Dietary Patterns and Type 2 Diabetes: A Systematic Literature Review and Meta-Analysis of Prospective Studies\textsuperscript{1–3}

Franziska Jannasch,\textsuperscript{4,5} Janine Kröger,\textsuperscript{4,5} and Matthias B Schulze\textsuperscript{4,5}

\textsuperscript{4}Department of Molecular Epidemiology, German Institute of Human Nutrition Potsdam-Rehbruecke, Nuthetal, Germany; and \textsuperscript{5}German Center for Diabetes Research, München-Neuherberg, Germany

Abstract

Background: Different methodologic approaches for constructing dietary patterns and differences in their composition limit conclusions on healthful patterns for diabetes prevention.

Objective: We summarized evidence from prospective studies that examined associations of dietary patterns with type 2 diabetes by considering different methodologic approaches.

Methods: The literature search (MEDLINE and Web of Science) identified prospective studies (cohorts or trials) that associated dietary patterns with diabetes incidence in nondiabetic and apparently healthy participants. We summarized evidence by meta-analyses and distinguished different methodologic approaches.

Results: The search resulted in 48 articles comprising 16 cohorts. Adherence to the Mediterranean diet (RR for comparing extreme quantiles: 0.87; 95% CI: 0.82, 0.93), Dietary Approaches to Stop Hypertension (DASH) (RR: 0.81; 95% CI: 0.72, 0.92), and Alternative Healthy Eating Index (AHEI) (RR: 0.79; 95% CI: 0.69, 0.90) was associated with significant risk reductions of incident diabetes. Patterns from exploratory factor and principal component analyses characterized by red and processed meat, refined grains, high-fat dairy, eggs, and fried products (“mainly unhealthy”) were positively associated with diabetes (RR: 1.44; 95% CI: 1.27, 1.62), whereas patterns characterized by vegetables, legumes, fruits, poultry, and fish (“mainly healthy”) were inversely associated with diabetes (RR: 0.84; 95% CI: 0.77, 0.91). Reduced rank regression (RRR) used diabetes-related biomarkers to identify patterns. These patterns were characterized by high intakes of refined grains, sugar-sweetened soft drinks, and processed meat and were all significantly associated with diabetes risk.

Conclusions: Our meta-analysis suggests that diets according to the Mediterranean diet, DASH, and AHEI have a strong potential for preventing diabetes, although they differ in some particular components. Exploratory dietary patterns were grouped based on concordant food groups and were significantly associated with diabetes risk despite single-component foods having limited evidence for an association. Still, they remain population-specific observations. Consistent positive associations with diabetes risk were observed for 3 RRR patterns. J Nutr 2017;147:1174–82.

Keywords: dietary patterns, type 2 diabetes, investigator-driven statistical methods, exploratory statistical methods, systematic review, meta-analysis

Introduction

In terms of diabetes prevention, evidence from clinical trials and observational studies suggests that the consumption of several foods and beverages is associated with a reduction in diabetes risk, e.g., a high intake of whole grains, nuts, coffee, and a moderate consumption of alcohol and low intake of processed and unprocessed red meats and sugar-sweetened beverages (SSBs)\textsuperscript{6} (1). However, people do not consume single food groups but rather a combination of many foods. To address this problem, the investigation of dietary patterns (DPs) has emerged

\textsuperscript{1} Supported by the German Federal Ministry of Education and Research and the Joint Programming Initiative “A Healthy Diet for a Healthy Life.”

\textsuperscript{2} Author disclosures: F Jannasch, J Kröger, and MB Schulze, no conflicts of interest.

\textsuperscript{3} Supplemental Figures 1–8 and Supplemental Tables 1–15 are available from the “Online Supporting Material” link in the online posting of the article and from the same link in the online table of contents at http://jn.nutrition.org.

\textsuperscript{4}To whom correspondence should be addressed. E-mail: franziska.jannasch@dife.de.

\textsuperscript{6} Abbreviations used: AHEI, Alternative Healthy Eating Index; DASH, Dietary Approaches to Stop Hypertension; DP, dietary pattern; HEI, Healthy Eating Index; PCA, principal component analysis; PREDIMED, Prevencion con Dieta Mediterranea; RRR, reduced rank regression; SIGN, Scottish Intercollegiate Guidelines Network; SLR, systematic literature review; SSB, sugar-sweetened beverage.
as a complementary approach. DPs can be derived from food consumption data by several approaches in observational studies (2, 3). A priori approaches estimate a person’s adherence to recommended intakes and need preliminary knowledge about the detrimental effects or benefits of specific foods to calculate indexes. Commonly used indexes have been the Mediterranean diet (4), the Dietary Approaches to Stop Hypertension (DASH) diet (5), the Healthy Eating Index (HEI) based on the USDA’s food guidance system (6), and the alternative HEI (AHEI) based on nutrients and foods predictive of chronic disease risk (7). Explanatory approaches such as principal component analysis (PCA), factor analysis, or cluster analysis create patterns based on correlations among food groups and are useful for characterizing population-specific DPs but do not necessarily identify optimal patterns with regard to chronic disease risk (2). As a mix of a priori and exploratory approaches, reduced rank regression (RRR) combines the pre-existing knowledge about specific mediating factors involved in disease development with a data-driven method for identifying DPs (8). The wide variety of approaches for evaluating DPs and the heterogeneity of pattern composition have not been adequately taken into account in previous systematic literature reviews (SLRs) that have aimed to summarize the evidence of DPs’ relation with diabetes risk. Reviews have been restricted to either a priori patterns (9) or exploratory approaches (10), or have summarized exploratory patterns along with a priori patterns such as the Mediterranean diet (11, 12), although they do not share identical components. Furthermore, evidence from rather “unhealthy” exploratory DPs has frequently been ignored in previous reviews (11, 13), although such patterns have been found to relate to diabetes risk (14, 15). Thus, this SLR aims to summarize evidence of prospective studies by evaluating the association between DPs and type 2 diabetes and considering the heterogeneity of different statistical approaches for generating DPs and differences in pattern composition.

Methods

Search strategy. To identify published studies on DPs and diabetes, we searched MEDLINE and Web of Science databases until 31 December 2015. The search strategy combined medical subject heading terms and partly truncated text words. We covered 4 thematic areas (dietary habits and patterns, a priori and a posteriori statistical approaches to generate dietary patterns, type 2 diabetes, and prospective design of the studies) with several selected search strings (Supplemental Table 1). The search was limited to English articles. Reference lists of articles were screened for further relevant articles.

Screening process. A hierarchical approach was applied for assessing the relevance of the studies. We independently screened titles, abstracts, and full texts, and disagreements were solved by consensus. Articles using single food groups or nutrients were excluded as well as studies with a cross-sectional or retrospective study design. Furthermore, gestational diabetes or type 1 diabetes was not considered. Studies restricted to patients with diabetes, impaired glucose tolerance, insulin resistance, or other chronic diseases were excluded as well.

Data extraction. Data were extracted with a standardized form developed by the investigators that included information on authors, year of publication, country, design, name and duration of the study, number of incident cases, size of study population, sex, age at baseline, dietary assessment method, outcome and its definition, method for deriving DPs, DP label, categorization, statistical parameter with 95% CIs, P-trends, and adjustment variables.

Quality assessment of the included studies. The Scottish Intercollegiate Guidelines Network (SIGN) checklist was used to assess the quality of studies (Supplemental Table 2). This checklist was specified for the evaluation of cohort studies, and in this SLR 14 questions were adapted from the original checklist. According to the number of questions, which could be answered with “yes,” “no,” or “cannot say,” the studies were rated as low quality, acceptable, or high quality. Intervention studies were evaluated with an adapted SIGN checklist for randomized controlled trials comprising 10 questions (Supplemental Table 3).

Meta-analyses. The meta-analyses were undertaken with Cochrane RevMan version 5.3, and pooled estimates were calculated according to each pattern approach. Furthermore, approaches repeatedly applied in one study population were restricted to the most recent publication. Patterns derived by exploratory methods need to be generally considered population-specific, which limits the potential for meta-analytical summarization. Therefore, patterns were only considered for meta-analysis if they were characterized by a set of concordant food groups, admitting one food group missing. For the RRR method, the originally derived RRR patterns and their confirmations in external study populations were meta-analytically summarized. This was because of the large heterogeneity of the derived RRR scores that used different diabetes-related biomarkers as responses. Two risk estimates from a confirmatory analysis (15) were recalculated according to their direction of association to make them comparable to the originally derived dietary patterns. To estimate the weight of each included study, the standard error of the logarithm of the studies’ risk estimate comparing the extreme quantities was calculated via an inverse variance method. Risk estimates of several studies were provided upon request. Heterogeneity was determined with the use of the I² statistic, and a value >25%, indicating moderate heterogeneity, supported the application of random-effects models rather than fixed-effects models (16). Potential publication bias was addressed by funnel plots, and asymmetry was further evaluated by the Egger test (17). However, this was exclusively applied to meta-analyses with ≥5 studies.

Results

The search in MEDLINE and Web of Science resulted in 1047 articles after combining and eliminating duplicates. The screening process resulted in 48 articles (5, 7, 14, 15, 18–61) (Supplemental Figure 1). Studies were conducted across 4 continents and included a comprehensive set of DPs in different regions. Most studies were conducted in the United States (n = 22), followed by Europe (n = 18), Asia (n = 5), and Australia (n = 3). However, no contributions from the African or South American continent met the inclusion criteria. In total, 16 individual study populations were investigated. Overall, 27 articles examined the participants’ adherence to predefined scores or indexes (Supplemental Table 4). Among this group, most articles determined the association between the Mediterranean diet and diabetes (n = 8), followed by the HEI or AHEI (n = 6) and the DASH diet (n = 5). Among 16 studies that used exploratory approaches, most studies applied factor analysis or PCA (n = 14). Patterns based on RRR were investigated in 6 studies.

A priori approaches

Mediterranean diet. Eight studies investigated adherence to the Mediterranean diet and the association with type 2 diabetes in different populations—5 in Southern Europe and 3 in non-Mediterranean populations. Fruits, nuts, vegetables, legumes, fish and seafood, and moderate alcohol consumption were always part of the diet indexes (Supplemental Table 5). However, some investigators implemented different food group subdivisions. For instance, Abiemo et al. (18) emphasized the beneficial effect of nonrefined grains. Meat was considered either
as total meat intake (26, 41, 53), restricted to red and processed meat (18, 23), or as a whitered meat ratio (54). Some investigators (26, 41, 52, 53) used total dairy; others (18) stressed whole-fat dairy as detrimental or excluded it because of restricted data availability (36). Olive oil is an essential part of the Mediterranean diet (62). However, in non-Mediterranean populations the MUFA:SFA ratio was a frequent surrogate (18, 23, 36). Moderate alcohol consumption was always included but with altering definitions (18, 23, 54, 63). In total, 5 of 6 studies observed a risk reduction ranging from 9% (36) to 25% (23) comparing extreme quantiles, whereas no significant association was observed in one US-based study (18). More than 50% of the studies were rated high quality; the remaining were rated acceptable (Supplemental Tables 2 and 3). Data from Jacobs et al. (36) were provided upon request. A meta-analysis of prospective cohort studies suggests that a higher Mediterranean diet score was related to a significant risk reduction (RR for comparing extreme quantiles: 0.87; 95% CI: 0.82, 0.93) (Figure 1A). The heterogeneity between the included studies was relatively low ($I^2 = 26\%$). Potential publication bias was not present according to the funnel plot (Supplemental Figure 2), in which the smallest study (18) did not contribute to the overall estimate but rather showed an opposite effect, even if the Egger test ($b = 0.92; P < 0.0001$) indicated a small study effect. The inverse association in observational cohort studies was confirmed in the PREDIMED (Prevencion con Dieta Mediterranea) intervention trial (54), in which a Mediterranean diet (diet advice either supplemented with olive oil or nuts) resulted in a 30% risk reduction compared with the control group (54).

**DASH.** The DASH score from Liese et al. (5) (Supplemental Table 6) was composed of 10 food groups: total grains; high-fiber grains; vegetables; fruits; total dairy; low-fat dairy; nuts, seeds, and legumes; meat; fats and oil; and sweets. Altogether, 6 studies investigated the association of the DASH score with diabetes and included relatively similar food groups. Whereas Liese et al. (5) and Kröger and colleagues (15) did not distinguish different meat sources, the remaining 4 studies (23, 24, 36, 37) considered red and processed meat and included SSBs and low sodium intake. Two studies (15, 23) were rated high quality, and 4 studies (5, 24, 36, 37) were rated acceptable (Supplemental Table 2). A high DASH score was associated with a significantly reduced risk of diabetes in 3 studies (23, 36, 37). One study (37) was not included in the meta-analysis because it was also part of the InterAct Consortium (15). Data from De Oliveira Otto et al. (24) were provided upon request. The pooled RR for comparing extreme quantiles was 0.82 (95% CI: 0.74, 0.92) (Figure 1B). All individual studies reported effect estimates suggesting an inverse association, but heterogeneity was present ($I^2 = 62\%$). Potential publication bias was not present based on the funnel plot (Supplemental Figure 3) and Egger test ($b = 0.79; P = 0.10$).

**HEI and AHEI.** Two studies investigated the HEI with regard to diabetes risk (23, 36). De Koning et al. (23) observed no association for HEI-2005, whereas Jacobs et al. (36) observed a risk reduction of 9% for HEI-2010. Although both HEI-2005 and HEI-2010 included whole grains, vegetables, fruits, and dairy, both studies used different score compositions (Supplemental Table 7) (36).

![FIGURE 1 Meta-analysis of prospective studies presenting the RRs and 95% CIs for type 2 diabetes incidence for the highest compared with the lowest intake of the Mediterranean diet (A), the DASH diet (B), and the AHEI (C). AHEI, Alternative Healthy Eating Index; DASH, Dietary Approaches to Stop Hypertension; EPIC, European Prospective Investigation into Cancer and Nutrition; HPFS, Health Professionals Follow-Up Study; IRAS, Insulin Resistance Atherosclerosis Study; MEC, Multiethnic Cohort; MESA, Multi-Ethnic Study of Atherosclerosis; NHS, Nurses’ Health Study; PREDIMED, Prevencion con Dieta Mediterranea; SUN, Seguimiento Universidad de Navarra; WHI, Women’s Health Initiative.](https://academic.oup.com/jn/article-abstract/147/6/1174/4630426?download=true)
The 9-component AHEI (64) shares similarities with the HEI but included the whitened meat ratio, *trans* fat, and the PUFA:SFA ratio, which were found to be associated with chronic disease risk. In addition, nuts and the long-term use of multivitamin supplements were included, whereas dairy was excluded. In total, 5 of 7 studies applied this original version of the AHEI (64) with minor changes in InterAct (15) (*trans* fats and multivitamins not included). Two studies applied an updated version (AHEI-2010) (7, 36). The quality was high in 4 studies (7, 15, 23, 29) and acceptable in 3 studies (24, 36, 50) (Supplemental Table 2). Data from De Oliveira Otto et al. (24) were provided upon request. Duplicates of the same study population (23, 29) were excluded from the meta-analysis, which showed a significant risk reduction (RR for comparing extreme quantiles: 0.79; 95% CI: 0.70, 0.89) (Figure 1C) but with high heterogeneity ($I^2 = 88\%$). The funnel plot (Supplemental Figure 4) indicated no publication bias, although the Egger test did ($b: 0.86; P = 0.003$).

Further indexes and scores. Studies have evaluated a variety of other a priori indexes and scores ($n = 15$). These indexes were heterogeneous in terms of the components and manner in which they were constructed (Supplemental Tables 8 and 9). Eight of the identified 15 studies showed a significant risk reduction (14–68%) (Supplemental Figure 5). Of these, more indexes were constructed according to knowledge of previous studies on specific food groups than measurements of the adherence to guidelines. The quality was high for 50% of the respective studies (Supplemental Table 2), but because of completely different approaches we did not summarize by meta-analysis.

A posteriori approaches

PCA. Half of the 14 studies that applied PCA or exploratory factor analysis (Supplemental Table 10) reported on patterns labeled “prudent” and/or “Western” (14, 40, 43, 49, 55, 57, 65). Studies differed in terms of the dietary assessment tools applied and the number of food groups or items [20 food groups (27) to 165 items (32)]. A significant inverse association with diabetes was observed for 5 of 32 evaluated patterns, but only 1 was labeled prudent (Supplemental Table 10). Three of the respective 5 patterns were derived in Asian populations (44, 48, 60). Eight patterns were significantly positively associated with diabetes (Supplemental Table 10). Although 3 of these patterns were labeled Western and shared some components, there were substantial differences in pattern composition. Supplemental Figure 6 illustrates the wide variety of different food groups characterizing the patterns. Because meta-analytical summarization would not be meaningful for patterns of very different composition, we evaluated similarities between individual component food groups. Two overall groups of patterns were identified based on this approach. The first group was characterized by vegetables, legumes, fruits, poultry, and fish and was labeled “mainly healthy.” Seven patterns shared this composition and were considered for meta-analysis, which indicated a significant risk reduction (RR for comparing extreme quantiles: 0.84; 95% CI: 0.77, 0.91) (Figure 2A) with a very low heterogeneity between studies ($I^2 = 6\%$). Publication bias was evident by the Egger test ($b: 0.59; P = 0.0043$), but the funnel plot (Supplemental Figure 7) showed a relatively heterogeneous distribution.

Five patterns belonged to a second group of DPs that was characterized by refined grains, high-fat dairy, eggs, red and processed meat, and French fries, and labeled “mainly unhealthy.” A meta-analysis suggested a significant increase in diabetes risk by 44% without heterogeneity ($I^2 = 0\%$) (Figure 2B). Publication bias was present according to the Egger test ($b: 1.56; P = 0.0055$), but the funnel plot depicted no effect of small studies on the overall effect estimate (Supplemental Figure 8).

Cluster analysis. In addition to the PCA, cluster analysis was applied in 2 studies (Supplemental Table 11) (21, 58). However, because of high heterogeneity, the calculation of a pooled estimate would not be reasonable.

RRR. Six identified studies applied RRR as the statistical means for identifying DPs (Supplemental Table 12). In 5 of 6 studies (31, 35, 39, 42, 56), biomarkers served as response variables; 1 study used nutrients known to be associated with diabetes (33). In 4 studies (35, 39, 42, 56), high concentrations of biomarkers, e.g., inflammatory markers, were associated with increased risk. One pattern (31) was associated with a favorable biomarker profile (high plasma concentrations of HDL cholesterol and adiponectin and lower concentrations of glycated hemoglobin and C-reactive protein)

![Image](https://academic.oup.com/jn/article-abstract/147/6/1174/4630426)

**FIGURE 2** Meta-analysis of prospective studies presenting the RRs and 95% CIs for type 2 diabetes incidence for the highest compared with the lowest intake of “mainly healthy” patterns derived by principal component or factor analysis (A) and “mainly unhealthy” patterns derived by principal component or factor analysis (B). ALSWH, Australian Longitudinal Study on Women’s Health; FMCHES, Finnish Mobile Clinic Health Examination Survey; HPFS, Health Professionals Follow-Up Study; NHS, Nurses’ Health Study; SCS, Singapore Chinese Health Study. Data from reference 55 with permission.
and reduced diabetes risk (Supplemental Table 13). All identified RRR patterns were related significantly to diabetes risk, with the strongest association observed with the use of thrombosis markers as responses (39). Participants in the highest quartile of this RRR pattern, characterized by relatively high intakes of red meat and low-fiber bread and cereals, dried beans, fried potatoes, tomatoes, eggs, cheese, cottage cheese, and a low intake of wine, had a 4-fold higher risk than participants within the lowest quartile (OR: 4.51; 95% CI: 1.60, 12.69) (Supplemental Table 13). Comparing the food groups contributing to the RRR patterns showed that refined grains, processed meat, SSBs, and wine loaded on the patterns in ≥4 of 6 studies (Supplemental Table 14). However, the RRR patterns also differed in regard to their characterization by food groups such as fruits, beer, red meat, legumes, poultry (31), diet soft drinks, vegetables, coffee (56), onions, burgers and sausages, snacks, jam, dressings, and whole grains (42).

Several RRR patterns were evaluated subsequently in independent cohort studies (Supplemental Table 15) (15, 35, 56). The pooled estimate for the RRR pattern originally derived by Heidemann et al. (31) indicated a significant diabetes risk reduction (RR for comparing extreme quantiles: 0.51; 95% CI: 0.27, 0.98) but with heterogeneity between the included studies ($I^2 = 86\%$) (Figure 3A). The RRR pattern (56) derived within the Nurses’ Health Study was validated internally and externally (15, 35, 56). The pooled estimate calculated by the random-effects model was RR for comparing extreme quantiles (RR: 2.53; 95% CI: 1.56, 4.10) (Figure 3B), showing heterogeneity ($I^2 = 94\%$) between US-based studies and the European InterAct Consortium study (15) with a considerably weaker, although still significant, positive association in the latter study. The meta-analysis of the third RRR pattern (42), replicated in 2 additional cohort studies (15, 35), suggested a significant increase in diabetes risk of approximately 40% (RR for comparing extreme quantiles: 1.39; 95% CI: 1.25, 1.54), and no heterogeneity was present ($I^2 = 0\%$) (Figure 3C).

FIGURE 3 Meta-analysis of prospective studies presenting the RRs and 95% CIs for type 2 diabetes incidence for the highest compared with the lowest intake of RRR pattern derived by Heidemann et al. (31) applied in 2 external study populations (A); RRR pattern derived by Schulze et al. (56) applied in 3 external study populations without blood donations [risk estimate by InterAct Consortium (15) recalculated according to the direction of association] (B); and RRR pattern derived by McNaughton et al. (42) applied in 2 external study populations [risk estimate by InterAct Consortium (15) recalculated according to the direction of association] (C). EPIC, European Prospective Investigation into Cancer and Nutrition; FOS, Framingham Offspring Study; NHS, Nurses’ Health Study; RRR, reduced risk regression; w.b., without blood donation; WHS II, Whitehall Study II.

Discussion

The aim of this SLR was to identify prospective studies on DPs and diabetes considering different methodologic approaches and summarizing evidence by means of meta-analyses. We identified 48 studies that included ~1.5 million participants. To our knowledge, this is the most comprehensive review on the topic, by far exceeding previous reviews by Alhazmi et al. (12) (15 articles), Esposito et al. (11) (18 articles), Schwingshackl and Hoffmann (9) (7 studies), and McEvoy et al. (10) (9 studies). Previous reviews have focused exclusively on a priori (9) or exploratory patterns (10) or did not separately investigate different methodologic approaches to generate patterns and thus largely ignored differences in their composition. Some reviews (11, 12) summarized studies evaluating various DPs ranging from the Mediterranean diet over DASH to the so-called prudent patterns from PCA that may share some components but also have differences in composition. For example, diet patterns described as Mediterranean differ substantially from DASH in whole grains, alcohol, SSBs, fish, sweets, and dairy consumption, and PCA-derived healthy or prudent patterns are frequently not related to low red meat or SSB intake. Although Esposito et al. (11) reported on those patterns with a described beneficial health effect, their approach ignored evidence from a large proportion of exploratory patterns. We identified a large number of studies observing increased diabetes risk of rather unhealthy DPs. Because the direction of the association of DPs is merely a function of the definition of the exposure groups [an unhealthy pattern (e.g., high in red and processed meats, SSBs, and refined grains) with a direct association with diabetes risk can simply be reversed into a healthy pattern (low in respective food groups) with a protective association by rescaling or with the use of a different reference group], previous reviews have given only a selected picture of the available evidence. One review (10) summarized the evidence of the association of exploratory DPs with diabetes but included studies in the meta-analysis based on the pattern label and not on the actual composition. Given that exploratory patterns per definition are population-specific, this
approach is questionable. In contrast, we summarized only patterns with similar compositions. Not surprisingly, the set of studies included in this review (10) shows limited overlap with ours (healthy patterns: 4 studies; unhealthy patterns: 3 studies).

We identified 6 prospective cohort studies that examined the association of the Mediterranean diet with diabetes. The overall risk estimate suggests a significant risk reduction. Previous meta-analyses (13, 66) reported a similar risk reduction, although the set of included studies slightly differed because of distinct inclusion criteria. One included study (18) observed no significant risk reduction. Possible reasons for the null finding could be the relative short follow-up time (6.6 y), the dietary measurement tool not specifically designed for the Mediterranean diet, or the omission of characteristic components such as olive oil (18). However, studies in non-Mediterranean populations (23, 36) facing similar difficulties observed risk reductions. In addition to cohort studies, the PREDIMED randomized trial observed a 30% risk reduction for participants following a Mediterranean diet compared with controls. Thus, there is strong evidence overall that adherence to the Mediterranean diet reduces diabetes risk.

We also found evidence that adherence to DASH reduces diabetes risk. Similar conclusions were drawn in a recent review (9). There is a considerable overlap of components of DASH and the Mediterranean diet, such as vegetables, fruits, nuts, and legumes as beneficial components [although evidence for their association with diabetes is limited (67, 68)] and red and processed meat as a rather detrimental component [with strong evidence for risk increase (69)]. However, unlike the Mediterranean diet, DASH includes whole grains, low-fat dairy, a broad group of fats and oils, and SSBs but does not consider alcohol. Evidence is quite strong for risk-reducing properties of low-fat dairy (70) and whole grains (71) and risk-increasing properties of SSBs (72). As for many of the Mediterranean diet components, the evidence for an association with diabetes is rather limited. It remains unclear which components are responsible for the preventive effect on diabetes risk. Although single food effects may be too weak to be detectable and only the combined effect of DPs triggers an association, results from the InterAct study also suggest that the association of the Mediterranean diet may mainly be related to alcohol, meat, and olive oil (52).

For adherence to AHEI, our meta-analysis observed a significant risk reduction. Interestingly, the 4 US-based studies observed significant risk reductions, whereas the European-based InterAct study observed no significant association. A possible explanation for this discrepancy could be the distinct distribution of dietary intake (73). One previous meta-analysis examined the association of the AHEI with diabetes but used a different study set (9). Although the AHEI shares some components with the DASH diet, moderate alcohol consumption as a well-established protective factor for diabetes (74) is an important difference. Although our meta-analysis supports that adherence to AHEI can reduce diabetes risk, generalizability to non-US populations should be further investigated.

Similar to the HEI, several investigations have evaluated scores reflecting adherence to national dietary recommendations. Although core components were always present (foods high in dietary fiber with low glycemic load and a good fat quality, described as the PUFA:SFA ratio), the heterogeneity of approaches prohibited a meta-analytical summarization.

We identified 32 PCA patterns evaluating the association with diabetes risk, although previous reviews were restricted to a considerably smaller number (10–12). Furthermore, our SLR clearly indicates that PCA patterns are not easily comparable between different study populations despite the use of similar labels by authors. Previous reviews (10–12) have summarized studies rather uncritically based on observed associations with diabetes risk but not based on pattern compositions—largely limiting the interpretability of the findings. To systematically address this point, the patterns in this SLR were only included in meta-analyses when characterized by concordant food groups, resulting in a considerably smaller number of exploratory patterns included in the meta-analysis than were published. Although we consider our approach as being strong, this also highlights that many published associations of exploratory patterns remain population-specific findings and single observations. We were able to identify 2 groups of patterns. First, patterns mainly characterized by vegetables, legumes, fruits, poultry, and fish were inversely associated with diabetes. Evidence for risk-reducing properties is limited for these foods (67–69, 75); however, DPs, being a combination of these foods, seem to reduce diabetes risk. A second group of patterns was characterized by refined grains, high-fat dairy, eggs, red and processed meat, and French fries and was related to an increased diabetes risk, consistent with associations observed for eggs (76) and red and processed meat (69). However, refined grains (71) and high-fat dairy (70) have not been consistently linked to diabetes risk. Overall, the contributions of single PCA-pattern components remain unknown to observed associations with diabetes risk. Furthermore, in every study that we evaluated, food items were condensed to food groups in a different manner, comprising various numbers, which may have affected the number and characteristics of the derived patterns (77).

We identified 3 RRR patterns that were repeatedly evaluated in prospective cohort studies beyond the studies from which they were initially derived. As an advantage of RRR compared with purely data-driven methods, pattern generation aims to explain maximum variance in a set of responses, e.g., biomarkers linked to diabetes. The associations with diabetes were relatively strong compared with other approaches. The heterogeneity between the studies was relatively high, but even the lowest reported effect size was quite comparable to those reported for other approaches. Furthermore, the I^2 measure of heterogeneity increases with increasing the sample size of included studies (78). Thus, estimates of heterogeneity may not be easily comparable between DP approaches. The use of glycated hemoglobin or HOMA-IR as responses could be criticized because they are prediction markers of type 2 diabetes. Although it was shown that the derived RRR patterns were similarly associated with diabetes risk in independent study populations, the patterns might be specific for diabetes but of less importance for other chronic diseases. The use of more “upstream” markers might be more useful for identifying patterns important for a variety of outcomes based on shared biological pathways, such as inflammation (56, 79). Still, our meta-analysis might indicate that RRR is advantageous for identifying diabetes-relevant DPs. Previous reviews summarized studies irrespective of different biomarker response sets and pattern composition (12, 13). Our meta-analyses of 3 selected RRR patterns revealed that refined grains, SSBs, and processed meat play a major role, independent of the biomarkers used as responses. This is partly in line with components of the mainly unhealthy group of PCA-derived patterns. Thus, DPs with these components seemed to increase diabetes risk, regardless of the applied approach. It is worth noting that each RRR pattern was also characterized by different components possibly because of different biomarker sets, reflecting different pathways in the metabolism leading to diabetes (15) or population-specific dietary habits, e.g., the negative loading of legumes to the RRR score derived by
Heidemann et al. (31) may reflect that legumes are often consumed as stews in combination with processed meat in this particular population (15).

The problem of potential confounding was addressed in the quality assessment of the studies and by summarizing only those risk estimates from the most comprehensively adjusted models. The funnel plots did not indicate publication bias, although such bias may not be fully ruled out in meta-analyses. Furthermore, the meta-analytical summarization of DPs generated by factor analysis and PCA may be questioned because they remain population-specific, even if similar components were identified. The summarized a priori patterns were partly characterized by slight differences in composition. Furthermore, risk estimates refer to the comparisons of extreme quantiles but did not consider dose-response relations.

To conclude, diets according to the Mediterranean diet, DASH, and AHEI each have a strong potential for preventing diabetes, although they differ in particular components. The 2 identified groups of exploratory DPs characterized by concordant food groups were significantly associated with diabetes risk. This observation suggests that the combination of several food groups allows the identification of DPs associated with diabetes risk even if single-component foods have limited evidence for an association. Still, exploratory DPs quite frequently remain population-specific observations. For 3 RRR patterns, consistent positive associations with diabetes were observed across independent populations that might favor the RRR approach over purely exploratory approaches.

Acknowledgments

The authors’ responsibilities were as follows—FJ: completed the first draft of the manuscript; JK and MBS: contributed to all content, editing, and the final draft of the manuscript; and all authors: read and approved the final manuscript.

References


