Title: Ethnic differences in response to lifestyle intervention for the prevention of type 2 diabetes in adults: a systematic review and meta-analysis

Running title: Ethnic differences in diabetes prevention

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Conflicts of interest statement

No potential conflicts of interest relevant to this article were reported.

Abstract

The risk of type 2 diabetes varies by ethnicity, but ethnic differences in response to diabetes prevention interventions remain unclear. This systematic review and meta-analysis assessed ethnic differences in the effects of lifestyle interventions on type 2 diabetes incidence, glycemic outcomes (fasting glucose, 2-h glucose, HbA_{1c}), anthropometric measures (weight, BMI, waist circumference) and lifestyle behaviours (physical activity, energy intake, energy from fat, fiber intake). MEDLINE, EMBASE and other databases were searched (to 15 June 2020) for randomized and non-randomized controlled trials on lifestyle interventions (diet and/or physical activity) in adults at risk of type 2 diabetes. Ethnicity was categorized into European, South Asian, East and Southeast Asian, Middle Eastern, Latin American and African groups. Forty-four studies (18,722 participants) were included in meta-analyses. Overall, lifestyle interventions resulted in significant improvement in diabetes incidence, glycemic outcomes, anthropometric measures, physical activity and energy intake (all $P<0.01$). Significant subgroup differences by ethnicity were found for 2-h glucose, weight, BMI and waist circumference (all $P<0.05$) but not for diabetes incidence, fasting glucose, HbA_{1c} and physical activity (all $P>0.05$). Few studies in non-European groups reported dietary intake. Lifestyle interventions in different ethnic groups likely have similar effects in reducing incidence of type 2 diabetes although this needs to be confirmed in further studies.

(207 words)

Abbreviations

US, United States

BMI, body mass index

RCT, randomized controlled trial

CI, confidence interval

OGTT, oral glucose tolerance test

RoB 2, Revised Cochrane Risk of Bias tool for Randomized Trials

ROBINS-I, Risk of Bias in Non-randomized Studies of Interventions

MD, mean difference

SMD, standardized mean difference

UK, United Kingdom

Introduction

Type 2 diabetes is a global public health challenge [1] and its prevalence varies widely by ethnicity [2]. In the US, the prevalence of diagnosed diabetes ranges from 14.7% in American Indians/Alaska Natives to 7.5% in white Americans [3]. In Europe, people of Latin American, East and Southeast Asian, Sub-Saharan African, Middle Eastern and North African, and South Asian origins are 1.3-3.7 times as likely to experience type 2 diabetes compared to white European populations [4]. The mechanism underlying the different risks of type 2 diabetes by ethnicity involves a complex interplay of biological, behavioural, social, environmental and healthcare system factors [2, 5]. Studies have documented that African, Latin American and Asian groups have greater insulin resistance independent of adiposity compared with people of European origin, accompanied by augmented insulin secretion or impaired insulin secretion [2, 6, 7]. The effect of body mass index (BMI) in predicting incident diabetes also differs by ethnicity, which has been shown to be the greatest in Asian populations who develop type 2 diabetes at a lower BMI characterized by excess visceral fat [8, 9]. These biological factors along with other contributors to the ethnic disparities in diabetes prevalence, such as suboptimal diet, physical inactivity, smoking and poor healthcare access [2, 7], may contribute to the differential responses to diabetes prevention interventions by ethnicity.

Large randomized trials have demonstrated that lifestyle modification can prevent or delay the onset of type 2 diabetes among high-risk individuals through weight management, increased physical activity and improved diet [10-13]. The US Diabetes Prevention Program examined the effects of lifestyle intervention in a large sample of ethnically diverse individuals and found no significant differences by ethnicity on the progression to type 2 diabetes [10], despite a significantly smaller weight loss among African-American women compared to white Americans, Hispanic Americans and African-American men [14]. Beyond this, evidence from systematic reviews on ethnic differences in the intervention effects for diabetes prevention is scarce. A systematic review [15] of 12 randomized controlled trials (RCTs) examined the effects of physical activity and diet in individuals with prediabetes from two ethnic groups. This study found that the "predominantly white" group had a better response to lifestyle intervention in reducing type 2 diabetes incidence (risk ratio 0.50, 95% confidence interval (CI) 0.43, 0.58) than the Asian group (risk ratio 0.68, 95%CI 0.56, 0.81; *P*=0.01), while no significant differences by ethnicity were found for fasting glucose, 2-h glucose and all-cause mortality. Another systematic review [16] of real-world studies showed a significant effect of lifestyle intervention on type 2 diabetes incidence in the white/European group (odds ratio 0.65, 95%CI 0.48, 0.87) but not in the Hispanic group (odds ratio 0.79, 95%CI 0.37, 1.67) with no data available on other ethnic groups. Other systematic reviews focused on a specific ethnic group without comparisons with other ethnic groups [17, 18]. None of the existing meta-analyses has investigated the effect of ethnicity on lifestyle behaviours [15-18] despite the key role of physical activity and diet in preventing type 2 diabetes [19]. Thus, there is a lack of a comprehensive comparison of the effects of lifestyle intervention for diabetes prevention across

all ethnic groups on glycemic, anthropometric and lifestyle behaviour outcomes. Understanding ethnic differences in response to lifestyle intervention for the prevention of type 2 diabetes is imperative to guide future efforts to implement diabetes prevention programs.

Therefore, this systematic review and meta-analysis aimed to assess differences in the effects of lifestyle intervention on type 2 diabetes incidence, glycemic outcomes, anthropometric measures and lifestyle behaviours between various ethnic groups.

Methods

Data sources and searches

Relevant studies were identified from MEDLINE, EMBASE, Pubmed, CINAHL, PsycInfo, Cochrane Central Register of Controlled Trials, Cochrane Pregnancy and Childbirth Group Trials Register, and EBM Reviews including Cochrane Database of Systematic Reviews, ACP Journal Club, Database of Abstracts of Reviews of Effects, Cochrane Methodology Register, Cochrane Clinical Answers, Health Technology Assessment and NHS Economic Evaluation Database. All databases were searched up to 15 June 2020. The search strategy included a combination of Medical Subject Headings (MeSH) and text words related to diabetes prevention and lifestyle interventions (see Table S1). The International Clinical Trials Registry Platform (http://apps.who.int/trialsearch/) was searched to identify relevant trials in 17 different international registries. The reference lists from identified systematic reviews were also hand searched for additional eligible studies. There was no language restriction and translations were obtained where possible. This systematic review and meta-analysis were conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [20]. The protocol was prospectively registered on PROSPERO (NO. CRD42020193503).

Study selection

RCTs and non-randomized controlled trials (non-RCTs) that compared lifestyle interventions (diet and/or physical activity) with controls (usual care, placebo, no intervention or minimal intervention) and aimed at preventing type 2 diabetes were included. To be eligible, studies had to include adults aged 18 years or older identified as being at risk of type 2 diabetes (e.g. prediabetes, high BMI, history of gestational diabetes, family history of diabetes, elevated diabetes risk score, metabolic syndrome), describe the ethnicity of the participants and report at least one of the following outcomes by ethnicity: diabetes incidence, fasting glucose, 2-h glucose during oral glucose tolerance test (OGTT), HbA_{1c}, body weight, BMI, waist circumference, physical activity, energy intake, energy from fat and fiber intake. The exclusion criteria included participants who were diagnosed with type 1 or type 2 diabetes, pregnant, or taking medications that would alter glycemic outcomes; interventions that did not involve diet or physical activity, or interventions that combined lifestyle with medications, supplements or surgeries; controls that were more

than usual care or minimal intervention (standard advice no more than once a year). All editorials, letters, commentaries, conference abstracts, dissertations, study protocols and reviews were excluded. All titles, abstracts and full texts were independently screened against the selection criteria for eligibility by two reviewers from a pool of four researchers (M.C., G.G.U., S.S. and C.J.B.). Any discrepancy was resolved by discussion or arbitration with a third reviewer (S.L.).

Data extraction

Study characteristics (study name, sample size, country, study population, follow-up length, intervention characteristics), participant characteristics (ethnicity, age, gender, baseline BMI, baseline glycemic level) and outcomes were extracted using a standardized form designed for this study. Primary outcomes included type 2 diabetes incidence (defined as fasting glucose ≥7.0 mmol/l, and/or 2-h glucose ≥11.1 mmol/l during OGTT, and/or HbA_{1c} ≥6.5%, or clinical diagnosis by a physician), glycemic outcomes (fasting glucose (mmol/l), 2-h glucose during OGTT (mmol/l), HbA_{1c} (%)) and anthropometric measures (body weight (kg), BMI (kg/m^2), waist circumference (cm)). Secondary outcomes were lifestyle behaviours (physical activity (steps/day, min/week, MET-min/week, or other exercise measurements), energy intake (kcal/day), energy from fat (%), fiber intake (g/day or g/1000 kcal)). For diabetes incidence, the number of diabetes cases at the end of intervention was extracted. For continuous outcomes, mean changes from baseline to the end of intervention or post-intervention means were extracted [21]. Change-from-baseline values were preferred to post-intervention values, when available. Authors were contacted for any missing information (e.g. study design, baseline data, outcome data). Data on multiple lifestyle intervention groups in one single study were combined as one intervention group where possible. If more than 80% of the study participants consisted of a particular ethnic group and no ethnic-specific data was reported, the overall result was deemed as the specific effect for the predominant ethnic group as in a previous systematic review [22]. Data were independently extracted by two reviewers from a pool of four researchers (M.C. G.G.U., S.S. and M.B.K.). Any disagreements were resolved by discussion or arbitration with a third reviewer (S.L.).

Risk of bias assessment

The quality of RCTs and non-randomized controlled trials were appraised using the Revised Cochrane Risk of Bias tool for Randomized Trials (RoB 2) [23] and the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool [24] respectively. The RoB 2 tool for individually randomized trials assesses bias in five domains (the randomization process, deviations from intended interventions, missing outcome data, measurement of the outcome, selection of the reported result), while for cluster-randomized trials, an additional domain (bias arising from the timing of identification or recruitment of participants within clusters) is included. The risk of bias for each domain of the RoB 2 tool was rated as low risk of bias, some concerns or high risk of bias. The ROBINS-I tool covers seven domains of bias (confounding, selection of participants

into the study, classification of interventions, deviations from intended interventions, missing data, measurement of outcomes, selection of the reported result). The risk of bias for each domain of the ROBINS-I tool was rated as low, moderate, serious or critical risk of bias, or no information. The overall risk of bias of each study was judged based on all the bias domains in the tools. Each study was independently appraised by two reviewers (M.C. and C.J.B.). Any discrepancy was resolved by discussion or arbitration with a third reviewer (S.L.).

Category of ethnicity

Ethnicity is a multifaceted construct that refers to a grouping of people based on shared characteristics including geographical and ancestral origins, cultural traditions, languages and religions [25]. In health research, ethnicity could be described by the study authors in several ways including race, ethnicity, name of the population, region or country of origin, region or country of birth and cultural background by region [25]. For this review, the ethnicity of participants was extracted as described by the authors of the included studies and subsequently categorized into one of the following six ethnic groups based on the World Bank regions [26]: European (white, Caucasian, Dutch, Danish, Australia-born, cultural background of Europe, Australia and New Zealand), South Asian (Indian, Bangladeshi, South Asian, South Asia-born), East and Southeast Asian (Chinese, Japanese, Korean, Thai, Filipino, Malay), Middle Eastern (Arab, Jordanian, Jewish, Bedouin), Latin American (Latino, Hispanic) and African (African American, cultural background of Africa) (Table 1). No studies on Indigenous groups (defined by the authors as Indigenous, Aboriginal or Native peoples) meeting the selection criteria were included in this review. If multi-ethnicities were included in one study and no ethnic-specific data was reported, the predominant ethnicity comprising at least 80% of the participants was used to define the ethnic group of the study as in a previous systematic review [22].

Data synthesis and analysis

Random-effects meta-analysis models adjusted by the Hartung-Knapp-Sidik-Jonkman method [27] were used to pool the intervention effects. Dichotomous outcomes (diabetes incidence) were expressed as risk ratios with 95% CIs using the DerSimonian-Laird estimator. Continuous outcomes were expressed as weighted mean differences (MDs) (glycemic outcomes, anthropometric measures, energy intake, energy from fat) or standardized mean differences (SMDs) (physical activity, fiber intake) with 95% CIs using the restricted maximum-likelihood estimator [28]. Subgroup analyses by ethnicity were conducted for each outcome to examine the effect of ethnicity with its significance being tested using the Chi^2 test. Effect sizes were visually presented using the forest plots. Homogeneity between the studies was assessed with the I^2 test where I^2 >50% indicates substantial heterogeneity [21]. To further explore the sources of heterogeneity between studies, subgroup analyses were also conducted on primary outcomes by age (<50 years or ≥50 years), gender (female <60% or ≥60%), baseline BMI (<30 kg/m^2 or ≥30 kg/m^2), prediabetes status at inclusion, follow-up

length (≤12 months or >12 months) and study design (RCT or non-RCT). Sensitivity analyses were undertaken to explore the effect of risk of bias on the overall estimate of primary outcomes. Publication bias was examined using the funnel plots and Egger's test when 10 or more studies were present. A two-sided *P* value <0.05 was considered statistically significant for all analyses. Analyses were performed using the meta package in R version 4.0.3 (Free Software Foundation, Inc. 1991, 1999, Boston, US).

Results

Identified studies

The search identified 17,374 articles as shown in Figure 1. After removing duplicates, 9,489 abstracts and titles were screened of which 744 were selected for full-text screening. Of these, 62 articles with 45 studies were included in this systematic review and 44 studies in meta-analyses. One study [29] was excluded from the meta-analysis due to insufficient data for analysis despite meeting inclusion criteria of reporting outcomes by ethnicity (i.e. standard deviations were not reported and the authors could not be contacted).

Study characteristics

The 45 included studies enrolled 18,789 participants across 14 countries. Fifty-three percent of the participants were female. The mean age ranged from 32.8 [30] to 63.9 [31] years. The mean BMI varied from 21.7 [32] to 36.4 [33] kg/m^2. About half of the studies were conducted in the US (n=15) and India (n=7), while the rest were studies from the UK (n=3), the Netherlands (n=3), Denmark (n=1), Australia (n=4), China (n=3), Japan (n=1), Thailand (n=2), Malaysia (n=1), Bangladesh (n=1), Saudi Arabia (n=2), Israel (n=1) and Jordan (n=1). The most frequently reported ethnicity in the studies was the European ethnic group (n=12), followed by South Asian (n=10), East and Southeast Asian (n=10), Middle Eastern (n=4), Latin American (n=3) and African ethnic groups (n=2). Four studies [14, 30, 34, 35] reported people of different ethnicities, including European, Asian, Latin American or African ethnic groups. Twenty-seven studies recruited participants who had prediabetes at baseline and six studies only included women with a history of gestational diabetes. All the studies had a combination of physical activity and diet intervention, except one [36], which included diet intervention only. The interventions lasted from 1.5 [33] to 72 [11] months. The incidence of type 2 diabetes was defined based on OGTT (n=11), fasting glucose (n=4), HbA_{1c} (n=1), or a combination of these measures (n=1). Study characteristics and participant characteristics of the included studies are presented in Table 1 and Table S2. Participant characteristics by ethnic groups are shown in Table S3.

Risk of bias assessment

As is summarized in Table S4-6, the majority of studies (40/45 studies) had an overall high or serious risk of bias, with the exception of two with some concerns [14, 37] and three with low risk of bias [38-40]. The overall high risk of bias mainly derived from the bias in deviations from intended interventions (39/45) due to low adherence to the interventions (less than 80% of participants completing intervention sessions or intervention

components), absence of fidelity measures of implementation (e.g. checklist, manual, session recording) or insufficient reporting on these measures. For all the randomized trials, about half (23/43) had a low risk of bias in the randomization process, achieved through the random allocation sequence, adequate allocation sequence concealment and balance between the intervention and control groups at baseline. For the cluster-randomized trials, all had a low risk of bias arising from the timing of identification or recruitment of participants within clusters, except one with some concerns [41] as no information was provided on this domain. For the non-randomized trials, one was at low risk of bias [40] and one at serious risk of bias [42] due to confounding. Both of the non-randomized trials were at low risk of bias in the selection of participants into the study and in the classification of interventions. Most of the included studies (30/45) had a low risk of bias in missing outcome data. All studies had a low risk of bias in the measurement of outcome except two studies [42, 43], where insufficient details were reported for the condition of glucose measurement (i.e. fasting or post-load) and thus resulted in high or serious risk of bias in this domain. Over half of the studies (30/45) had some concerns or moderate risk of bias in selection of the reported result mainly as no pre-specified analysis plan was found.

Meta-analysis

Diabetes incidence and glycemic outcomes

Lifestyle interventions resulted in a significantly lower risk of developing type 2 diabetes and greater reduction in fasting glucose, 2-h glucose and HbA_{1c} compared with controls (all $P<0.01$; Table 2 and Figure S1-4). No heterogeneity was present in diabetes incidence ($I^2=0\%$), while substantial heterogeneity ($I^2>50\%$) was seen in all glycemic outcomes. Significant subgroup differences by ethnicity were observed for 2-h glucose ($P=0.038$), with significant improvement in 2-h glucose only found in the East and Southeast Asian group (MD -1.04 mmol/l, 95%CI -2.04, -0.04, $I^2=90\%$). There were no significant subgroup differences for diabetes incidence, fasting glucose and HbA_{1c} (all $P>0.05$).

Subgroup analyses by age, gender, baseline BMI, prediabetes status at inclusion, follow-up length and study design for diabetes incidence and glycemic outcomes are shown in Table S7-8. The one non-RCT included in the subgroup analyses had a significant greater reduction in fasting glucose and HbA_{1c} compared with RCTs (both $P<0.001$). Lower baseline BMI (<30 kg/m^2) and prediabetes at inclusion were significantly associated with a greater improvement in 2-h glucose ($P=0.037$ and $P<0.001$ respectively). No other significant associations were seen in the subgroup analyses with diabetes incidence and glycemic outcomes (all $P>0.05$).

Anthropometric outcomes

Lifestyle interventions produced significantly greater improvement in body weight, BMI and waist circumference in comparison to controls (all $P<0.001$; Table 3 and Figure S5-7). There was substantial

heterogeneity (I^2>50%) in each of the anthropometric outcomes. Significant subgroup differences by ethnicity were seen in all anthropometric measures (all P<0.001). All ethnic groups had a significant reduction in weight, BMI or waist circumference, with the exception of the African group who exhibited no significant changes in these outcomes.

Subgroup analyses by age, gender, baseline BMI, prediabetes status at inclusion, follow-up length and study design showed higher baseline BMI (≥30 kg/m^2) was significantly associated with greater weight loss (P=0.002; Table S9); shorter follow-up length (≤12 months) was significantly associated with a greater reduction in BMI (P=0.001); higher mean participant age (≥50 years) and shorter follow-up length (≤12 months) were significantly associated with a greater reduction in waist circumference (P=0.016 and P<0.001 respectively). No other significant associations were seen in the subgroup analyses for anthropometric outcomes (all P>0.05).

Lifestyle behaviours

Lifestyle interventions resulted in significantly increased physical activity and reduced total energy intake compared with control groups, with no significant effect in energy from fat and fiber intake (Table S10 and Figure S8-11). There was substantial heterogeneity (I^2>50%) in energy intake and energy from fat. Significant subgroup differences by ethnicity were found in energy intake and energy from fat (both P<0.001), but not in physical activity and fiber intake (both P>0.05). Of note, apart from the European group, few studies in other ethnic groups reported dietary intake.

Sensitivity analyses

In the sensitivity analyses, studies with low or moderate risk of bias showed a greater effect on weight loss (MD -3.53 kg, 95%CI -5.40, -1.65) than those with high risk of bias (MD -1.80 kg, 95%CI -2.41, -1.18; P=0.036). There was no significant effect of risk of bias on other primary outcomes (all P>0.05).

Publication bias was found for studies reporting weight and waist circumference, suggested by asymmetrical funnel plots and significant Egger's tests (P=0.025 and P<0.001 respectively). No publication bias was indicated for other outcomes (Figure S12).

Discussion

To our knowledge, this is the first systematic review to comprehensively evaluate differences in the effects of lifestyle interventions on type 2 diabetes incidence, glycemic outcomes, anthropometric measures and lifestyle behaviours between various ethnic groups, including in individuals from European, South Asian, East and Southeast Asian, Middle Eastern, Latin American and African groups. Meta-analysis showed that lifestyle interventions resulted in significant improvement in diabetes incidence, glycemic outcomes,

anthropometric measures, physical activity and energy intake, as consistent with previous systematic reviews [44-47]. Subgroup analyses showed significant differences by ethnicity for intervention effects on 2-h glucose, weight, BMI and waist circumference, while no ethnic differences were found for diabetes incidence, fasting glucose, HbA_{1c} and physical activity.

Our study showed that lifestyle interventions significantly reduced diabetes incidence, fasting glucose and HbA_{1c} with no differences between ethnic groups for these outcomes. The absence of ethnic differences in these key indicators of diabetes status suggests that current diabetes prevention programs aiming at weight loss, increasing physical activity and improving diet are broadly effective in reducing the progression to type 2 diabetes in high-risk individuals regardless of ethnicity. This is consistent with the findings in the US Diabetes Prevention Program that all ethnic groups benefited similarly from lifestyle intervention in preventing the development of type 2 diabetes [10]. However, our study observed ethnic differences in 2-h glucose on OGTT with significant reduction only found in the East and Southeast Asian group (e.g. Chinese, Thai, Malay) and not in other ethnic groups. In contrast, a previous systematic review [15] found no significant ethnic differences in 2-h glucose in response to diet and physical activity for diabetes prevention between the Asian and "predominantly white" groups, however, the Asian group in the review included South Asians who have a different diabetes risk profile from East and Southeast Asian populations [2]. Previous studies have shown that individuals of certain Asian origins such as Chinese and Thai had greater postprandial glycemic response than people of European origin [48-50], which may lend itself to greater improvement in 2-h glucose with lifestyle intervention as seen in the current study. Nevertheless, heterogeneity remained high within subgroups in our study. Subgroup analyses exploring the sources of heterogeneity suggested other participant characteristics such as baseline BMI and baseline prediabetes status may have also contributed to the heterogeneity in the outcomes. Given the similar benefits of lifestyle interventions across all ethnic groups on key diagnostic features of diabetes including diabetes incidence, fasting glucose and HbA_{1c} reported in our study, future efforts of lifestyle modification for type 2 diabetes prevention should focus on how to reach and engage the various ethnic groups around the world.

Regarding anthropometric measures, we found significant ethnic differences in the effects of lifestyle intervention on body weight, BMI and waist circumference. A significant reduction in body weight, BMI or waist circumference was found in all ethnic groups except in the African group. Success in weight loss after 6 months of lifestyle intervention has previously been demonstrated in African Americans, although a smaller amount of weight loss was achieved compared with white Americans [51]. Future work is needed to develop culturally tailored interventions specific to this group to optimize diabetes prevention in this population. Weight loss is the primary driver of diabetes risk reduction, with every kilogram of weight loss associated with a 16% reduction in risk [52]. The effect of weight loss in reducing type 2 diabetes incidence

was found to be equal in all ethnic groups, regardless of age, sex, level of physical activity and initial BMI categories [52]. Despite significant ethnic differences in anthropometric outcomes reported in our study, these were not sufficient to result in differential responses in diabetes incidence, fasting glucose and HbA_{1c} which remained the same across ethnic groups. Similar improvement in diabetes incidence despite differential responses in anthropometric changes supports the benefits of lifestyle modification beyond weight loss in type 2 diabetes prevention [52], particularly in certain ethnic groups.

In terms of lifestyle behaviours, we found lifestyle interventions significantly increased physical activity with no differences between ethnic groups. However, lifestyle behaviour outcomes particularly dietary intake were rarely reported in non-European ethnic groups. When reported, physical activity and dietary intake were often measured using a variety of tools and measures (e.g. self-reported diet quality scores), which could not be benchmarked against the physical activity or dietary related diabetes prevention goals. The main goals of current diabetes prevention programs include 3-7% weight loss, increased physical activity, reduced total and saturated fat intake, and increased intake of dietary fiber [53]. Physical activity and healthy diet play an important role in type 2 diabetes prevention, not only through promoting weight loss but also through independent effects to reduce diabetes risk [52, 54]. In the US Diabetes Prevention Program, the achievement of physical activity and dietary goals provided a further reduction in diabetes risk in addition to the achievement of the weight loss goal [52]. Similarly, the Finnish Diabetes Prevention Study also showed the number of goals (weight, diet, physical activity) achieved incrementally decreased the risk of developing type 2 diabetes [54]. Physical activity, healthy diet and their resulting weight loss can improve insulin sensitivity and protect β-cell function to prevent or slow the progression to type 2 diabetes in high-risk individuals [55, 56]. Such benefits could last for at least 24 years after discontinuation of the active intervention [57]. Considering the clinical significance of physical activity and diet in type 2 diabetes prevention, future studies should consistently report lifestyle behaviour outcomes using standardized tools.

The unique strength of this systematic review is the comprehensive assessment of differential responses to lifestyle intervention in a wide range of ethnic groups (European, South Asian, East and Southeast Asian, Middle Eastern, Latin American and African) across glycemic, anthropometric and lifestyle behaviour outcomes on type 2 diabetes prevention. However, this study has several limitations. First, the ethnicity data collected in our study was as described by the authors of the included studies. The way in which ethnicity was described lacks consistency across the studies (including race, ethnicity and proxies such as country of birth). This has been acknowledged as a major challenge on ethnicity studies in health research [25, 58]. Second, we used the predominant ethnicity comprising at least 80% of the population to define the ethnic group for some studies (13/45 studies) as done in a previous systematic review [22]. The presence of other ethnicities, although in small proportions, could have confounded the effect sizes of the particular ethnic group in the

same study. Third, the majority of included studies were rated as overall high risk of bias, mainly caused by suboptimal adherence to the intervention which is a common challenge in clinical trials [59]. We also detected that smaller studies with larger weight loss and smaller studies with null or greater increase in waist circumference were less likely to be published. Fourth, due to the small number of studies in some ethnic groups (e.g. Middle Eastern, Latin American, African), the subgroup analyses for some outcomes may not be powered for statistical significance. Insufficient studies also limit the capacity for pairwise comparisons between subgroups in this study. Furthermore, the included studies were of high heterogeneity. After stratified by ethnicity, large heterogeneity was still present within some subgroups for most outcomes, suggesting the heterogeneity could be attributable to factors other than ethnicity such as baseline BMI and follow-up length as identified in the subgroup analyses. Last, the Latin American and African groups included in our study were mainly from the populations residing in the US, as such their findings may not be generalizable to participants residing in other countries. Therefore, the results from this review should be interpreted with caution in light of the present limitations.

In conclusion, our findings suggest lifestyle interventions across ethnic groups likely have similar effects in reducing type 2 diabetes incidence, fasting glucose and HbA_{1c}, with opportunities to further optimize 2-h glucose and anthropometric outcomes in certain ethnic groups. Considering the growing burden of type 2 diabetes worldwide, future efforts could assume similar effects of lifestyle interventions across ethnic groups in terms of reducing the incidence of type 2 diabetes and instead focus on how to reach different ethnic groups in diabetes prevention programs to optimize engagement and subsequent health outcomes.

References

1 IDF. IDF Diabetes Atlas: Ninth edition. International Diabetes Federation: Brussels, Belgium 2019.

2 Spanakis EK, Golden SH. Race/ethnic difference in diabetes and diabetic complications. *Curr Diab Rep*. 2013; 13: 814-23.

3 CDC. National Diabetes Statistics Report, 2020. Centers for Disease Control and Prevention, U.S. Department of Health and Human Services: Atlanta, GA 2020.

4 Meeks KA, Freitas-Da-Silva D, Adeyemo A, Beune EJ, Modesti PA, Stronks K, *et al.* Disparities in type 2 diabetes prevalence among ethnic minority groups resident in Europe: a systematic review and meta-analysis. *Intern Emerg Med*. 2016; 11: 327-40.

5 Goff LM. Ethnicity and Type 2 diabetes in the UK. *Diabet Med*. 2019; 36: 927-38.

6 Goff LM, Ladwa M, Hakim O, Bello O. Ethnic distinctions in the pathophysiology of type 2 diabetes: a focus on black African-Caribbean populations. *Proc Nutr Soc*. 2020; 79: 184-93.

7 Mehta A, Singh S, Saeed A, Mahtta D, Bittner VA, Sperling LS, *et al.* Pathophysiological Mechanisms Underlying Excess Risk for Diabetes and Cardiovascular Disease in South Asians: The Perfect Storm. *Curr Diabetes Rev*. 2020.

8 Chan JC, Malik V, Jia W, Kadowaki T, Yajnik CS, Yoon KH, *et al.* Diabetes in Asia: epidemiology, risk factors, and pathophysiology. *Jama*. 2009; 301: 2129-40.

9 Ramachandran A, Snehalatha C, Vijay V. Low risk threshold for acquired diabetogenic factors in Asian Indians. *Diabetes Res Clin Pract*. 2004; 65: 189-95.

10 Knowler WC, Barrett-Connor E, Fowler SE, Hamman RF, Lachin JM, Walker EA, *et al.* Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. *N Engl J Med*. 2002; 346: 393-403.

11 Pan XR, Li GW, Hu YH, Wang JX, Yang WY, An ZX, *et al.* Effects of diet and exercise in preventing NIDDM in people with impaired glucose tolerance. The Da Qing IGT and Diabetes Study. *Diabetes care*. 1997; 20: 537-44.

12 Ramachandran A, Snehalatha C, Mary S, Mukesh B, Bhaskar AD, Vijay V. The Indian Diabetes Prevention Programme shows that lifestyle modification and metformin prevent type 2 diabetes in Asian Indian subjects with impaired glucose tolerance (IDPP-1). *Diabetologia*. 2006; 49: 289-97.

13 Tuomilehto J, Lindström J, Eriksson JG, Valle TT, Hämäläinen H, Ilanne-Parikka P, *et al.* Prevention of type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance. *N Engl J Med*. 2001; 344: 1343-50.

14 West DS, Prewitt T, Bursac Z, Felix HC. Weight loss of black, white, and Hispanic men and women in the diabetes prevention program. *Obesity*. 2008; 16: 1413-20.

15 Hemmingsen B, Gimenez-Perez G, Mauricio D, Roqué IFM, Metzendorf MI, Richter B. Diet, physical activity or both for prevention or delay of type 2 diabetes mellitus and its associated complications in people at increased risk of developing type 2 diabetes mellitus. *Cochrane Database Syst Rev*. 2017; 12: Cd003054.

16 Galaviz KI, Weber MB, Straus A, Haw JS, Narayan KMV, Ali MK. Global Diabetes Prevention Interventions: A Systematic Review and Network Meta-analysis of the Real-World Impact on Incidence, Weight, and Glucose. *Diabetes Care*. 2018; 41: 1526-34.

17 Jenum AK, Brekke I, Mdala I, Muilwijk M, Ramachandran A, Kjøllesdal M, *et al.* Effects of dietary and physical activity interventions on the risk of type 2 diabetes in South Asians: meta-analysis of individual participant data from randomised controlled trials. *Diabetologia*. 2019; 62: 1337-48.

18 McCurley JL, Gutierrez AP, Gallo LC. Diabetes Prevention in U.S. Hispanic Adults: A Systematic Review of Culturally Tailored Interventions. *Am J Prev Med*. 2017; 52: 519-29.

19 Kolb H, Martin S. Environmental/lifestyle factors in the pathogenesis and prevention of type 2 diabetes. *BMC Med*. 2017; 15: 131.
20 Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, *et al.* The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Bmj*. 2021; 372: n71.
21 Higgins J, Thomas J. Cochrane Handbook for Systematic Reviews of Interventions version 6.1: Cochrane 2020.
22 Vounzoulaki E, Khunti K, Abner SC, Tan BK, Davies MJ, Gillies CL. Progression to type 2 diabetes in women with a known history of gestational diabetes: systematic review and meta-analysis. *Bmj*. 2020; 369: m1361.
23 Sterne JAC, Savović J, Page MJ, Elbers RG, Blencowe NS, Boutron I, *et al.* RoB 2: a revised tool for assessing risk of bias in randomised trials. *Bmj*. 2019; 366: l4898.
24 Sterne JA, Hernán MA, Reeves BC, Savović J, Berkman ND, Viswanathan M, *et al.* ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. *Bmj*. 2016; 355: i4919.
25 Bhopal RS. Ethnicity, Race, and Health in Multicultural Societies: Foundations for better epidemiology, public health, and health care: Oxford University Press 2009.
26 The World Bank Group. World Bank Country and Lending Groups. Available from https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.
27 IntHout J, Ioannidis JP, Borm GF. The Hartung-Knapp-Sidik-Jonkman method for random effects meta-analysis is straightforward and considerably outperforms the standard DerSimonian-Laird method. *BMC Med Res Methodol*. 2014; 14: 25.
28 Veroniki AA, Jackson D, Viechtbauer W, Bender R, Bowden J, Knapp G, *et al.* Methods to estimate the between-study variance and its uncertainty in meta-analysis. *Res Synth Methods.* 2016; 7: 55-79.
29 Bender MS, Cooper BA, Flowers E, Ma R, Arai S. Filipinos Fit and Trim - A feasible and efficacious DPP-based intervention trial. *Contemporary clinical trials communications.* 2018; 12: 76-84.
30 Cheung NW, Blumenthal C, Smith BJ, Hogan R, Thiagalingam A, Redfern J, *et al.* A Pilot Randomised Controlled Trial of a Text Messaging Intervention with Customisation Using Linked Data from Wireless Wearable Activity Monitors to Improve Risk Factors Following Gestational Diabetes. *Nutrients*. 2019; 11.
31 Davies MJ, Gray LJ, Troughton J, Gray A, Tuomilehto J, Farooqi A, *et al.* A community based primary prevention programme for type 2 diabetes integrating identification and lifestyle intervention for prevention: The Let's Prevent Diabetes cluster randomised controlled trial. *Preventive Medicine: An International Journal Devoted to Practice and Theory*. 2016; 84: 48-56.
32 Fottrell E, Ahmed N, Morrison J, Kuddus A, Shaha SK, King C, *et al.* Community groups or mobile phone messaging to prevent and control type 2 diabetes and intermediate hyperglycaemia in Bangladesh (DMagic): a cluster-randomised controlled trial. *The lancet diabetes and endocrinology*. 2019; 7: 200-12.
33 Bernstein A, Gendy G, Rudd N, Doyle J, Fay S, Moffett K, *et al.* Management of prediabetes through lifestyle modification in overweight and obese African-American women: The Fitness, Relaxation, and Eating to Stay Healthy (FRESH) randomized controlled trial. *Public Health.* 2014; 128: 674-77.
34 Block G, Azar KM, Romanelli RJ, Block TJ, Hopkins D, Carpenter HA, *et al.* Diabetes prevention and weight loss with a fully automated behavioral intervention by email, Web, and mobile phone: A randomized controlled trial among persons with prediabetes. *Journal of Medical Internet Research*. 2015; 17: No Pagination Specified.
35 O'Reilly SL, Dunbar JA, Versace V, Janus E, Best JD, Carter R, *et al.* Mothers after Gestational Diabetes in Australia (MAGDA): A Randomised Controlled Trial of a Postnatal Diabetes Prevention Program. *PLoS Med*. 2016; 13: e1002092.
36 Auslander W, Haire-Joshu D, Houston C, Rhee CW, Williams JH. A controlled evaluation of staging dietary

patterns to reduce the risk of diabetes in African-American women. *Diabetes Care*. 2002; 25: 809-14.
37 Inouye J, Matsuura C, Li D, Castro R, Leake A. Lifestyle intervention for Filipino Americans at risk for diabetes. *Journal of Community Health Nursing*. 2014; 31: 225-37.
38 Duijzer G, Haveman-Nies A, Jansen SC, Beek JT, van Bruggen R, Willink MGJ, *et al*. Effect and maintenance of the SLIMMER diabetes prevention lifestyle intervention in Dutch primary healthcare: a randomised controlled trial. *Nutrition & diabetes*. 2017; 7: e268.
39 Heideman WH, de Wit M, Middelkoop BJ, Nierkens V, Stronks K, Verhoeff AP, *et al*. Diabetes risk reduction in overweight first degree relatives of type 2 diabetes patients: Effects of a low-intensive lifestyle education program (DiAlert): A randomized controlled trial. *Patient Education and Counseling*. 2015; 98: 476-83.
40 Ibrahim N, Moy FM, Awalludin IAN, Ali ZM, Ismail IS. Effects of a community-based healthy lifestyle intervention program (Co-HELP) among adults with prediabetes in a developing country: a quasi-experimental study. *Plos one*. 2016; 11.
41 Aekplakorn W, Tantayotai V, Numsangkul S, Tatsato N, Luckanajantachote P, Himathongkam T. Evaluation of a Community-Based Diabetes Prevention Program in Thailand: a Cluster Randomized Controlled Trial. *Journal of primary care & community health*. 2019; 10: 2150132719847374.
42 Lim S, Wyatt LC, Chauhan H, Zanowiak JM, Kavathe R, Singh H, *et al*. A Culturally Adapted Diabetes Prevention Intervention in the New York City Sikh Asian Indian Community Leads to Improvements in Health Behaviors and Outcomes. *Health Behav Res*. 2019; 2.
43 Islam NS, Zanowiak JM, Wyatt LC, Chun K, Lee L, Kwon SC, *et al*. A randomized-controlled, pilot intervention on diabetes prevention and healthy lifestyles in the New York City Korean community. *J Community Health*. 2013; 38: 1030-41.
44 Aguiar EJ, Morgan PJ, Collins CE, Plotnikoff RC, Callister R. Efficacy of interventions that include diet, aerobic and resistance training components for type 2 diabetes prevention: A systematic review with meta-analysis. *The International Journal of Behavioral Nutrition and Physical Activity Vol 11 2014, ArtID 2*. 2014; 11.
45 Glechner A, Harreiter J, Gartlehner G, Rohleder S, Kautzky A, Tuomilehto J, *et al*. Sex-specific differences in diabetes prevention: a systematic review and meta-analysis. *Diabetologia*. 2015; 58: 242-54.
46 Johnson M, Jones R, Freeman C, Woods HB, Gillett M, Goyder E, *et al*. Can diabetes prevention programmes be translated effectively into real-world settings and still deliver improved outcomes? A synthesis of evidence. *Diabet Med*. 2013; 30: 3-15.
47 Balk EM, Earley A, Raman G, Avendano EA, Pittas AG, Remington PL. 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. *Ann Intern Med*. 2015; 163: 437-51.
48 Dickinson S, Colagiuri S, Faramus E, Petocz P, Brand-Miller JC. Postprandial hyperglycemia and insulin sensitivity differ among lean young adults of different ethnicities. *J Nutr*. 2002; 132: 2574-9.
49 Kataoka M, Venn BJ, Williams SM, Te Morenga LA, Heemels IM, Mann JI. Glycaemic responses to glucose and rice in people of Chinese and European ethnicity. *Diabet Med*. 2013; 30: e101-7.
50 Simper T, Dalton C, Broom D, Ibrahim W, Li L, Bankole C, *et al*. Greater Glycaemic Response to an Oral Glucose Load in Healthy, Lean, Active and Young Chinese Adults Compared to Matched Caucasians. *Nutrients*. 2018; 10.
51 Wingo BC, Carson TL, Ard J. Differences in weight loss and health outcomes among African Americans and whites in multicentre trials. *Obes Rev*. 2014; 15 Suppl 4: 46-61.
52 Hamman RF, Wing RR, Edelstein SL, Lachin JM, Bray GA, Delahanty L, *et al*. Effect of weight loss with lifestyle intervention on risk of diabetes. *Diabetes Care*. 2006; 29: 2102-7.
53 Guess ND. Dietary Interventions for the Prevention of Type 2 Diabetes in High-Risk Groups: Current State

of Evidence and Future Research Needs. *Nutrients*. 2018; 10.
54 Lindström J, Ilanne-Parikka P, Peltonen M, Aunola S, Eriksson JG, Hemiö K, *et al*. Sustained reduction in the incidence of type 2 diabetes by lifestyle intervention: follow-up of the Finnish Diabetes Prevention Study. *Lancet*. 2006; 368: 1673-9.
55 de Mello VD, Lindström J, Eriksson J, Ilanne-Parikka P, Keinänen-Kiukaanniemi S, Sundvall J, *et al.* Insulin secretion and its determinants in the progression of impaired glucose tolerance to type 2 diabetes in impaired glucose-tolerant individuals: the Finnish Diabetes Prevention Study. *Diabetes Care.* 2012; 35: 211-7.
56 Kitabchi AE, Temprosa M, Knowler WC, Kahn SE, Fowler SE, Haffner SM, *et al.* Role of insulin secretion and sensitivity in the evolution of type 2 diabetes in the diabetes prevention program: effects of lifestyle intervention and metformin. *Diabetes.* 2005; 54: 2404-14.
57 Gong Q, Zhang P, Wang J, Ma J, An Y, Chen Y, *et al.* Morbidity and mortality after lifestyle intervention for people with impaired glucose tolerance: 30-year results of the Da Qing Diabetes Prevention Outcome Study. *Lancet Diabetes Endocrinol*. 2019; 7: 452-61.
58 Kaplan JB, Bennett T. Use of race and ethnicity in biomedical publication. *Jama*. 2003; 289: 2709-16.
59 Kearney A, Rosala-Hallas A, Bacon N, Daykin A, Shaw ARG, Lane AJ, *et al.* Reducing attrition within clinical trials: The communication of retention and withdrawal within patient information leaflets. *PLoS One.* 2018; 13: e0204886.
60 Abujudeh BA, Abu Al Rub RF, Al-Faouri IG, Gharaibeh MK. The impact of lifestyle modification in preventing or delaying the progression of type 2 diabetes mellitus among high-risk people in Jordan. *Journal of Research in Nursing.* 2012; 17: 32-44.
61 Aguiar EJ, Morgan PJ, Collins CE, Plotnikoff RC, Young MD, Callister R. Efficacy of the type 2 diabetes prevention using lifestyle education program RCT. *American Journal of Preventive Medicine*. 2016; 50: 353-64.
62 Rollo ME, Aguiar EJ, Pursey KM, Morgan PJ, Plotnikoff RC, Young MD, *et al.* Impact on dietary intake of a self-directed, gender-tailored diabetes prevention program in men. *World journal of diabetes*. 2017; 8: 414-21.
63 Al-Hamdan R, Avery A, Salter A, Al-Disi D, Al-Daghri NM, McCullough F. Identification of Education Models to Improve Health Outcomes in Arab Women with Pre-Diabetes. *Nutrients.* 2019; 11.
64 Amer OE, Sabico S, Alfawaz HA, Aljohani N, Hussain SD, Alnaami AM, *et al.* Reversal of Prediabetes in Saudi Adults: Results from an 18 Month Lifestyle Intervention. *Nutrients*. 2020; 12: 18.
65 Auslander W, Haire-Joshu D, Houston C, Williams JH, Krebill H. The short-term impact of a health promotion program for low-income African American women. *Research on Social Work Practice*. 2000; 10: 78-97.
66 Block G, Azar KM, Romanelli RJ, Block TJ, Palaniappan LP, Dolginsky M, *et al.* Improving diet, activity and wellness in adults at risk of diabetes: randomized controlled trial. *Nutrition & diabetes.* 2016; 6: e231.
67 Holmes VA, Draffin CR, Patterson CC, Francis L, Irwin J, McConnell M, *et al.* Postnatal Lifestyle Intervention for Overweight Women With Previous Gestational Diabetes: a Randomized Controlled Trial. *Journal of clinical endocrinology and metabolism.* 2018; 103: 2478-87.
68 Islam NS, Zanowiak JM, Wyatt LC, Kavathe R, Singh H, Kwon SC, *et al.* Diabetes prevention in the New York City Sikh Asian Indian community: a pilot study. *Int J Environ Res Public Health*. 2014; 11: 5462-86.
69 Juul L, Andersen VJ, Arnoldsen J, Maindal HT. Effectiveness of a brief theory-based health promotion intervention among adults at high risk of type 2 diabetes: One-year results from a randomised trial in a community setting. *Primary Care Diabetes*. 2016; 10: 111-20.
70 Kramer MK, Molenaar DM, Arena VC, Venditti EM, Meehan RJ, Miller RG, *et al.* Improving employee health: evaluation of a worksite lifestyle change program to decrease risk factors for diabetes and cardiovascular disease. *Journal of occupational and environmental medicine*. 2015; 57: 284-91.

71 Kramer M, Vanderwood KK, Arena VC, Miller RG, Meehan R, Eaglehouse YL, *et al.* Evaluation of a diabetes prevention program lifestyle intervention in older adults: A randomized controlled study in three senior/community centers of varying socioeconomic status. *The Diabetes Educator*. 2018; 44: 118-29.
72 Limaye T, Kumaran K, Joglekar C, Bhat D, Kulkarni R, Nanivadekar A, *et al.* Efficacy of a virtual assistance-based lifestyle intervention in reducing risk factors for Type 2 diabetes in young employees in the information technology industry in India: LIMIT, a randomized controlled trial. *Diabetic medicine*. 2017; 34: 563-68.
73 Moungngern Y, Sanguanthammarong S, Teparak P, Sriwijitkamol A. Effects of a health promotion program conducted by nurses on stabilization of HBA1C in subjects at risk for diabetes: a phase III randomized controlled trial. *Chotmaihet thangphaet [journal of the medical association of thailand]*. 2018; 101: 1343-48.
74 Muralidharan S, Ranjani H, Mohan Anjana R, Jena S, Tandon N, Gupta Y, *et al.* Engagement and Weight Loss: results from the Mobile Health and Diabetes Trial. *Diabetes technology & therapeutics*. 2019.
75 Nanditha A, Thomson H, Susairaj P, Srivanichakorn W, Oliver N, Godsland IF, *et al.* A pragmatic and scalable strategy using mobile technology to promote sustained lifestyle changes to prevent type 2 diabetes in India and the UK: a randomised controlled trial. *Diabetologia*. 2020.
76 Ockene IS, Tellez TL, Rosal MC, Reed GW, Mordes J, Merriam PA, *et al.* Outcomes of a Latino community-based intervention for the prevention of diabetes: the Lawrence Latino Diabetes Prevention Project. *American journal of public health*. 2012; 102: 336-42.
77 O'Reilly S, Versace V, Mohebbi M, Lim S, Janus E, Dunbar J. The effect of a diabetes prevention program on dietary quality in women with previous gestational diabetes. *BMC women's health*. 2019; 19: 88.
78 Li G, Zhang P, Wang J, Gregg EW, Yang W, Gong Q, *et al.* The long-term effect of lifestyle interventions to prevent diabetes in the China Da Qing diabetes prevention study: A 20-year follow-up study. *The Lancet*. 2008; 371: 1783-89.
79 Pan X, Li G, Hu Y. Effect of dietary and/or exercise intervention on incidence of diabetes in 530 subjects with impaired glucose tolerance from 1986-1992. *Zhonghua nei ke za zhi [Chinese journal of internal medicine]*. 1995; 34: 108-12.
80 Parikh P, Simon EP, Fei K, Looker H, Goytia C, Horowitz CR. Results of a pilot diabetes prevention intervention in East Harlem, New York City: project HEED. *American journal of public health*. 2010; 100 Suppl 1: S232-9.
81 Patel RM, Misra R, Raj S, Balasubramanyam A. Effectiveness of a Group-Based Culturally Tailored Lifestyle Intervention Program on Changes in Risk Factors for Type 2 Diabetes among Asian Indians in the United States. *Journal of diabetes research*. 2017; 2017: 2751980.
82 Peacock AS, Bogossian FE, Wilkinson SA, Gibbons KS, Kim C, McIntyre HD. A randomised controlled trial to delay or prevent type 2 diabetes after gestational diabetes: walking for exercise and nutrition to prevent diabetes for you. *International journal of endocrinology*. 2015; 2015.
83 Snehalatha C, Mary S, Joshi VV, Ramachandran A. Beneficial effects of strategies for primary prevention of diabetes on cardiovascular risk factors: results of the Indian Diabetes Prevention Programme. *Diabetes & vascular disease research*. 2008; 5: 25-29.
84 Nanditha A, Snehalatha C, Raghavan A, Vinitha R, Satheesh K, Susairaj P, *et al.* The post-trial analysis of the Indian SMS diabetes prevention study shows persistent beneficial effects of lifestyle intervention. *Diabetes research and clinical practice*. 2018; 142: 213-21.
85 Ram J, Selvam S, Snehalatha C, Nanditha A, Simon M, Shetty AS, *et al.* Improvement in diet habits, independent of physical activity helps to reduce incident diabetes among prediabetic Asian Indian men. *Diabetes research and clinical practice*. 2014; 106: 491-95.
86 Ramachandran A, Snehalatha C, Ram J, Selvam S, Simon M, Nanditha A, *et al.* Effectiveness of mobile

phone messaging in prevention of type 2 diabetes by lifestyle modification in men in India: a prospective, parallel-group, randomised controlled trial. *The lancet Diabetes & endocrinology*. 2013; 1: 191-98.

87 den Boer AT, Herraets IJ, Stegen J, Roumen C, Corpeleijn E, Schaper NC, *et al.* Prevention of the metabolic syndrome in IGT subjects in a lifestyle intervention: results from the SLIM study. *Nutrition, metabolism, and cardiovascular diseases : NMCD.* 2013; 23: 1147-53.

88 Roumen C, Corpeleijn E, Feskens EJ, Mensink M, Saris WH, Blaak EE. Impact of 3-year lifestyle intervention on postprandial glucose metabolism: the SLIM study. *Diabetic medicine*. 2008; 25: 597-605.

89 Roumen C, Feskens EJ, Corpeleijn E, Mensink M, Saris WH, Blaak EE. Predictors of lifestyle intervention outcome and dropout: the SLIM study. *European journal of clinical nutrition.* 2011; 65: 1141-47.

90 Sakane N, Sato J, Tsushita K, Tsujii S, Kotani K, Tominaga M. Effect of baseline HbA1c level on the development of diabetes by lifestyle intervention in primary healthcare settings: insights from subanalysis of the Japan Diabetes Prevention Program. *BMJ open diabetes research & care*. 2014; 2: e000003.

91 Sakane N, Sato J, Tsushita K, Tsujii S, Kotani K, Tsuzaki K, *et al.* Prevention of type 2 diabetes in a primary healthcare setting: three-year results of lifestyle intervention in Japanese subjects with impaired glucose tolerance. *BMC public health.* 2011; 11: 40.

92 Shek NW, Ngai CS, Lee CP, Chan JY, Lao TT. Lifestyle modifications in the development of diabetes mellitus and metabolic syndrome in Chinese women who had gestational diabetes mellitus: a randomized interventional trial. *Archives of gynecology and obstetrics*. 2014; 289: 319-27.

93 Lotfaliany M, Sathish T, Shaw J, Thomas E, Tapp RJ, Kapoor N, *et al.* Effects of a lifestyle intervention on cardiovascular risk among high-risk individuals for diabetes in a low- and middle-income setting: secondary analysis of the Kerala Diabetes Prevention Program. *Preventive medicine.* 2020: 106068-.

94 Thankappan KR, Sathish T, Tapp RJ, Shaw JE, Lotfaliany M, Wolfe R, *et al.* A peer-support lifestyle intervention for preventing type 2 diabetes in India: a cluster-randomized controlled trial of the Kerala Diabetes Prevention Program. *Plos medicine.* 2018; 15.

95 Van Name MA, Camp AW, Magenheimer EA, Li F, Dziura JD, Montosa A, *et al.* Effective Translation of an Intensive Lifestyle Intervention for Hispanic Women With Prediabetes in a Community Health Center Setting. *Diabetes care*. 2016; 39: 525-31.

96 Weber MB, Ranjani H, Staimez LR, Anjana RM, Ali MK, Narayan KM, *et al.* The Stepwise Approach to Diabetes Prevention: results From the D-CLIP Randomized Controlled Trial. *Diabetes care*. 2016; 39: 1760-67.

97 Miller CK, Weinhold KR, Marrero DG, Nagaraja HN, Focht BC. A translational worksite diabetes prevention trial improves psychosocial status, dietary intake, and step counts among employees with prediabetes: a randomized controlled trial. *Preventive medicine reports.* 2015; 2: 118-26.

98 Miller CK, Weinhold KR, Nagaraja HN. Impact of a worksite diabetes prevention intervention on diet quality and social cognitive influences of health behavior: A randomized controlled trial. *Journal of Nutrition Education and Behavior*. 2016; 48: 160-69.

99 Weinhold KR, Miller CK, Marrero DG, Nagaraja HN, Focht BC, Gascon GM. A randomized controlled trial translating the diabetes prevention program to a university worksite, Ohio, 2012-2014. *Preventing Chronic Disease: Public Health Research, Practice, and Policy Vol 12 2015, ArtID 150301*. 2015; 12.

100 Wong CK, Fung CS, Siu SC, Lo YY, Wong KW, Fong DY, *et al.* A short message service (SMS) intervention to prevent diabetes in Chinese professional drivers with pre-diabetes: a pilot single-blinded randomized controlled trial. *Diabetes research and clinical practice*. 2013; 102: 158-66.

101 Yates T, Edwardson CL, Henson J, Gray LJ, Ashra NB, Troughton J, *et al.* Walking Away from Type 2 diabetes: a cluster randomized controlled trial. *Diabetic medicine*. 2017; 34: 698-707.

102 Zilberman-Kravits D, Meyerstein N, Abu-Rabia Y, Wiznitzer A, Harman-Boehm I. The impact of a cultural

lifestyle intervention on metabolic parameters after gestational diabetes mellitus a randomized controlled trial. *Maternal and Child Health Journal.* 2018; 22: 803-11.

Table 1. Characteristics of included studies

Author, year	Study name	Country	Ethnicity described by authors	Ethnic group*	Sample size‡	Endpoint (months)	Population
Abujudeh et al 2012 [60]		Jordan	Jordanian	Middle Eastern	113	6	At least one risk factor for type 2 diabetes
Aekplakorn et al 2019 [41]		Thailand	Thai	East and Southeast Asian	1903	24	Prediabetes
Aguiar et al 2016; Rollo et al 2017 [61, 62]	PULSE	Australia	Australia-born Caucasian (89%)	European	101	6	Elevated diabetes risk score and high BMI
Al-Hamdan et al 2019 [63]		Saudi Arabia	Arab	Middle Eastern	190	3	Prediabetes and high BMI
Amer et al 2020 [64]		Saudi Arabia	Arab	Middle Eastern	180	18	Prediabetes and high BMI
Auslander et al 2000; Auslander et al 2002 [36, 65]	Eat Well Live Well	US	African American	African	398	3	High BMI
Bender et al 2018 [29]	Fit & Trim	US	Filipino	East and Southeast Asian	67	3	Prediabetes, elevated diabetes risk score and high BMI
Bernstein et al 2014 [33]	FRESH	US	African American	African	27	1.5	Prediabetes and high BMI
Block et al 2015; Block et al 2016 [34, 66]	Alive-PD	US	White (68%), Chinese, Japanese and other Asian (15%), Hispanic (6%), South Asian (5%)	European, East and Southeast Asian, Latin American, South Asian	339	6	Prediabetes and high BMI
Cheung et al 2019 [30]	Smart Mums with Smart Phones	Australia	South Asia-born (57%), Australia-born (18%)	South Asian, European	60	6	GDM history
Davies et al 2016 [31]	Let's Prevent Diabetes	UK	White European (84%)	European	880	36	Prediabetes
Duijzer et al 2017 [38]	SLIMMER	Netherlands	Dutch (88%)	European	316	12	Prediabetes or elevated diabetes risk score
Fottrell et al 2019 [32]	DMagic	Bangladesh	Bangladeshi	South Asian	2470	26	Prediabetes
Heideman et al 2015 [39]	DiAlert	Netherlands	Dutch (80%)	European	96	9	Overweight and first degree relative with type 2 diabetes
Holmes et al 2018 [67]	PAIGE	UK	White (85%)	European	60	6	GDM history and high BMI
Ibrahim et al 2016 [40]	Co-HELP	Malaysia	Malay (89%)	East and Southeast Asian	268	12	Prediabetes and high BMI
Inouye et al 2014 [37]	Health is Wealth	US	Filipino	East and Southeast Asian	40	6	Elevated diabetes risk score

Islam et al 2013 [43]	Project RICE	US	Korean	East and Southeast Asian	48	6	Elevated diabetes risk score
Islam et al 2014; Lim et al 2019 [42, 68]	Project RICE	US	Indian	South Asian	174	6	Elevated diabetes risk score
Juul et al 2016 [69]		Denmark	Danish	European	127	12	Prediabetes
Knowler et al 2002; West et al 2008 [10, 14]	DPP	US	White (54%), African American (20%), Hispanic (16%)	European, African, Latin American	2161	33.6§	Prediabetes and high BMI
Kramer et al 2015 [70]	Healthy Lifestyle Project	US	White (93%)	European	89	6	Prediabetes or metabolic syndrome, and high BMI
Kramer et al 2018 [71]	Healthy Lifestyle Project	US	White (94%)	European	134	6	Prediabetes or metabolic syndrome, and high BMI
Limaye et al 2017 [72]	LIMIT	India	Indian	South Asian	265	12	Three or more risk factors for type 2 diabetes
Moungngern et al 2018 [73]		Thailand	Thai	East and Southeast Asian	125	6	Elevated diabetes risk score
Muralidharan et al 2019 [74]	mDiab	India	Indian	South Asian	741	3	Prediabetes or high BMI
Nanditha et al 2020 [75]		India	Indian	South Asian	1171	24	Prediabetes and three or more risk factors for type 2 diabetes
Ockene et al 2012 [76]	LLDPP	US	Latino (60% of Dominican origin and 40% Puerto Rican)	Latin American	312	12	Elevated diabetes risk score and high BMI
O'Reilly et al 2016; O'Reilly et al 2019 [35, 77]	MAGDA	Australia	Cultural background of Europe, Australia and New Zealand (52%), Asia (39%), Africa (3%)	European, Asian†, African	573	12	GDM history
Pan et al 1995; Pan et al 1997; Li et al 2008 [11, 78, 79]	China Da Qing Diabetes Prevention Study	China	Chinese	East and Southeast Asian	577	72	Prediabetes
Parikh et al 2010 [80]	Project HEED	US	Hispanic (89%)	Latin American	99	12	Prediabetes and high BMI
Patel et al 2017 [81]		US	Indian	South Asian	70	3	Elevated diabetes risk score
Peacock et al 2015 [82]	WENDY	Australia	Caucasian (90%)	European	31	3	GDM history and high BMI
Ramachandran et al 2006;	IDPP-1	India	Indian	South Asian	269	36	Prediabetes

Snehalatha et al 2008 [12, 83]							
Ramachandran et al 2013; Ram et al 2014; Nanditha et al 2018 [84-86]		India	Indian	South Asian	537	24	Prediabetes, family history of type 2 diabetes and high BMI
Roumen et al 2008; Roumen et al 2011; denBoer et al 2013 [87-89]	SLIM	Netherlands	Dutch	European	147	50.4‖	Prediabetes, and family history of diabetes or high BMI
Sakane et al 2011; Sakane et al 2014 [90, 91]	Japan Diabetes Prevention Program	Japan	Japanese	East and Southeast Asian	296	36	Prediabetes
Shek et al 2014 [92]		China	Chinese	East and Southeast Asian	450	36	GDM history and prediabetes
Thankappan et al 2018; Lotfaliany et al 2020 [93, 94]	K-DPP	India	Indian	South Asian	1007	12	Elevated diabetes risk score
VanName et al 2016 [95]		US	Hispanic (90%)	Latin American	130	12	Prediabetes and at least one risk factor for type 2 diabetes
Weber et al 2016 [96]	D-CLIP	India	Indian	South Asian	578	4	Prediabetes, and overweight or obesity
Weinhold et al 2015; Miller et al 2015; Miller et al 2016 [97-99]		US	White (81%)	European	78	4	Prediabetes and high BMI
Wong et al 2013 [100]		China	Chinese	East and Southeast Asian	104	24	Prediabetes
Yates et al 2017 [101]	Walking Away from Type 2 Diabetes	UK	White European (89%)	European	808	36	Elevated diabetes risk score
Zilberman-Kravits et al 2018 [102]		Israel	Jewish (74%) and Bedouin (26%)	Middle Eastern	180	24	GDM history

BMI, body mass index; GDM, gestational diabetes mellitus; US, United States; UK, United Kingdom

Prediabetes is defined as impaired fasting glucose, and/or impaired glucose tolerance, and/or elevated HbA_{1c}.

* Ethnicity described by authors was categorized into six ethnic groups based on the World Bank regions.

† This study did not provide detailed information on ethnicity in participants from Asian cultural backgrounds, so it was not available to separate these participants into the South Asian and East and Southeast Asian groups. The data from this Asian group was not included in meta-analysis.

‡ Number of participants from lifestyle intervention and control groups at baseline.

§ Data on weight change available at 30 months.

|| Data on diabetes incidence and dietary intake available at 3 years.

Table 2. The effect of lifestyle intervention on type 2 diabetes incidence and glycemic outcomes

	Diabetes incidence			Fasting glucose (mmol/l)			2-h glucose (mmol/l)			HbA_{1c} (%)		
	n*	Risk ratio (95% CI)	I^2 (%)	n	MD (95% CI)	I^2 (%)	n	MD (95% CI)	I^2 (%)	n	MD (95% CI)	I^2 (%)
Overall	25	0.74 (0.69, 0.80)	0.0	36	-0.14 (-0.23, -0.05)	85.7	19	-0.50 (-0.80, -0.20)	90.8	27	-0.06 (-0.10, -0.03)	66.8
European	4	0.73 (0.37, 1.45)	26.9	12	-0.08 (-0.14, -0.01)	34.7	6	-0.10 (-0.52, 0.32)	47.9	12	-0.06 (-0.12, 0.00)	70.7
South Asian	8	0.78 (0.70, 0.87)	0.0	8	-0.16 (-0.30, -0.02)	83.2	4	-0.46 (-1.27, 0.34)	90.3	5	-0.05 (-0.13, 0.02)	51.8
East and Southeast Asian	7	0.70 (0.58, 0.83)	18.0	8	-0.22 (-0.46, 0.02)	77.7	5	-1.04 (-2.04, -0.04)	90.2	4	-0.13 (-0.31, 0.06)	83.5
Middle Eastern	2	0.13 (0.01, 2.50)	NA	4	0.00 (-1.13, 1.14)	96.4	1	-0.12 (-0.42, 0.18)	NA	1	-0.10 (-0.23, 0.03)	NA
Latin American	3	0.55 (0.01, 42.10)	0.0	3	0.00 (-0.33, 0.33)	0.0	2	-0.61 (-2.50, 1.28)	0.0	3	-0.04 (-0.18, 0.10)	0.0
African	1	NA	NA	1	-0.54 (-1.28, 0.20)	NA	1	-0.61 (-1.62, 0.40)	NA	2	0.06 (-0.96, 1.09)	19.1
P for overall effect		<0.001			0.003			0.003			0.001	
P for subgroup differences		0.401			0.299			0.038			0.478	

n, number of studies; MD, mean difference; NA, not applicable

* There were five studies in which diabetes did not occur in both the intervention and control groups and risk ratio was not estimated: 1 in South Asian, 1 in East and Southeast Asian, 1 in Middle Eastern, 1 in Latin American and 1 in African groups.

Table 3. The effect of lifestyle intervention on anthropometric outcomes

	Body weight (kg)			BMI (kg/m^2)			Waist circumference (cm)		
	n	MD (95% CI)	I^2 (%)	n	MD (95% CI)	I^2 (%)	n	MD (95% CI)	I^2 (%)
Overall	42	-2.11 (-2.71, -1.51)	86.6	42	-0.70 (-0.90, -0.49)	80.1	38	-1.92 (-2.52, -1.31)	87.6
European	14	-2.42 (-3.59, -1.26)	87.5	13	-0.85 (-1.30, -0.40)	88.0	13	-2.53 (-3.82, -1.25)	84.4
South Asian	8	-1.01 (-1.63, -0.39)	80.5	10	-0.46 (-0.67, -0.26)	54.0	9	-1.24 (-1.89, -0.59)	58.2
East and Southeast Asian	9	-1.77 (-2.57, -0.97)	47.6	10	-0.66 (-0.94, -0.38)	45.5	7	-2.09 (-3.29, -0.89)	45.4
Middle Eastern	3	-3.72 (-6.39, -1.05)	0.0	4	-1.36 (-1.91, -0.82)	0.0	4	-0.73 (-2.74, 1.29)	81.6
Latin American	4	-4.10 (-7.54, -0.66)	82.9	2	-1.48 (-11.42, 8.46)	86.4	3	-3.26 (-3.88, -2.64)	0.0
African	4	-1.19 (-5.41, 3.03)	83.1	3	0.16 (-0.90, 1.22)	1.7	2	-1.68 (-20.46, 17.11)	0.0
P for overall effect		<0.001			<0.001			<0.001	
P for subgroup differences		<0.001			<0.001			<0.001	

n, number of studies; MD, mean difference; BMI, body mass index