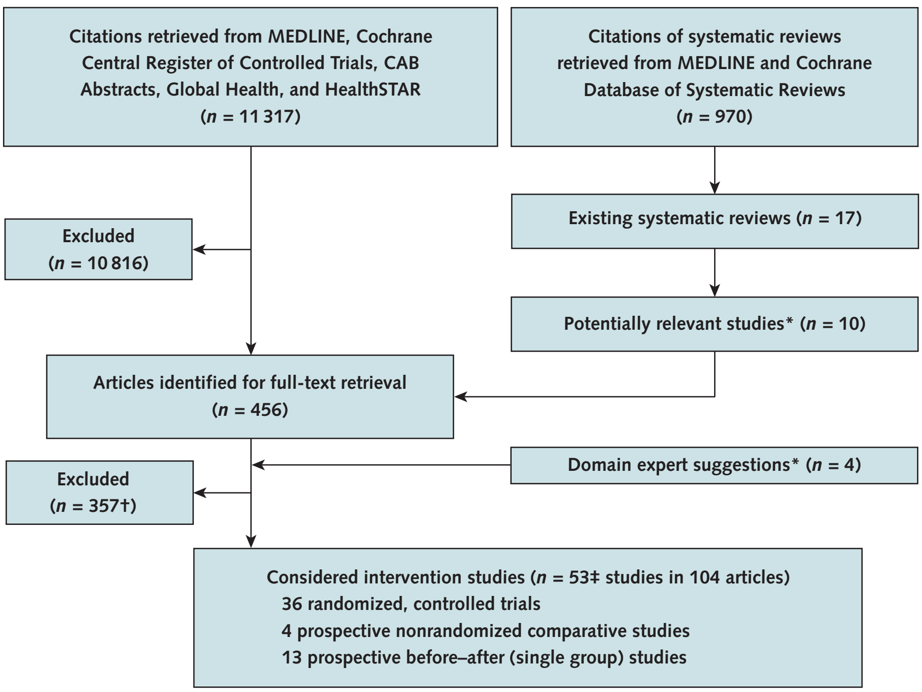
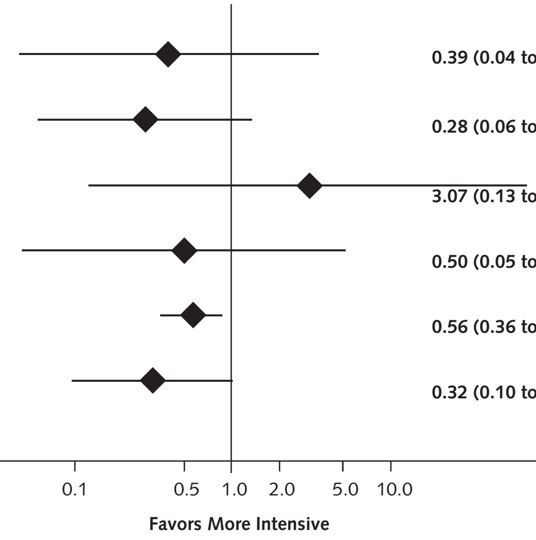
Appendix Figure 1. Summary of evidence search and selection.



* Not already screened.
† Not a population of interest (*n* = 70), diet or physical activity alone (*n* = 47), no outcome of interest reported (*n* = 36), not intervention of interest (*n* = 31), single-group study with <100 participants (*n* = 25), protocol or baseline data only (*n* = 21), not a primary study (*n* = 18), no additional data compared with included article (*n* = 18), cost-effectiveness analysis only (*n* = 15), <30 participants per group (*n* = 15), >10% of participants did not meet eligibility criteria (*n* = 15), intervention lasted <3 mo or involved only 1 session (*n* = 13), <6 mo of follow-up (*n* = 13), no analyses of interest (*n* = 10), abstract only (*n* = 6), retrospective study or retracted or unavailable article (*n* = 4).
‡ Excludes 1 prospective nonrandomized comparative study not analyzed because of limited quality of execution.

Appendix Figure 2. Forest plot of RR of incident diabetes in at-risk participants in more intensive vs. less intensive combined diet and physical activity promotion programs.

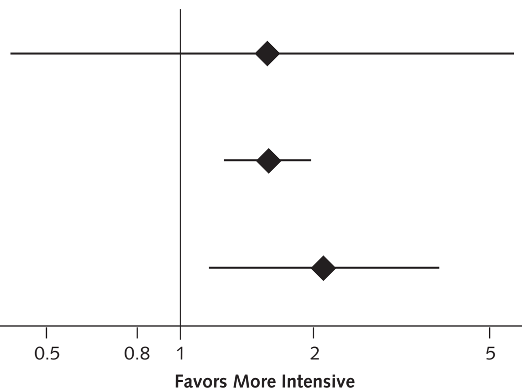
Study, Year (Reference)	Follow-up, *y*	RR (95% CI)	Rate, *n/N* (%): More Intensive	Rate, *n/N* (%): Less Intensive	RD (95% CI), *percentage points*
Gagnon et al, 2011 (45)	1	0.39 (0.04 to 3.52)	1/22 (5)	3/26 (12)	−7 (−22 to 8)
Katula et al, 2011 (56)	1	0.28 (0.06 to 1.34)	2/151 (1)	7/150 (5)	−3 (−7 to 0)
Ma et al, 2013 (28)	1.25	3.07 (0.13 to 74.37)	1/79 (1)	0/81 (0)	1 (−1 to 4)
Liao et al, 2002 (48)	2	0.50 (0.05 to 5.21)	1/29 (3)	2/29 (7)	−3 (−15 to 8)
Saito et al, 2011 (50)	3	0.56 (0.36 to 0.87)	35/311 (11)	51/330 (16)	−4 (−9 to 1)
Kosaka et al, 2005 (47)	4	0.32 (0.10 to 1.01)	3/102 (3)	33/356 (9)	−6 (−11 to −2)



RD = risk difference; RR = risk ratio.

Appendix Figure 3. Forest plot of RR of reversion to normoglycemia in at-risk participants in more intensive vs. less intensive combined diet and physical activity promotion programs.

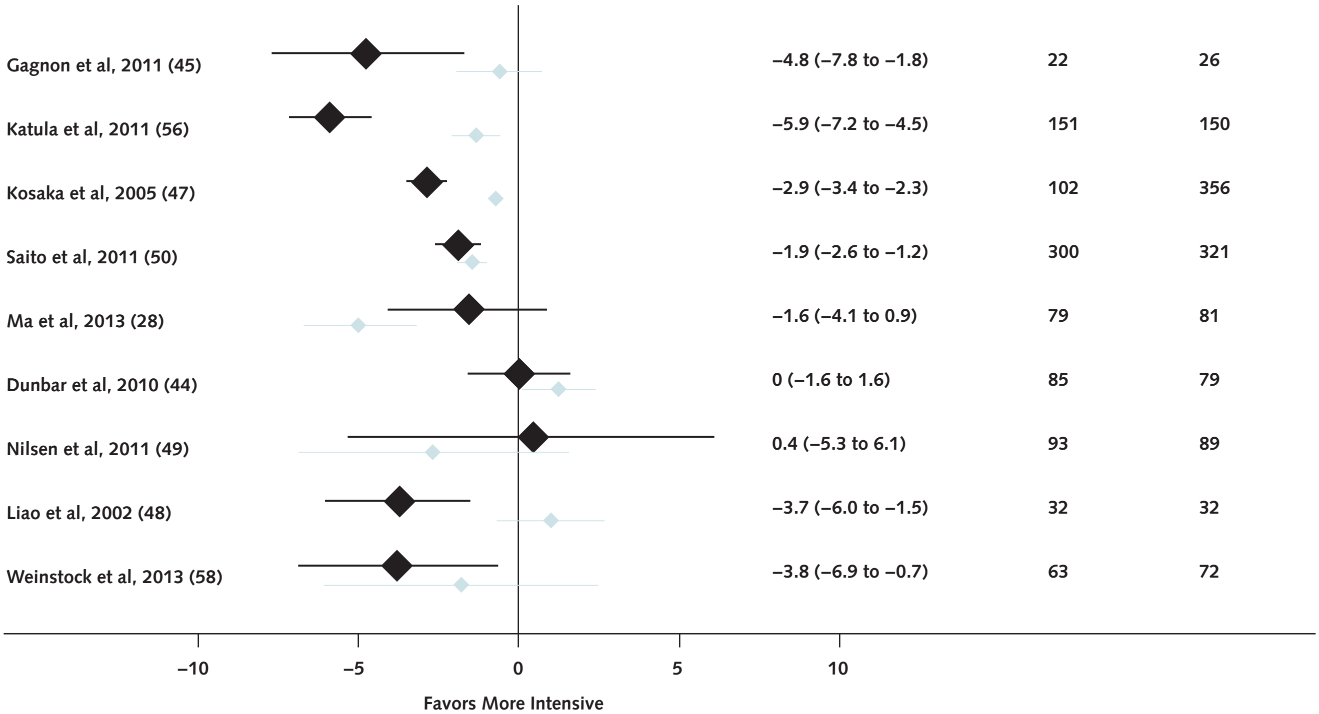
Study, Year (Reference)	RR (95% CI)	Rate, *n/N* (%): More Intensive	Rate, *n/N* (%): Less Intensive	RD (95% CI), *percentage points*
Gagnon et al, 2011 (45)	1.58 (039 to 6.30)	4/22 (18)	3/26 (12)	7 (−14 to 27)
Kosaka et al, 2005 (47)	1.59 (1.26 to 2.00)	55/102 (54)	121/356 (34)	20 (9 to 31)
Liao et al, 2002 (48)	2.11 (1.15 to 3.86)	19/29 (66)	9/29 (31)	34 (10 to 59)



RD = risk difference; RR = risk ratio.

Appendix Figure 4. Forest plot of net percentage of change in weight (from baseline) in at-risk participants in more intensive vs. less intensive combined diet and physical activity promotion programs.

Study, Year (Reference)	Net Weight Change, %	Participants, *n*: More Intensive	Participants, *n*: Less Intensive
Gagnon et al, 2011 (45)	−4.8 (−7.8 to −1.8)	22	26
Katula et al, 2011 (56)	−5.9 (−7.2 to −4.5)	151	150
Kosaka et al, 2005 (47)	−2.9 (−3.4 to −2.3)	102	356
Saito et al, 2011 (50)	−1.9 (−2.6 to −1.2)	300	321
Ma et al, 2013 (28)	−1.6 (−4.1 to 0.9)	79	81
Dunbar et al, 2010 (44)	0 (−1.6 to 1.6)	85	79
Nilsen et al, 2011 (49)	0.4 (−5.3 to 6.1)	93	89
Liao et al, 2002 (48)	−3.7 (−6.0 to −1.5)	32	32
Weinstock et al, 2013 (58)	−3.8 (−6.9 to −0.7)	63	72



Green lines show percentage of weight change in less intensive groups. The study by Ackermann and colleagues (35) was not included because it reported only that there was no significant difference between the more intensive and less intensive interventions at 12 mo (overall mean weight loss, 3.3% [CI, 2.7% to 3.9%]; *P* = 0.26 between interventions).