MAYO CLINIC

Refined Grain Intake and Risk of Type 2 Diabetes

Glenn A. Gaesser, PhD

From the College of Health Solutions, Arizona State University, Phoenix, AZ.

Grain foods are considered part of a healthy diet, and current US dietary guidelines recommend that at least one-half of grain consumption come from whole grains.[1] Health benefits of whole grains are well established, and several meta-analyses have demonstrated inverse associations between whole grain intake and risk of several chronic diseases, including type 2 diabetes (T2D).[2,3] Less than 7% of the US population consumes the recommended minimum 3 servings per day of whole grains, and more than 70% of Americans consume less than 1 serving per day of whole grains.[4] In contrast, refined grain consumption in the United States is approximately 5 times greater than whole grains, averaging ~84% of total grain intake.[5] Because of this imbalance, the 2015 Dietary Guidelines Advisory Committee (DGAC) recommended that Americans should "replace most refined grains with whole grains,"[6] and the 2020 DGAC emphasized that "a shift toward higher proportion of total grains as whole grains and a reduction in refined grains is needed."[7] Specifically with regard to T2D, both DGACs concluded that the strength of scientific evidence was "moderate" that a reduced intake of refined grains was associated with lower risk of T2D.

The conclusions of the 2015 and 2020 DGACs with regard to refined grains and risk of T2D were based predominantly on dietary pattern research. "Healthy" dietary patterns are characterized by higher consumption of fruits, vegetables, whole grains, low-fat or non-fat dairy products, seafood, legumes, and nuts. In contrast, "unhealthy" (Western) dietary patterns are characterized by higher intakes of red and processed meat, sugar-sweetened foods and beverages, French fries, high-fat dairy products, and refined grains. A substantial body of research shows that a healthy dietary pattern is associated with a lower risk of T2D and that an unhealthy dietary pattern is associated with increased risk of T2D.[8,9] However, dietary pattern research does not provide for an assessment of the risks associated with each particular food group within each dietary pattern. It is plausible that the risk associated with refined grain intake is not attributable to refined grains per se but rather to the other foods within the unhealthy dietary pattern.[10] For example, risk of T2D has been shown to be associated with consumption of red and processed meat[3,11,12] and sugar-sweetened beverages.[3,12] To establish the T2D risk associated with refined grain intake, it is necessary to include studies in which refined grains are considered as a separate food category and not within a dietary pattern. Moreover, interpretation of the published data on health risks associated with refined grain intake is complicated by how refined grain foods are defined in research studies. Refined grains can include both staple grain foods (eg, bread, cereal, pasta, rice) and indulgent grain foods (eg, cakes, cookies, and pastries).[10]

The purpose of this commentary is to summarize published research on the association between refined grain intake and risk of T2D. PubMed, the Institute for Scientific Information's Web of Science, and the Cochrane Database of Systematic Reviews were searched to identify relevant meta-analyses and prospective cohort studies that published relative risks (RRs) or hazard ratios (HRs) for T2D associated with refined grain intake. Only studies that analyzed refined grains as a distinct food category were considered relevant to this commentary. All RRs or HRs presented in text and

Mayo Clin Proc. ■ August 2022;97(8):1428-1436 ■ https://doi.org/10.1016/j.mayocp.2022.05.004
www.mayoclinicproceedings.org ■

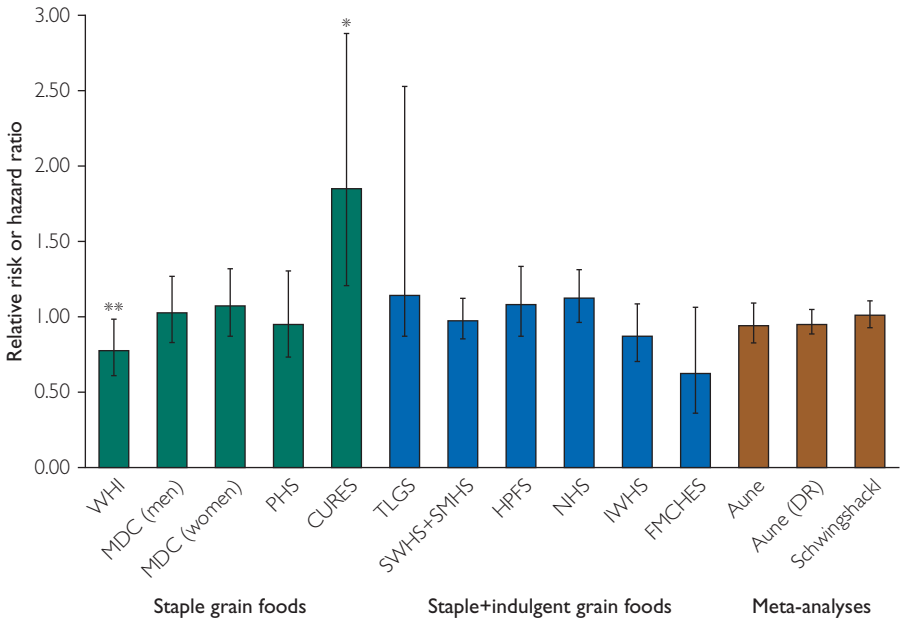

FIGURE 1. Refined-grain intake and risk of type 2 diabetes in cohort studies, comparing highest and lowest (referent = 1.00) intakes. Vertical bars = 95% confidence intervals. *Risk estimate significantly higher for highest intake group, $P<.05$. **Risk estimate significantly lower for the highest intake group, $P<.05$. CURES, Chennai Urban Rural Epidemiological Study;[22] DR, dose-response meta-analysis (per 3 servings per day);[2] FMCHES, Finnish Mobile Clinic Health Exam Survey;[20] HPFS, Health Professionals Follow-up Study;[17] IWHS, Iowa Women's Health Study;[15] MDC, Malmo Diet and Cancer study;[13] NHS, Nurses' Health Study;[14] PHS, Physicians' Health Study;[18] SHWS, Shanghai Women's Health Study;[21] SHMS, Shanghai Men's Health Study;[21] TGLS, Tehran Lipid and Glucose Study;[19] WHI, Women's Health Initiative observational study.[16]

in figures represent results for fully adjusted statistical models, which typically included age, sex, body mass index, smoking status, physical activity, family history of T2D, total energy intake, and intake of other foods and beverages.

Refined Grain Intake and T2D Risk

Ten publications (11 cohorts) provided data on T2D risk associated with intake of refined grains, including 4 cohorts of women,[13-16] 3 cohorts of men,[13,17,18] and 4 cohorts of women and men combined.[19-22] These cohorts included a total of 268,419 women and 130,575 men. Of the 11 cohorts, 1 reported a higher risk of T2D when comparing the highest and lowest intakes of refined grains;[22] 1 reported a lower risk;[16] and 9 reported risk estimates, indicating no statistically significant associations (Figure 1). The single study reporting a higher T2D risk was the smallest cohort (1376 men and women from India), in which the major source of refined grains was white rice.[22] In the Women's Health Initiative Observational Study,[16] the HR for the highest (≥6 servings per day) compared with the lowest (<1 serving per day) category of refined grain intake was 0.77 (95% confidence interval [CI], 0.61 to 0.98). In this study, the lower HR for the highest intake of refined grains was similar to that for the highest intake of whole grains. Seven of these 11 cohorts[13-18,20] were included in 2 published meta-analyses, each of which reported summary risk estimates that demonstrated no significant association between refined grain intake and T2D (Figure 1).[2,3]

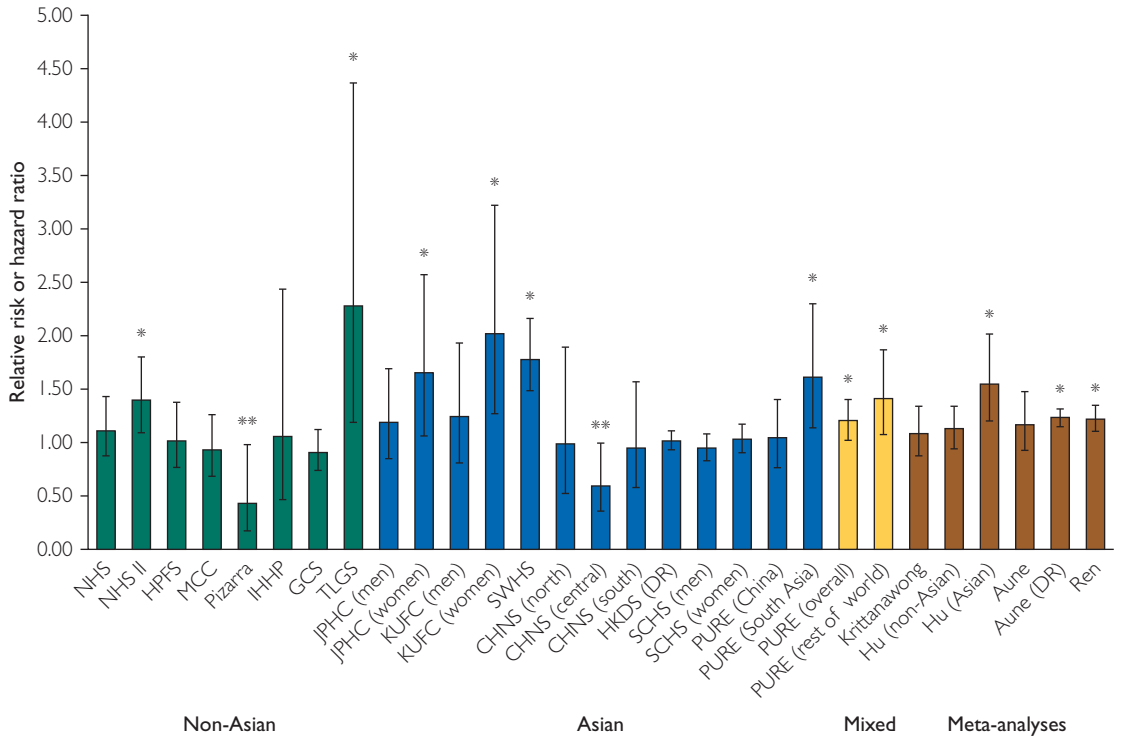

FIGURE 2. White rice intake and risk of type 2 diabetes in cohort studies, comparing highest and lowest (referent = 1.00) intakes, and in dose-response (DR) analyses. Vertical bars = 95% confidence intervals. *Risk estimate significantly higher for highest intake group, $P<.05$. **Risk estimate significantly lower for the highest intake group, $P<.05$. In HKDS DR, dose = per standard deviation in rice intake (g per week). In the DR meta-analysis,[2] the risk is per 1 serving per day. CHNS, China Health and Nutrition Survey;[30] GCS, Golestan Cohort Study;[31] HKDS, Hong Kong Dietary Survey;[34] HPFS, Health Professionals Follow-up Study;[26] IHHP, Isfahan Healthy Heart Program;[28] JPHC, Japan Public Health Center-based prospective study;[24] KUFC, Kyushu University Fukuoka Cohort;[23] MCC, Melbourne Collaborative Cohort;[32] NHS, Nurses' Health Study;[26] NHS II, Nurses' Health Study II;[26] PURE, Prospective Urban Rural Epidemiology study;[29] SCHS, Singapore Chinese Health Study;[25] SWHS, Shanghai Women's Health Study;[27] TLGS, Tehran Lipid and Glucose Study.[31]

The lack of association between intake of refined grain and T2D is surprising, considering the foods defined as refined grains. In addition to staple refined grain foods mentioned here, refined grains were defined to include cakes,[14,17,20] cookies,[20] sweets and desserts,[14,15] sweet rolls and bread,[14,17,19,20] pancakes,[14,15,17,20] waffles,[14,15,17] muffins,[14,17] and pizza.[14,15,17] These foods typically contain high amounts of sugar and fat and low amounts of fiber. None of the cohort studies examined the separate associations between T2D risk and intake of either staple or indulgent refined grain foods or provided information as to the percentage contributions of the different refined grain foods to total refined grain intake.

However, it is interesting to note that 4 of the cohort studies presented in Figure 1 included only staple grain foods in their definitions of refined grains, such as refined cereal products,[13,22] refined grain bread,[16] and refined grain breakfast cereals.[16,18] The T2D risks associated with the highest consumption of these refined grain foods are similar to those in cohorts that included both staple and indulgent grain foods in their analyses. Thus, even with inclusion of indulgent grain-based foods, none of the studies showed an elevated risk of T2D associated with the highest intake of refined grains, and none of the meta-analyses indicated an association between refined grain intake and T2D.

Mayo Clin Proc. ■ August 2022;97(8):1428-1436 ■ https://doi.org/10.1016/j.mayocp.2022.05.004
www.mayoclinicproceedings.org

White Rice Intake and T2D Risk

Data from 23 cohorts provided T2D risk estimates for white rice intake (Figure 2). These include data from 6 cohorts of women,[23-27] 5 cohorts of men,[23-26,28] and 12 cohorts of men and women combined,[29-34] with a total of 566,963 participants. Thirteen of the cohorts are from Asian populations,[23-25,27,29,30,34] 8 from non-Asian populations,[26,28,31-33] and 2 include a mixture of Asian and non-Asian populations.[29] Also shown in Figure 2 are results from 5 meta-analyses comparing highest vs lowest intakes,[2,35,36] and 1 dose-response meta-analysis,[2] on the association between white rice intake and T2D risk. All cohort studies but 1 shown in Figure 2 are included in 1 or more of the meta-analyses.[29]

Higher T2D risk in the highest white rice intake group was found in 8 cohorts and in 3 of the meta-analyses. Most of these were observed in Asian cohorts[23,27,29] or in cohorts that included both Asian and non-Asian populations.[29] Consumption of white rice is generally much higher in Asian populations. For example, rice consumption in the highest intake groups in 3 US cohorts of health professionals[26] is comparable with that of the lowest intake groups of Asian cohorts.[23-25,29] High intake of white rice is associated with high dietary glycemic index (GI) and glycemic load (GL), and meta-analyses have shown that high GI and GL are associated with higher risk of T2D.[37,38] The higher T2D risk associated with high GI and GL appears to be stronger in Asian cohorts than in cohorts from the United States or Europe.[37] None of the cohort studies presented in Figure 2 adjusted for GI or GL in their statistical models, and thus it is possible that this could have influenced the results. However, application of GI values of foods from diet records and food frequency questionnaires used in all of the cohort studies is problematic,[39] and this may be especially true for white rice, with reported GI values ranging from 17 to 94.[40]

Moreover, high consumption of white rice among Asian populations may not fully explain the higher T2D risk because high intake of white rice was not consistently associated with increased T2D risk across all Asian cohorts. Consumption of white rice in the highest intake groups across cohorts was ~600 to 900 g per day. Although this level of white rice consumption was associated with increased T2D risk in some Asian cohorts,[23,24,29] risk of T2D was not higher among men and women in the highest white rice intake group in the Singapore Chinese Health Study (683 g per day),[25] the Japan Public Health Center-based study (762 g per day),[24] and the China cohort of the Prospective Urban Rural Epidemiology (PURE) study (800 g per day),[29] or among men in the Kyushu University Fukuoka Cohort Study (616 g per day).[23] The 149,823 men and women in these cohorts constitute nearly 60% of the total participants for all Asian cohorts presented in Figure 1. Thus, factors other than high consumption of white rice may contribute to the higher risk of T2D in some of the Asian cohorts.

The results of the meta-analyses are in line with the inconsistent results from the

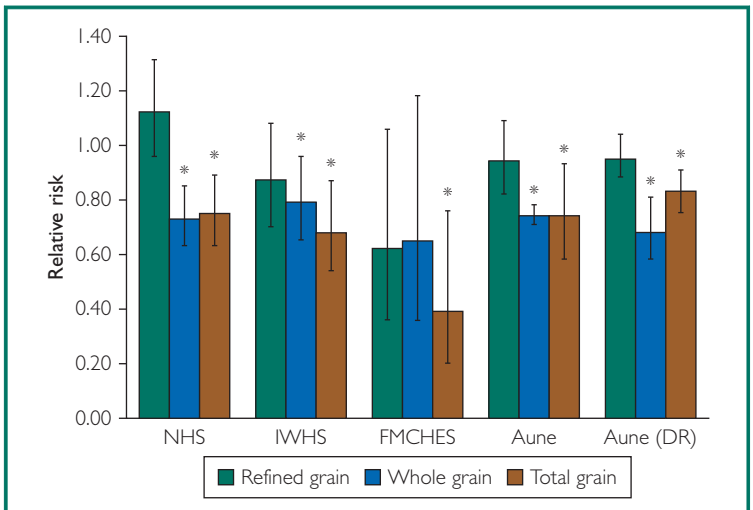

FIGURE 3. Risk of type 2 diabetes associated with intake of refined grain, whole grain, and total grain, comparing highest and lowest (referent = 1.00) intakes, and in dose-response (DR) analyses. Vertical bars = 95% confidence intervals. *Risk estimate significantly lower for the highest intake group, $P<.05$. FMCHES, Finnish Mobile Clinic Health Exam Survey;[20] IWHS, Iowa Women's Health Study;[15] NHS, Nurses' Health Study.[14] In the DR meta-analysis, the risk is per 3 servings per day.[2]

cohort studies (Figure 2). Hu et al[35] found high intake of white rice to be associated with risk of T2D in Asian cohorts only. The higher risk observed in the meta-analysis by Ren et al[41] included data primarily from Asian cohorts (7 of 9). By contrast, the meta-analyses of Krittanawong et al[36] and Aune et al[2] included relatively more non-Asian populations.

Total Grain Intake and Risk of T2D

Although it has been recommended that Americans replace refined grains with whole grains and reduce overall intake of refined grains,[6,7] to reduce risk of T2D this may not be necessary. In 3 cohort studies,[14,15,20] total grain consumption (calculated as the sum of refined grain and whole grain intake, either as g per day[15] or servings per week[20]) has been reported to be associated with significantly lower risk of T2D (Figure 3). In the Nurses' Health Study, whole-grain intake was associated with significantly lower risk of T2D compared with refined-grain intake, but the relative risk for the highest quintile of whole-grain intake was essentially the same as that for total grain intake.[14] In the Iowa Women's Health Study[15] and the Finnish Mobile Clinic Health Exam Survey,[20] the relative risks for refined grain, whole grain, and total grain intake are not significantly different from one another. But, in the Finnish Mobile Clinic Health Exam Survey, only for total grain intake was the relative risk (RR),0.68; 95% CI, 0.54 to 0.87 of highest intake quartile significantly lower than the lowest intake quartile.[20] The fact that the RR for highest intake of total grain was lower than that of whole grain suggests that consumption of refined grains did not offset any benefit of whole grain consumption.

Quantities of refined grain consumption were not reported in the Nurses' Health Study, but in the Iowa Women's Health Study refined grain intake comprised >50% of total grain intake in the highest quintile of total grain intake. Finally, in the Women's Health Initiative observational study, both refined grain and whole grain intake were associated with ~20% to 25% lower risk of T2D.[16] As high intake of whole grain was associated with high intake of refined grain, it is likely that total grain intake was associated with lower risk of T2D, even though this was not reported in that study.

The results for total grain intake are further supported by a meta-analysis[2] that included 3 of the studies cited here[14,15,20] and an additional cohort study that reported T2D risk associated with total intake of cereal.[32] In the categorical analysis of highest vs lowest intakes, high intake of total grains was associated with a 26% lower risk of T2D, and in the dose-response analysis, each 3 servings per day of total grains was associated with a 17% lower risk of T2D (Figure 3). The dose-response revealed a nonlinear association, with steeper reductions in T2D risk at the lower and higher end of the intake range (up to ~10 servings per day). This amount of grain consumption exceeds current intake of grain among Americans, although it must be acknowledged that the dose-response meta-analysis was performed using 4 cohorts composed of non-Asian—predominantly White—participants.[14,15,20,32]

Ratio of Refined- to Whole-Grain Intake

Although refined-grain intake is not associated with risk of T2D, and total grain intake is associated with reduced risk of T2D, it is possible that the ratio of refined to whole grain intake may influence risk of T2D. In the Nurses' Health Study, the highest quintile of refined to whole grain ratio was associated with a 26% higher risk of T2D compared with the lowest refined to whole grain ratio.[14] Unfortunately, quantitative information on the actual ratio of refined to whole grain intake was not provided in this study. It is not likely that total grain intake influenced this result because total grain intake was not significantly related to the ratio of intakes (Spearman $r = -0.05$). No other study has reported T2D risk according to refined- to whole-grain intake ratio. However, in the Finnish Mobile Clinic Health Examination Survey, the T2D RR associated with whole grain intake was independent of refined grain intake.[20] Moreover, in the Women's Health Initiative observational

Mayo Clin Proc. ■ August 2022;97(8):1428-1436 ■ https://doi.org/10.1016/j.mayocp.2022.05.004
www.mayoclinicproceedings.org

study, the lower T2D risk associated with refined-grain intake was similar (HRs between 0.75 and 0.83 in fully adjusted models, all statistically significant) across all intake levels of refined grain, even though the ratio of refined to whole grain intake varied by >3-fold across refined-grain intake groups.[16]

Discussion

The results of these cohort studies are contrary to the conclusions of the 2015 and 2020 DGACs. This is most likely because the DGACs relied primarily on studies of dietary patterns and their association with T2D risk rather than on studies in which refined grain foods were considered as a distinct food category. The higher T2D risk associated with the unhealthy (Western) dietary pattern is likely attributable to consumption of red and processed meat and sugar-sweetened beverages rather than to refined grain foods per se.

The results for consumption of white rice suggest that very high intakes may increase T2D risk in some Asian populations. The reasons for this are unclear, as most of the Asian cohorts indicated no elevated T2D risk associated with intake of white rice, even at consumption levels comparable with those cohorts in which higher risk was reported.

Even though refined-grain intake was found to be largely unrelated to risk of T2D, meta-analyses have shown that high intakes of refined grains[42] and white rice[36] are associated with increased risk for metabolic syndrome. Both of these meta-analyses included a majority of Asian cohorts, and this may be especially relevant for interpreting the results for intake of white rice. Also, criteria used to define the metabolic syndrome were not consistent across studies used in the meta-analyses, and the metabolic syndrome definition includes variables such as blood pressure and blood concentrations of triglycerides and high-density lipoprotein (HDL)-cholesterol, which are not necessarily useful for predicting risk of T2D.

A major limitation of the results from cohort studies is that they are observational, and the T2D risk estimates may have been influenced by factors not measured. The risk estimates presented herein represent those from fully adjusted statistical models. Nevertheless, residual confounding is possible because numerous confounders documented to be associated with T2D risk were not measured. For example, dietary fiber was not always included in the statistical models. Even if included, the source of dietary fiber was not considered in any of the studies, and it has been documented that cereal fiber has a stronger inverse association with T2D risk than other sources of dietary fiber such as fruits and vegetables.[12,43] This is highly relevant because 54.5% of all intake of fiber in the United States comes from grain foods, and ~72% of the grain contribution to total fiber intake comes from refined grains.[44] Also, red and processed meat[3,11,12] and sugar-sweetened beverages[3,12] are associated with increased risk of T2D, and none of the cohort studies specifically indicated whether intake of these foods were included in statistical models. Finally, even though all but 1 cohort study[20] included adjustments for physical activity, none of the cohort studies included assessments of sedentary behavior, which is a significant predictor of T2D risk independent of physical activity.[45]

Randomized controlled trials (RCTs) provide a higher level of confidence than cohort studies but generally are limited to examining the effects of relatively short-term dietary interventions on metabolic factors associated with T2D rather than incidence of disease. Several relevant meta-analyses of RCTs have been published and show superior benefits of whole-grain foods compared with refined-grain foods for reducing postprandial glucose and insulin responses[46] but, surprisingly, no consistent benefit for reducing fasting-blood concentrations of glucose and insulin or for improving homeostatic model assessment of insulin resistance (HOMA-IR).[46-48] Thus, the advantage of whole grains compared with refined grains for reducing risk of T2D may

largely be due to their postprandial effects, as the postprandial glucose response has been shown to be a significant predictor of T2D.[49]

Although research strongly supports the recommendation to increase consumption of whole grains for reducing risk of T2D, the optimal amount of whole-grain intake is not entirely clear. Risk appears to be reduced significantly up to about 3 servings per day of whole grains.[2,3] Americans currently consume less than 1 serving per day. A nonlinear dose-response has been reported for total grain intake and reduced risk of T2D, with reductions evident up to at least 10 servings per day.[2] This may be particularly relevant for US dietary recommendations, as this level of total grain consumption exceeds current grain intake among Americans.

It is possible that the ~5-fold greater consumption of refined grains compared with whole grains among Americans could contribute to excess energy intake, which could increase risk for obesity and other chronic diseases. However, as reviewed elsewhere,[10,50] most cohort studies show no association between intake of refined grains and body mass index or measures of adiposity. Also, meta-analyses of cohort studies indicate that intake of refined grains is not associated with risk of cardiovascular disease, stroke, cancer, or all-cause mortality.[10]

It is also important to emphasize that most refined grains consumed in America are enriched with thiamin, riboflavin, niacin, and iron and are fortified with folic acid. Enriched grains are meaningful contributors to nutrient density and can help deliver shortfall nutrients to the American population.[51] The DGACs considered the important micronutrient contribution of refined (enriched) grains when recommending that Americans make half of their grains whole grains.[1,6,7]

Conclusion

Overall, published data suggest that, with few exceptions, intake of refined grains is not associated with increased risk of T2D. Only 1 (the smallest) of 11 cohort studies reported an elevated risk of T2D associated with the highest intake of refined grains, and 1 large cohort of women actually indicated a lower risk of T2D in the highest refined-grain intake group. Whether refined grains were defined to include staple grain foods only—or a combination of staple and indulgent grain foods—did not appear to influence the results. Total grain intake, defined as the sum of refined- and whole-grain intake, is associated with lower risk of T2D. High intake of white rice, particularly in Asian populations, may increase risk of T2D.

POTENTIAL COMPETING INTERESTS

Glenn Gaesser is a member of the scientific advisory boards of the Grain Foods Foundation and the Wheat Foods Council.

Abbreviations and Acronyms: **DGAC**, Dietary Guidelines Advisory Committee; **T2D**, type 2 diabetes

Grant Support: This work was supported in part by the Grain Foods Foundation.

Correspondence: address to Glenn A. Gaesser, PhD, 550 North Third Street, Phoenix, AZ 85004 (Glenn.gaesser@asu.edu).

ORCID

Glenn A. Gaesser: https://orcid.org/0000-0001-5127-5336

REFERENCES

1. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans, 2020-2025*. 9th Edition. https://www.DietaryGuidelines.gov. Accessed Accessed May 25, 2021.
2. Aune D, Norat T, Romundstad P, Vatten LJ. Whole grain and refined grain consumption and the risk of type 2 diabetes: a systematic review and dose-response meta-analysis of cohort studies. *Eur J Epidemiol*. 2013;28(11):845-858.
3. Schwingshackl L, Hoffmann G, Lampousi AM, et al. Food groups and risk of type 2 diabetes mellitus: a systematic review and meta-analysis of prospective studies. *Eur J Epidemiol*. 2017; 32(5):363-375.
4. O'Neil CE, Nicklas TA, Zanovec M, Cho S. Whole-grain consumption is associated with diet quality and nutrient intake in adults: the National Health and Nutrition Examination Survey, 1999-2004. *J Am Diet Assoc*. 2010;110(10):1461-1468.
5. Ahluwalia N, Herrick KA, Terry AL, Hughes JP. Contribution of whole grains to total grains intake among adults aged 20 and over: United States, 2013-2016. *NCHS Data Brief*. 2019;(341): 1-8.
6. Dietary Guidelines Advisory Committee. *2015. Scientific Report of the 2015 Dietary Guidelines Advisory Committee: Advisory Report to the Secretary of Health and Human Services and the Secretary of Agriculture*. https://health.gov/dietaryguidelines/2015-scientific-report/
7. Dietary Guidelines Advisory Committee. *2020. Scientific Report of the 2020 Dietary Guidelines Advisory Committee: Advisory*

Report to the Secretary of Agriculture and the Secretary of Health and Human Services. https://www.dietaryguidelines.gov/2020-advisory-committee-report
8. Alhazmi A, Stojanovski E, McEvoy M, Garg ML. The association between dietary patterns and type 2 diabetes: a systematic review and meta-analysis of cohort studies. *J Hum Nutr Diet*. 2014;27(3):251-260.
9. Jannasch F, Kroger J, Schulze MB. Dietary patterns and type 2 diabetes: a systematic literature review and meta-analysis of prospective studies. *J Nutr*. 2017;147(6):1174-1182.
10. Gaesser GA. Perspective: Refined grains and health: genuine risk, or guilt by association? *Adv Nutr*. 2019;10(3):361-371.
11. Micha R, Wallace SK, Mozaffarian D. Red and processed meat consumption and risk of incident coronary heart disease, stroke, and diabetes mellitus: a systematic review and meta-analysis. *Circulation*. 2010;121(21):2271-2283.
12. Neuenschwander M, Ballon A, Weber KS, et al. Role of diet in type 2 diabetes incidence: umbrella review of meta-analyses of prospective observational studies. *BMJ*. 2019;366:l2368.
13. Ericson U, Sonestedt E, Gullberg B, et al. High intakes of protein and processed meat associate with increased incidence of type 2 diabetes. *Br J Nutr*. 2013;109(6):1143-1153.
14. Liu S, Manson JE, Stampfer MJ, et al. A prospective study of whole-grain intake and risk of type 2 diabetes mellitus in US women. *Am J Public Health*. 2000;90(9):1409-1415.
15. Meyer KA, Kushi LH, Jacobs DR Jr, Slavin J, Sellers TA, Folsom AR. Carbohydrates, dietary fiber, and incident type 2 diabetes in older women. *Am J Clin Nutr*. 2000;71(4):921-930.
16. Parker ED, Liu S, Van Horn L, et al. The association of whole grain consumption with incident type 2 diabetes: the Women's Health Initiative Observational Study. *Ann Epidemiol*. 2013;23(6):321-327.
17. Fung TT, Hu FB, Pereira MA, et al. Whole-grain intake and the risk of type 2 diabetes: a prospective study in men. *Am J Clin Nutr*. 2002;76(3):535-540.
18. Kochar J, Djousse L, Gaziano JM. Breakfast cereals and risk of type 2 diabetes in the Physicians' Health Study I. *Obesity (Silver Spring)*. 2007;15(12):3039-3044.
19. Esmaillzadeh A, Mirmiran P, Azizi F. Whole-grain consumption and the metabolic syndrome: a favorable association in Tehranian adults. *Eur J Clin Nutr*. 2005;59(3):353-362.
20. Montonen J, Knekt P, Jarvinen R, Aromaa A, Reunanen A. Whole-grain and fiber intake and the incidence of type 2 diabetes. *Am J Clin Nutr*. 2003;77(3):622-629.
21. Yu D, Zheng W, Cai H, et al. Long-term diet quality and risk of type 2 diabetes among urban chinese adults. *Diabetes Care*. 2018;41(4):723-730.
22. Anjana RM, Sudha V, Nair DH, et al. Diabetes in Asian Indians: how much is preventable? Ten-year follow-up of the Chennai Urban Rural Epidemiology Study (CURES-142). *Diabetes Res Clin Pract*. 2015;109(2):253-261.
23. Hirata A, Ohnaka K, Tashiro N, et al. Effect modification of green tea on the association between rice intake and the risk of diabetes mellitus: a prospective study in Japanese men and women. *Asia Pac J Clin Nutr*. 2017;26(3):545-555.
24. Nanri A, Mizoue T, Noda M, et al. Rice intake and type 2 diabetes in Japanese men and women: the Japan Public Health Center-based Prospective Study. *Am J Clin Nutr*. 2010;92(6):1468-1477.
25. Seah JYH, Koh WP, Yuan JM, van Dam RM. Rice intake and risk of type 2 diabetes: the Singapore Chinese Health Study. *Eur J Nutr*. 2019;58(8):3349-3360.
26. Sun Q, Spiegelman D, van Dam RM, et al. White rice, brown rice, and risk of type 2 diabetes in US men and women. *Arch Intern Med*. 2010;170(11):961-969.
27. Villegas R, Liu S, Gao YT, et al. Prospective study of dietary carbohydrates, glycemic index, glycemic load, and incidence of type 2 diabetes mellitus in middle-aged Chinese women. *Arch Intern Med*. 2007;167(21):2310-2316.
28. Khosravi-Boroujeni H, Sarrafzadegan N, Mohammadifard N, et al. White rice consumption and CVD risk factors among Iranian population. *J Health Popul Nutr*. 2013;31(2):252-261.
29. Bhavadharini B, Mohan V, Dehghan M, et al. White rice intake and incident diabetes: a study of 132,373 participants in 21 countries. *Diabetes Care*. 2020;43(11):2643-2650.
30. Dong F, Howard AG, Herring AH, Popkin BM, Gordon-Larsen P. White rice intake varies in its association with metabolic markers of diabetes and dyslipidemia across region among Chinese adults. *Ann Nutr Metab*. 2015;66(4):209-218.
31. Golozar A, Khalili D, Etemadi A, et al. White rice intake and incidence of type-2 diabetes: analysis of two prospective cohort studies from Iran. *BMC Public Health*. 2017;17(1):133.
32. Hodge AM, English DR, O'Dea K, Giles GG. Glycemic index and dietary fiber and the risk of type 2 diabetes. *Diabetes Care*. 2004;27(11):2701-2706.
33. Soriguer F, Colomo N, Olveira G, et al. White rice consumption and risk of type 2 diabetes. *Clin Nutr*. 2013;32(3):481-484.
34. Yu R, Woo J, Chan R, et al. Relationship between dietary intake and the development of type 2 diabetes in a Chinese population: the Hong Kong Dietary Survey. *Public Health Nutr*. 2011;14(7):1133-1141.
35. Hu EA, Pan A, Malik V, Sun Q. White rice consumption and risk of type 2 diabetes: meta-analysis and systematic review. *BMJ*. 2012;344:e1454.
36. Krittanawong C, Tunhasiriwet A, Zhang H, et al. Is white rice consumption a risk for metabolic and cardiovascular outcomes? A systematic review and meta-analysis. *Heart Asia*. 2017;9(2):e010909.
37. Hardy DS, Garvin JT, Xu H. Carbohydrate quality, glycemic index, glycemic load and cardiometabolic risks in the US, Europe and Asia: a dose-response meta-analysis. *Nutr Metab Cardiovasc Dis*. 2020;30(6):853-871.
38. Livesey G, Taylor R, Livesey HF, et al. Dietary glycemic index and load and the risk of type 2 diabetes: a systematic review and updated meta-analyses of prospective cohort studies. *Nutrients*. 2019;11(6):1280.
39. Gaesser GA, Miller Jones J, Angadi SS. Perspective: does glycemic index matter for weight loss and obesity prevention? Examination of the evidence on "fast" compared with "slow" carbs. *Adv Nutr*. 2021;12(6):2076-2084.
40. The University of Sydney. The International Glycemic Index (GI) Database. Accessed December 20, 2021. http://www.glycemicindex.com/
41. Ren G, Qi J, Zou Y. Association between intake of white rice and incident type 2 diabetes: an updated meta-analysis. *Diabetes Res Clin Pract*. 2021;172:108651.
42. Guo H, Ding J, Liang J, Zhang Y. Associations of whole grain and refined grain consumption with metabolic syndrome: a meta-analysis of observational studies. *Front Nutr*. 2021;8:695620.
43. McRae MP. Dietary fiber intake and type 2 diabetes mellitus: an umbrella review of meta-analyses. *J Chiropr Med*. 2018;17(1):44-53.
44. Kranz S, Dodd KW, Juan WY, Johnson LK, Jahns L. Whole grains contribute only a small proportion of dietary fiber to the U.S. diet. *Nutrients*. 2017;9(2):153.
45. Guo C, Zhou Q, Zhang D, et al. Association of total sedentary behaviour and television viewing with risk of overweight/obesity, type 2 diabetes and hypertension: a dose-response meta-analysis. *Diabetes Obes Metab*. 2020;22(1):79-90.
46. Marventano S, Vetrani C, Vitale M, Godos J, Riccardi G, Grosso G. Whole grain intake and glycaemic control in healthy subjects: a systematic review and meta-analysis of randomized controlled trials. *Nutrients*. 2017;9(7):769.
47. Wang W, Li J, Chen X, Yu M, Pan Q, Guo L. Whole grain food diet slightly reduces cardiovascular risks in obese/overweight adults: a systematic review and meta-analysis. *BMC Cardiovasc Disord*. 2020;20(1):82.

48. Ye EQ, Chacko SA, Chou EL, Kugizaki M, Liu S. Greater whole-grain intake is associated with lower risk of type 2 diabetes, cardiovascular disease, and weight gain. *J Nutr*. 2012;142(7):1304-1313.
49. Ahuja V, Aronen P, Pramodkumar TA, et al. Accuracy of 1-hour plasma glucose during the oral glucose tolerance test in diagnosis of type 2 diabetes in adults: a meta-analysis. *Diabetes Care*. 2021;44(4):1062-1069.
50. Williams PG. Evaluation of the evidence between consumption of refined grains and health outcomes. *Nutr Rev*. 2012;70(2):80-99.
51. Papanikolaou Y, Slavin JL, Clemens R, et al. Do refined grains have a place in a healthy dietary pattern: perspectives from an expert panel consensus meeting. *Curr Dev Nutr*. 2020;4(10):nzaa125.

Mayo Clin Proc. ■ August 2022;97(8):1428-1436 ■ https://doi.org/10.1016/j.mayocp.2022.05.004
www.mayoclinicproceedings.org