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Breakfast Skipping Is Associated with Increased Risk of Type 2 Diabetes among Adults: A Systematic Review and Meta-Analysis of Prospective Cohort Studies

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ABSTRACT

Background: Epidemiologic studies have indicated that breakfast skipping is associated with risk of type 2 diabetes. However, the shape of the dose-response relation and the influence of adiposity on this association have not been reported.

Objective: We investigated the association between breakfast skipping and risk of type 2 diabetes by considering the influence of the body mass index (BMI).

Methods: In this systematic review and meta-analysis, PubMed and Web of Science were searched up to August 2017. Prospective cohort studies on breakfast skipping and risk of type 2 diabetes in adults were included. Summary RRs and 95% CIs, without and with adjustment for BMI, were estimated with the use of a random-effects model in pairwise and dose-response meta-analyses.

Results: In total 6 studies, based on 96,175 participants and 4935 cases, were included. The summary RR for type 2 diabetes comparing ever with never skipping breakfast was 1.33 (95% CI: 1.22, 1.46, $n = 6$ studies) without adjustment for BMI, and 1.22 (95% CI: 1.12, 1.34, $n = 4$ studies) after adjustment for BMI. Nonlinear dose-response meta-analysis indicated that risk of type 2 diabetes increased with every additional day of breakfast skipping, but the curve reached a plateau at 4–5 d/wk, showing an increased risk of 55% (summary RR: 1.55; 95% CI: 1.41, 1.71). No further increase in risk of type 2 diabetes was observed after 5 d of breakfast skipping/wk (P for nonlinearity = 0.08).

Conclusions: This meta-analysis provides evidence that breakfast skipping is associated with an increased risk of type 2 diabetes, and the association is partly mediated by BMI. *J Nutr* 2019;149:106–113.

Keywords: breakfast skipping, type 2 diabetes, systematic review, meta-analysis

Introduction

Diabetes is a major public health problem and accounts for the most common noncommunicable diseases in the 21st century (1). Worldwide, the prevalence of diabetes has increased dramatically, and in 2017 it was estimated that 451 million adults aged 20–79 y had diabetes (8.8% of the world population). This number is expected to rise to 629 million by 2045 (2). The risk of type 2 diabetes (the most common form of diabetes) is multifactorial, and lifestyle factors, including diet, play an important role in the etiology. Evidence from epidemiologic studies has shown that high intake of red meat (3), food with high glycemic index or load (4), and sugar-sweetened beverages (5) were associated with increased risk of type 2 diabetes, whereas whole-grain products (6) and coffee consumption (7) were associated with reduced risk. There is also evidence available that a healthy dietary pattern (e.g., adherence to a Mediterranean diet) is associated with lower risk of type 2 diabetes (8). Beyond this, studies have indicated that eating patterns including breakfast skipping are not only related to weight gain and obesity, but also with insulin resistance and risk of type 2 diabetes (9, 10). In 2010, between 1.7% and

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30% of adults reported skipping breakfast worldwide (11). Breakfast skipping is a modifiable behavior factor, and thus of great public health interest regarding the prevention of type 2 diabetes and its associated burden and costs. A meta-analysis examining the association between breakfast skipping and type 2 diabetes reported a positive association (12). However, the influence of BMI, a potential mediator for this association, was only evaluated in cross-sectional, but not in cohort, studies ($n = 4$ studies). In addition, no dose-response meta-analysis was conducted. Since then, 2 further prospective cohort studies that investigated breakfast skipping and risk of type 2 diabetes have been published, and thus analyses can be updated and amplified.

Thus, the aim of our study was to conduct a systematic review on breakfast skipping and risk of type 2 diabetes, and to summarize findings on ever compared with never skipping breakfast, in a linear (per 1 d/wk) and nonlinear dose-response meta-analysis. In addition, we will evaluate if BMI is a mediator for this association.

Methods

The systematic review was planned and conducted according to the standards of the Meta-analysis Of Observational Studies in Epidemiology (13).

Search strategy and study selection

The literature search and study selection were conducted by 2 investigators (AB, MN). The search focused on meal patterns, eating habits, and risk of type 2 diabetes in general, but for this systematic review and meta-analysis we only included breakfast skipping as exposure. PubMed and Web of Science were searched until August 2017. The following search terms were used in combination: ("dining out" OR "breakfast" OR "lunch" OR "dinner" OR "snack" OR "meal skipping" OR "eating out" OR "meal" OR "evening meal" OR "meal timing" OR "meal frequency" OR "eating patterns" OR "meal patterns" OR "feeding behaviour" OR "meal regularity" OR "fast food" OR "home food preparation") AND ("Diabetes" OR "T2D") AND ("observational study" OR "prospective" OR "cohort" OR "cohorts" OR "longitudinal" OR "case-control" OR "retrospective" OR "follow-up" OR "cross-sectional" OR "population-based" OR "relative-risk" OR "odds ratio" OR "hazard ratio" OR "incidence rate ratio").

Studies that were included had to investigate the association between breakfast skipping and risk of type 2 diabetes. The title and abstract of each study were reviewed. If the title or abstract seemed relevant, the full text of the record was assessed. We only included peer-reviewed prospective cohort studies published in English. Abstracts (14–16), reviews and meta-analyses (12, 17), non-English studies (18), studies with no RR estimates (19), studies with no relevant data (20), studies with nonrelevant exposure (21–28) or nonrelevant outcome (29–38), cross-sectional studies (30–32), ecologic studies (39), and duplicates were excluded for this report.

Data extraction and quality assessment

The following data were extracted from each study: last name of the first author, year of publication, the country where the study was conducted, the cohort name (if any), duration of follow-up, characteristics of the cohort at baseline (age, sex), total number of participants, number of cases of type 2 diabetes, exposure (breakfast skipping), exposure assessment (questionnaire with or without validation, interviews), outcome assessment (self-report of diabetes with or without objective medical details, use of diabetes medication, blood test, medical records), categories of exposure and risk estimates expressed as RRs or HRs with corresponding 95% CIs, and the adjustment factors. We extracted risk estimates and 95% CIs with and without adjustment for BMI, if data were available.

Study quality was evaluated by 2 investigators (AB, SS) with the use of the Newcastle-Ottawa Scale (40). Studies were rated on a scale from 0 to 9 following the checklist. A study having a quality score between 4 and 6 or between 7 and 9 was considered as having a moderate or high quality score, respectively.

Statistical analysis

We used a random-effects model, which takes into account both within- and between-study variability (41), to calculate summary RRs and 95% CIs for the associations between breakfast skipping and type 2 diabetes. The I^2 test and Cochran's test were used to evaluate the heterogeneity between studies. I^2 values of 25%, 50%, and 75% indicated low, moderate, and high heterogeneity, respectively (42). Publication bias was assessed through the use of Egger's test and funnel plots. Asymmetry of the funnel plot, added to a P value for Egger's test <0.10, was considered to indicate possible publication bias (43).

Different types of analyses were conducted: first, summary RRs and 95% CIs were calculated for ever and never skipping breakfast. Because obesity is a potential intermediate risk factor on the causal pathway between breakfast skipping and risk of type 2 diabetes, separate models adjusting for BMI were conducted to evaluate if associations between breakfast skipping and risk of type 2 diabetes were independent of general body fatness. BMI was not included in all studies as a potential confounder, and thus, we conducted a sensitivity analysis for this subset of studies by showing summary RRs (95% CIs) without and with adjustment for BMI. In addition, we conducted subgroup analyses to assess potential heterogeneity between studies. The analyses were stratified by sex, geographic location (United States, Asia), duration of follow-up (<10 and ≥ 10 y of age), number of cases (<1000 and 1000 to <2000), quality score (<7 or ≥ 7), and adjustment for confounding factors (age, sex, smoking, alcohol intake, total energy, family history of diabetes mellitus, physical activity, and education). Heterogeneity between subgroups was evaluated by a meta-regression analysis (42). Second, we conducted a dose-response meta-analysis on breakfast skipping per 1 d/wk and summary RR (95% CI) of type 2 diabetes via the method described by Greenland and Longnecker (44). We computed study-specific slopes (linear trends) and 95% CIs from the natural log of the RRs and 95% CIs across categories of breakfast skipping per week. For this analysis we needed the number of cases per category, the number of person-years, and the exposure value with RRs and corresponding 95% CIs of ≥ 3 categories. The distribution of cases has been estimated for studies that did not report these, but which provided information on the total number of cases and number of total participants plus the follow-up period as previously described in detail (45, 46). For this, the number of person-years per category was multiplied by the RR in each category ("new person-years per category"), and summed to obtain "total new person-years." Then the proportion between "new person-years per category" and "total new person-years" was calculated for each category. Finally, this proportion was multiplied with the total number of cases (reported in the paper), which yields the number of cases for each category. Studies that did not quantify the days of breakfast skipping per week were excluded from the dose-response analysis. If studies reported the breakfast categories according to ranges (e.g., breakfast skipping 0–3, 4–5, and 6–7 d/wk), the midpoint between the lower and upper limits was calculated for each category. For open categories (e.g., breakfast skipping at >5 d/wk), a similar range to the adjacent category was assumed.

Third, a potential nonlinear dose-response relation between breakfast consumption and summary RR (95% CI) of type 2 diabetes was assessed, through the use of a restricted cubic spline model, with 3 knots at the 10th, 50th, and 90th percentiles of the frequency of breakfast skipping (47). To evaluate the difference between the linear and the nonlinear model, a likelihood ratio was used to test for nonlinearity.

All statistical analyses were performed with the use of Stata version 14.2 software (StataCorp, College Station, TX).

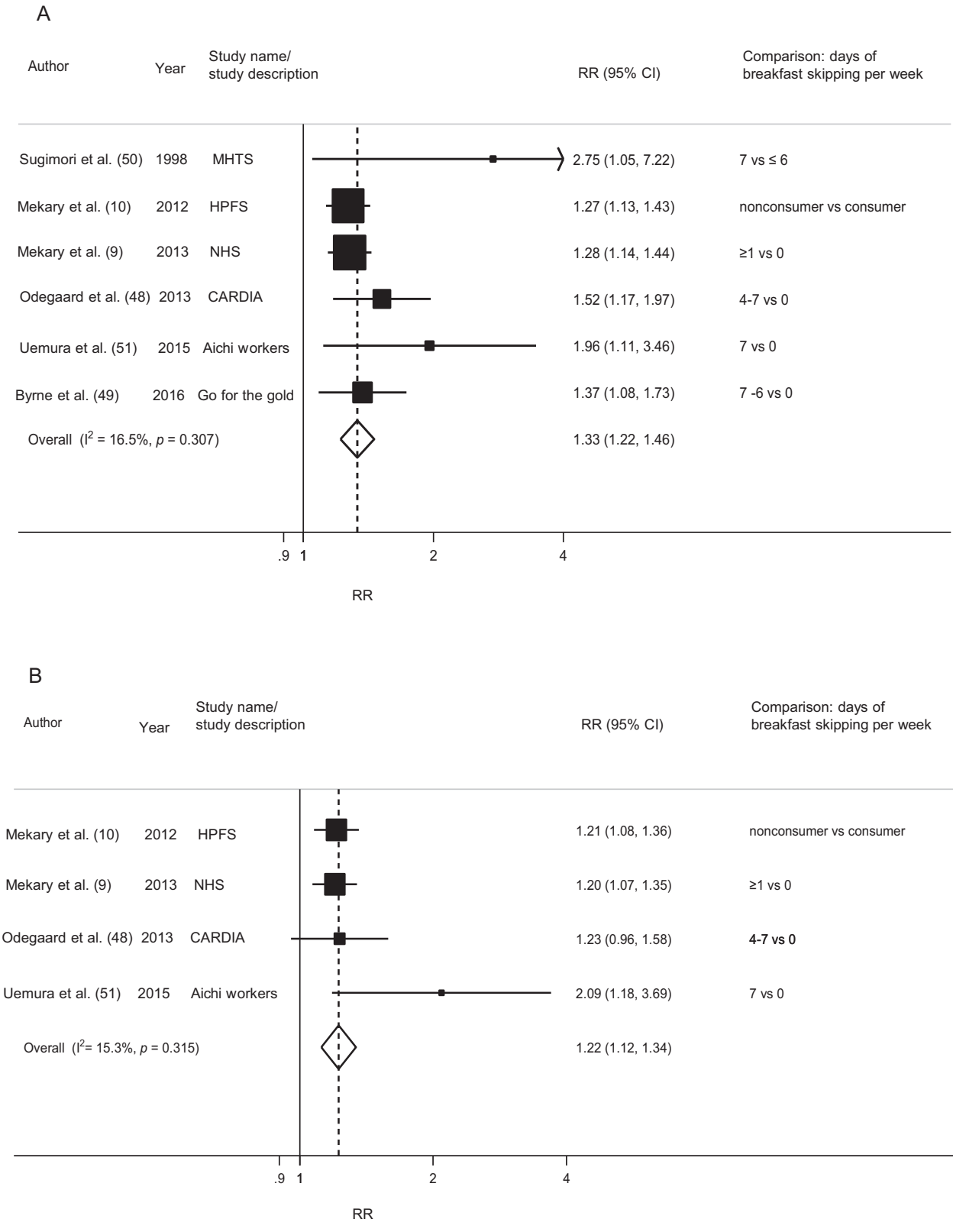

FIGURE 1 Meta-analysis on ever compared with never skipping breakfast and risk of type 2 diabetes (A) without adjustment for BMI and (B) with adjustment for BMI in adults. CARDIA, Coronary Artery Risk Development in Young Adults; HPFS, Health Professionals Follow-Up Study; MHTS, Mutiphasic Health Testing and Services; NHS, Nurses' Health Study.

Results

Literature search

Out of the 2920 studies identified, 45 articles were considered for inclusion, and after screening the full texts, 6 met the inclusion criteria (**Supplemental Figure 1**). The characteristics of the studies are shown in **Supplemental Table 1** with according Supplemental References. Four studies were conducted in the United States and 2 in Japan. The duration of follow-up ranged from 6 to 18 y of age. According to the Newcastle-Ottawa Scale 2 studies had a moderate quality score and 4 had a high quality score (Supplemental Table 1).

Ever or never skipping breakfast and risk of type 2 diabetes

Six studies (9, 10, 48–51) were included in the meta-analysis of ever or never skipping breakfast and risk of type 2 diabetes, involving 4935 cases among 96,175 participants. The summary RR for type 2 diabetes was 1.33 (95% CI: 1.22, 1.46; $I^2 = 16.5\%$, $P_{heterogeneity} = 0.307$; $n = 6$ studies), comparing ever with never skipping breakfast (Figure 1A). Out of the 6 studies, 4 (9, 10, 48, 51) provided results both adjusted and not adjusted for BMI. The summary RR for the risk of type 2 diabetes not adjusted for BMI was 1.32 (95% CI: 1.20, 1.44) in these studies and adjusted for BMI 1.22 (95% CI: 1.12, 1.34; $I^2 = 15.3\%$, $P_{heterogeneity} = 0.315$) (Figure 1B), respectively.

There was no significant heterogeneity between subgroups after stratification by sex, geographic location, duration of follow-up, quality scores, and adjustments for confounding factors (Table 1).

There was an indication of publication bias with $P < 0.001$ from Egger's test and according to the funnel plot. Asymmetry was represented by the lack of small studies with negative results (**Supplemental Figure 2**). Through the use of the trim and fill method, 3 studies were added and findings did not change appreciably (summary RR: 1.29; 95% CI: 1.16, 1.44; based on 6 studies without adjustment for BMI), compared with our main findings.

Dose-response meta-analysis on breakfast skipping and risk of type 2 diabetes

Three studies were included in the dose-response meta-analysis (48, 49, 51). The summary RR for type 2 diabetes per 1 d of breakfast skipping/wk was 1.06 (95% CI: 1.03, 1.09; $I^2 = 15.1\%$, $P_{heterogeneity} = 0.308$) (Figure 2A). When we considered adjustment for BMI in our linear dose-response meta-analysis, 2 studies remained and the summary RR for type 2 diabetes was 1.05 (95% CI: 1.01, 1.09; $I^2 = 0\%$, $P_{heterogeneity} = 0.405$).

The summary RR of type 2 diabetes increased with the number of days of breakfast skipping, reached a peak at 4–5 d of breakfast skipping/wk, and no further increase in risk of type 2 diabetes was observed beyond this (Figure 2B). However, the test for nonlinearity did not reach statistical significance (P for nonlinearity = 0.08). Skipping breakfast for 4–5 d/wk was associated with 55% increased RR of type 2 diabetes (summary RR: 1.55; 95% CI: 1.41, 1.71) (Figure 3). When we included the BMI-adjusted RRs (95% CIs) (available in 2 out of 3 studies) in our nonlinear dose-response meta-analysis, the shape of the associations remained similar, but the summary RRs were slightly attenuated. The summary RR of type 2 diabetes for 4–5 d breakfast skipping/wk was 1.40 (95% CI: 1.16, 1.70), with P for nonlinearity = 0.19.

TABLE 1 Summary RRs and 95% CIs from meta-analysis for ever or never skipping breakfast and risk of type 2 diabetes in adults by subgroups[1]

	Studies, *n*	Summary RRs (95% CIs)	I^2 (%)	P_{within}[2]	$P_{between}$[3]
All studies	6	1.33 (1.22, 1.46)	16.5	0.307	
Sex					
Women	2	1.60 (0.81, 3.18)	57.9	0.123	
Men	1	1.27 (1.13, 1.43)			
Men & women	3	1.47 (1.25, 1.74)	0	0.497	0.741[4]
Geographic location					
Asia	2	2.14 (1.31, 3.49)	0	0.553	
United States	4	1.30 (1.21, 1.40)	0	0.617	0.121
Duration of follow-up, y					
<10	2	1.44 (0.99, 2.10)	51.9	0.149	
≥10	4	1.36 (1.19, 1.54)	21.8	0.280	0.841
Number of cases					
<1000	4	1.50 (1.27, 1.77)	0	0.398	
1000 to <2000	2	1.28 (1.17, 1.39)	0	0.926	0.157
NOS quality score					
4–6	2	1.30 (1.17, 1.44)	0	0.610	
7–9	4	1.47 (1.18, 1.83)	46.0	0.135	0.618
Adjustment for age					
Yes	5	1.35 (1.20, 1.51)	31.9	0.209	
No	1	1.37 (1.08, 1.73)			0.792
Adjustment for sex					
Yes	5	1.35 (1.20, 1.51)	31.9	0.209	
No	1	1.37 (1.08, 1.73)			0.792
Adjustment for family history of diabetes mellitus					
Yes	3	1.29 (1.18, 1.41)	7.9	0.338	
No	3	1.47 (1.23, 1.74)	1.3	0.363	0.262
Adjustment for alcohol intake					
Yes	5	1.35 (1.20, 1.51)	31.9	0.209	
No	1	1.37 (1.08, 1.73)			0.792
Adjustment for total energy intake					
Yes	4	1.32 (1.20, 1.44)	16.7	0.308	
No	2	1.65 (0.90, 3.01)	47.1	0.169	0.580
Adjustment for physical activity					
Yes	4	1.32 (1.20, 1.44)	16.7	0.308	
No	2	1.65 (0.90, 3.01)	47.1	0.169	0.580
Adjustment for smoking status					
Yes	4	1.32 (1.20, 1.44)	16.7	0.308	
No	2	1.65 (0.90, 3.01)	47.1	0.169	0.580
Adjustment for education					
Yes	1	1.52 (1.17, 1.97)			
No	5	1.31 (1.20, 1.44)	15.6	0.315	0.362

[1] Summary RRs were calculated with the use of random-effects models. NOS, Newcastle-Ottawa Scale.
[2] P_{within}, P for heterogeneity within each subgroup.
[3] $P_{between}$, P for heterogeneity between subgroups with meta-regression.
[4] Heterogeneity between men and women (excluding studies with both sexes combined).

Discussion

In this meta-analysis, breakfast skipping was associated with increased risk of type 2 diabetes, and only partly mediated by BMI. Skipping breakfast 4–5 d/wk was associated with 55% increased RR of type 2 diabetes.

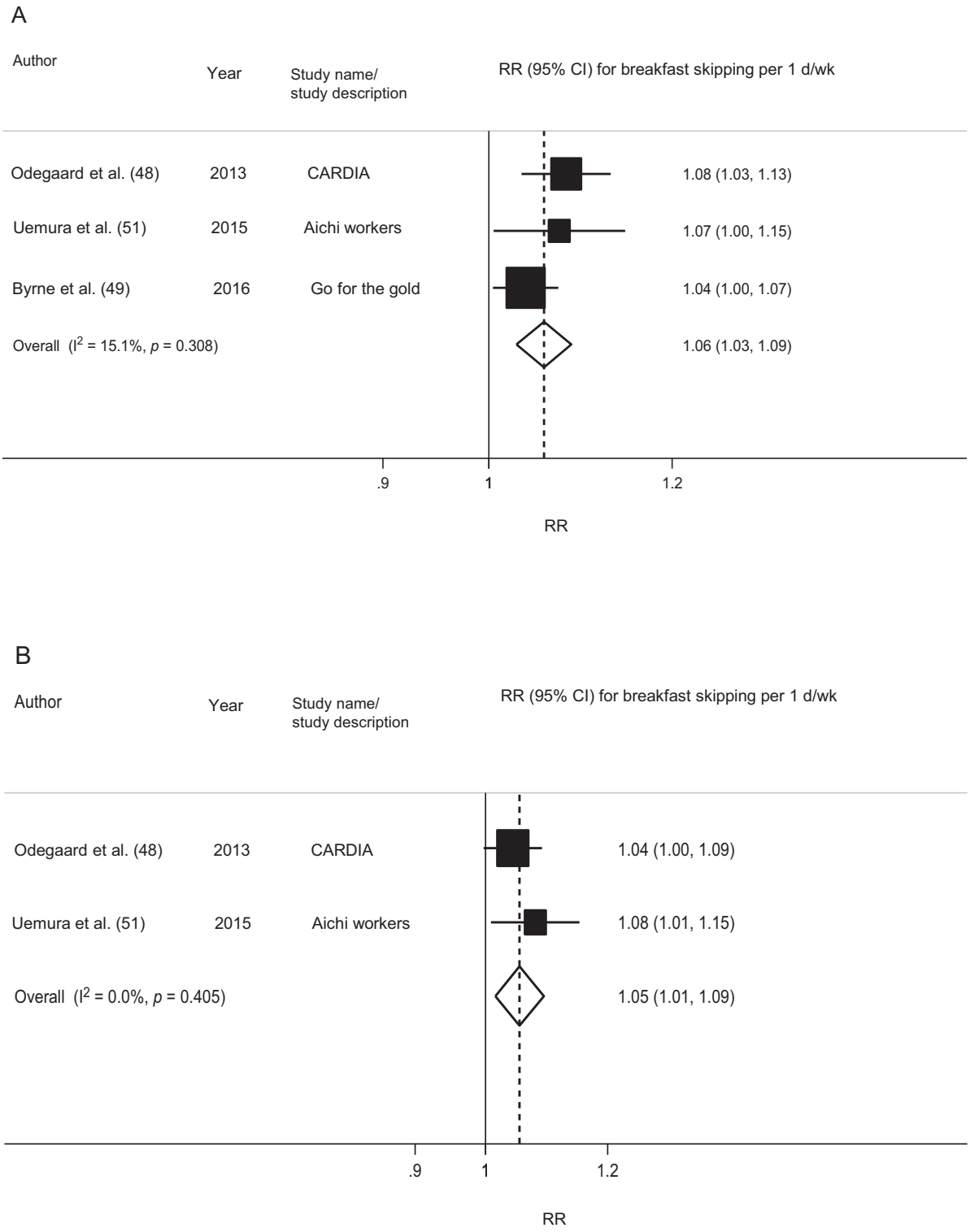

FIGURE 2 Linear dose-response meta-analysis for breakfast skipping and risk of type 2 diabetes (A) without adjustment for BMI and (B) with adjustment for BMI in adults. CARDIA, Coronary Artery Risk Development in Young Adults.

The result of our meta-analysis on breakfast skipping and risk of type 2 diabetes, in prospective studies only, is in line with the result of the previous meta-analysis (12). Ever compared with never skipping breakfast was associated with a 32% increased RR of type 2 diabetes. Even though the effect was slightly attenuated after adjustment for BMI, the association persisted. The linear dose-response meta-analysis adds to current knowledge that breakfast skipping 1 d/wk was associated with a 6% increased RR of type 2 diabetes. Furthermore, the most important adverse effect was observed for 4–5 d/wk of breakfast skipping.

There are several potential mechanisms that can explain the association between breakfast skipping and risk of type 2 diabetes. It has been shown that breakfast skipping was

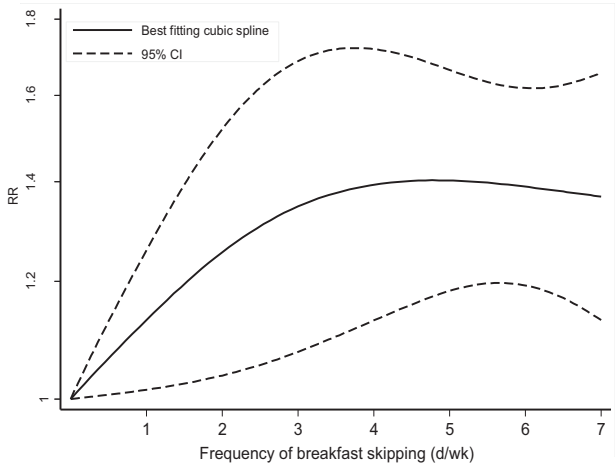

FIGURE 3 Nonlinear dose-response meta-analysis for breakfast skipping and risk of type 2 diabetes in adults.

associated with an increase in body weight and higher prevalence of obesity, which are known risk factors for type 2 diabetes (52, 53). In our analysis, we compared the findings without and with adjustment for BMI. Our findings showed that the association between breakfast skipping and type 2 diabetes was partly mediated by BMI, but a positive association still persisted, which indicates that other factors might have an influence on this association. Studies have reported that the consumption of breakfast is not only associated with increased satiation and appetite regulation, but also with a higher dietary quality in general including higher intake of fiber, vitamins, and minerals and lower intake of added sugars (54), which might have an influence on the risk of type 2 diabetes. Most of the studies included in our systematic review and meta-analysis adjusted for dietary factors (51), dietary pattern scores (9, 10), or a dietary quality score (48), indicating that breakfast skipping is independently associated with risk of type 2 diabetes. Interestingly, the strongest association with type 2 diabetes was observed for the combination of breakfast skipping and having a Western dietary pattern among men from the Health Professionals Follow-Up Study (10). Moreover, it has been shown that breakfast skipping was associated with poor glycemic control (defined by fasting plasma glucose) in patients with type 2 diabetes and in healthy individuals (55, 56), as well as with other cardiometabolic risk markers such as LDL- and HDL-cholesterol in young adults (57). A recent clinical study indicated that longer fasting periods, due to breakfast skipping, were associated with a higher inflammatory response after lunch (29). These cardiometabolic and inflammatory alterations might influence the risk of type 2 diabetes. Beyond breakfast skipping, it has been recently reported that the quality of breakfast also has an influence on long-term hyperglycemia and cardiometabolic risk markers (58). A breakfast high in processed meat and low in whole-grain cereals was associated with higher levels of adverse cardiometabolic risk, defined by glycated hemoglobin, C-reactive protein, TGs, and LDL and HDL cholesterol. Altogether, these findings emphasize the importance of the consumption of a high-quality breakfast regarding the prevention of type 2 diabetes.

For this meta-analysis of observational studies, possible limitations must be taken into consideration. Different definitions of breakfast skipping were used among the included studies [less than just a roll and a cup of coffee (49), no evidence of a given definition (10, 48, 50, 51), or less than coffee and tea (9)]. In addition, the categories of breakfast skipping or consumption, respectively, varied from yes/no to every day/almost every day/3–5 days per week/1–2 days per week/none. However, we conducted a dose-response meta-analysis to account for these different comparisons. Moreover, the underlying studies only adjusted for BMI, a marker of general obesity, but not for markers of abdominal obesity, such as waist circumference. Studies have shown that BMI was strongly correlated with waist circumference and even with body fat (59); however, BMI does not control for body fat distribution, which might be of greater importance regarding the risk of type 2 diabetes (60). Furthermore, breakfast skipping might also be associated with other unhealthy lifestyle behaviors. For example, it has been reported that breakfast skippers are more often smokers, are less physically active, and have a higher alcohol consumption and a higher intake of total energy compared with breakfast consumers (54). However, most of the studies included in our meta-analysis adjusted for known confounding factors (physical activity, fat intake, total energy, etc.), although residual confounding cannot be ruled out. There was evidence for publication bias indicating that small studies with negative results were missing. The Cochrane collaboration recommends that ≥10 studies are necessary to obtain clear conclusions on publication bias (61). We used the trim and fill method and our findings did not change substantially. However, more research investigating the association between breakfast skipping and risk of type 2 diabetes is needed. Finally, included studies were only performed in the United States and in Asia, hence the results obtained can only be applied for those regions.

Strengths of the present report include the prospective study design of the underlying studies, which avoids recall bias and reduces the potential for selection bias. In addition, to our knowledge this is the first report focusing on linear and nonlinear dose-response relations between breakfast skipping and risk of type 2 diabetes, which clarified the shape of the association.

In conclusion, the study indicated that there is an association between breakfast skipping and risk of type 2 diabetes. The association is partly mediated by obesity, but associations are still significant after adjustment for BMI. To strengthen the evidence on this association, more studies are warranted, especially from different geographic locations because the current evidence came from only the United States and Asia. Future studies should also focus on breakfast quality to support public health recommendations regarding breakfast consumption and health.

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References

1. World Health Organization. Global report on diabetes [Internet]. 2016 [cited 2018 May]. Available from: http://www.who.int/diabetes/global-report/en/.

2. International Diabetes Federation. IDF Diabetes Atlas. 8th ed. 2017 [cited 2018 May]. Available from: http://www.diabetesatlas.org.
3. Schwingshackl L, Hoffmann G, Lampousi A-M, Knüppel S, Iqbal K, Schwedhelm C, Bechthold A, Schlesinger S, Boeing H. Food groups and risk of type 2 diabetes mellitus: a systematic review and meta-analysis of prospective studies. Eur J Epidemiol 2017;32(5):363–75.
4. Bhupathiraju SN, Tobias DK, Malik VS, Pan A, Hruby A, Manson JE, Willett WC, Hu FB. Glycemic index, glycemic load, and risk of type 2 diabetes: results from 3 large US cohorts and an updated meta-analysis. Am J Clin Nutr 2014;100(1):218–32.
5. Imamura F, O'Connor L, Ye Z, Mursu J, Hayashino Y, Bhupathiraju SN, Forouhi NG. Consumption of sugar sweetened beverages, artificially sweetened beverages, and fruit juice and incidence of type 2 diabetes: systematic review, meta-analysis, and estimation of population attributable fraction. BMJ 2015;351:h3576.
6. The InterAct Consortium. Dietary fibre and incidence of type 2 diabetes in eight European countries: the EPIC-InterAct Study and a meta-analysis of prospective studies. Diabetologia 2015;58(7):1394–408.
7. Ding M, Bhupathiraju SN, Chen M, van Dam RM, Hu FB. Caffeinated and decaffeinated coffee consumption and risk of type 2 diabetes: a systematic review and a dose-response meta-analysis. Diabetes Care 2014;37(2):569–86.
8. Koloverou E, Esposito K, Giugliano D, Panagiotakos D. The effect of Mediterranean diet on the development of type 2 diabetes mellitus: a meta-analysis of 10 prospective studies and 136,846 participants. Metabolism 2014;63(7):903–11.
9. Mekary RA, Giovannucci E, Cahill L, Willett WC, van Dam RM, Hu FB. Eating patterns and type 2 diabetes risk in older women: breakfast consumption and eating frequency. Am J Clin Nutr 2013;98(2):436–43.
10. Mekary RA, Giovannucci E, Willett WC, van Dam RM, Hu FB. Eating patterns and type 2 diabetes risk in men: breakfast omission, eating frequency, and snacking. Am J Clin Nutr 2012;95(5):1182–9.
11. Mullan BA, Singh M. A systematic review of the quality, content, and context of breakfast consumption. Nutr Food Sci 2010;40(1):81–114.
12. Bi H, Gan Y, Yang C, Chen Y, Tong X, Lu Z. Breakfast skipping and the risk of type 2 diabetes: a meta-analysis of observational studies. Public Health Nutr 2015;18(16):3013–19.
13. Stroup DF, Berlin JA, Morton SC, Olkin I, Williamson GD, Rennie D, Moher D, Becker BJ, Sipe TA, Thacker SB. Meta-analysis of observational studies in epidemiology: a proposal for reporting. JAMA 2000;283(15):2008–12.
14. Lajous M, Bijon A, Fagherazzi G, Balkau B, Boutron-Ruault M-C, Clavel-Chapelon F. Abstract P392: eating frequency and snacking and risk of incident type 2 diabetes among French women. Circulation 2016;127(Suppl 12):AP392.
15. Clowry CM, Beatty SJ, Thomson CA, Wertheim BC, Neuhouser ML. The association between eating frequency and risk of type 2 diabetes: the Women's Health Initiative dietary modification trial. FASEB J 2017;31(1 Supplement):789.12.
16. Uemura M, Yatsuya H, Li Y, Wang C, Hilawe EH, Chiang C, Toyoshima H, Tamakoshi K, Zhang Y, Aoyama A. Positive association between breakfast skipping and incidence of type 2 diabetes mellitus: evidence from a Japanese worksite-based cohort. Int J Epidemiol 2015;44:225–6.
17. Pereira M, Erickson E, McKee P, Schrankler K, Raatz SK, Lytle LA, Pellegrini AD. Breakfast frequency and quality may affect glycemia and appetite in adults and children. J Nutr 2011;141(1):163–8.
18. Miyakawa M. Risk factors for diabetes mellitus evaluated by long-term observation. Nippon Eiseigaku Zasshi 1996;50(5):986–97.
19. Lundgren H, Bengtsson C, Blohmé G, Isaksson B, Lapidus L, Lenner RA, Saaek A, Winther E. Dietary habits and incidence of noninsulin-dependent diabetes mellitus in a population study of women in Gothenburg, Sweden. Am J Clin Nutr 1989;49(4):708–12.
20. Whincup PH, Owen CG, Sattar N, Cook DG. School dinners and markers of cardiovascular health and type 2 diabetes in 13–16 year olds: cross sectional study. BMJ 2005;331(7524):1060–1.
21. Kochar J, Djousse L, Gaziano JM. Breakfast cereals and risk of type 2 diabetes in the Physicians' Health Study I. Obesity 2007;15(12):3039–44.
22. Morimoto A, Ohno Y, Tatsumi Y, Mizuno S, Watanabe S. Effects of healthy dietary pattern and other lifestyle factors on incidence of diabetes in a rural Japanese population. Asia Pac J Clin Nutr 2012;21(4):601–8.
23. Wahlqvist ML, Kouris-Blazos A, Wattanapenpaiboon N. The significance of eating patterns: an elderly Greek case study. Appetite 1999;32(1):23–32.
24. Naja F, Hwalla N, Itani L, Salem M, Azar ST, Zeidan MN, Nasreddine L. Dietary patterns and odds of type 2 diabetes in Beirut, Lebanon: a case-control study. Nutr Metab (Lond) 2012;9(1):111.
25. Gittelsohn J, Wolever TM, Harris SB, Harris-Giraldo R, Hanley AJ, Zinman B. Specific patterns of food consumption and preparation are associated with diabetes and obesity in a Native Canadian community. J Nutr 1998;128(3):541–7.
26. Almoosawi S, Prynne CJ, Hardy R, Stephen AM. Diurnal eating rhythms: association with long-term development of diabetes in the 1946 British birth cohort. Nutr Metab Cardiovasc Dis 2013;23(10):1025–30.
27. Zong G, Eisenberg DM, Hu FB, Sun Q. Consumption of meals prepared at home and risk of type 2 diabetes: an analysis of two prospective cohort studies. PLoS Med 2016;13(7):e1002052.
28. Krishnan S, Coogan PF, Boggs DA, Rosenberg L, Palmer JR. Consumption of restaurant foods and incidence of type 2 diabetes in African American women. Am J Clin Nutr 2010;91(2):465–71.
29. Nas A, Mirza N, Hägele F, Kahlhöfer J, Keller J, Rising R, Kufer TA, Bosy-Westphal A. Impact of breakfast skipping compared with dinner skipping on regulation of energy balance and metabolic risk. Am J Clin Nutr 2017;105(6):1351–61.
30. Voronova NV, Nikitin AG, Chistiakov AP, Chistiakov DA. Skipping breakfast is correlated with impaired fasting glucose in apparently healthy subjects. Cent Eur J Med 2012;7(3):376–82.
31. Bodicoat DH, Carter P, Comber A, Edwardson C, Gray LJ, Hill S, Webb D, Yates T, Davies MJ, Khunti K. Is the number of fast-food outlets in the neighbourhood related to screen-detected type 2 diabetes mellitus and associated risk factors? Public Health Nutr 2015;18(9):1698–705.
32. Nishiyama M, Muto T, Minakawa T, Shibata T. The combined unhealthy behaviors of breakfast skipping and smoking are associated with the prevalence of diabetes mellitus. Tohoku J Exp Med 2009;218(4):259–64.
33. Asghari G, Yuzbashian E, Mirmiran P, Bahadoran Z, Azizi F. Prediction of metabolic syndrome by a high intake of energy-dense nutrient-poor snacks in Iranian children and adolescents. Pediatr Res 2016;79(5):697–704.
34. Cahill LE, Chiuve SE, Mekary RA, Jensen MK, Flint AJ, Hu FB, Rimm EB. Prospective study of breakfast eating and incident coronary heart disease in a cohort of male US health professionals. Circulation 2013;128(4):337–43.
35. Dominguez LJ, Martinez-Gonzalez MA, Basterra-Gortari FJ, Gea A, Barbagallo M, Bes-Rastrollo M. Fast food consumption and gestational diabetes incidence in the SUN Project. PLoS One 2014;9(9):e106627.
36. Jaaskelainen A, Schwab U, Kolehmainen M, Pirkola J, Jarvelin MR, Laitinen J. Associations of meal frequency and breakfast with obesity and metabolic syndrome traits in adolescents of Northern Finland Birth Cohort 1986. Nutr Metab Cardiovasc Dis 2013;23(10):1002–9.
37. Osorio-Yanez C, Gelaye B, Qiu CF, Bao W, Cardenas A, Enquobahrie DA, Williams MA. Maternal intake of fried foods and risk of gestational diabetes mellitus. Ann Epidemiol 2017;27(6):384–90.
38. Pereira MA, Kartashov AI, Ebbeling CB, Van Horn L, Slattery M, Jacobs DR, Ludwig DS. Fast-food habits, weight gain, and insulin resistance (the CARDIA study): 15-year prospective analysis. Lancet 2005;365(9453):36–42.
39. Polsky JY, Moineddin R, Glazier RH, Dunn JR, Booth GL. Relative and absolute availability of fast-food restaurants in relation to the development of diabetes: a population-based cohort study. Can J Public Health 2016;107(Suppl 1):5312.
40. Wells G, Shea B, O'Connell D, Robertson J, Peterson J, Welch V, Losos M, Tugwell P. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses [Internet] [cited 2018 Jun 5]. Ottawa, ON: Ottawa Hospital Research Institute; 2011. Available from: http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp.
41. DerSimonian R, Laird N. Meta-analysis in clinical trials. Control Clin Trials 1986;7(3):177–88.
42. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. Stat Med 2002;21(11):1539–58.

43. Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. BMJ 1997;315(7109):629–34.
44. Greenland S, Longnecker MP. Methods for trend estimation from summarized dose-response data, with applications to meta-analysis. Am J Epidemiol 1992;135(11):1301–9.
45. Chêne G, Thompson S. Methods for summarizing the risk associations of quantitative variables in epidemiologic studies in a consistent form. Am J Epidemiol 1996;144:610–21.
46. Aune D, Greenwood DC, Chan DSM, Vieira R, Vieira AR, Navarro Rosenblatt DA, Cade JE, Burley VJ, Norat T. Body mass index, abdominal fatness and pancreatic cancer risk: a systematic review and non-linear dose–response meta-analysis of prospective studies. Ann Oncol 2012;23(4):843–52.
47. Durrleman S, Simon R. Flexible regression models with cubic splines. Stat Med 1989;8:551–61.
48. Odegaard AO, Jacobs DR Jr, Steffen LM, Van Horn L, Ludwig DS, Pereira MA. Breakfast frequency and development of metabolic risk. Diabetes Care 2013;36(10):3100–6.
49. Byrne DW, Rolando LA, Aliyu MH, McGown PW, Connor LR, Awalt BM, Holmes MC, Wang L, Yarbrough MI. Modifiable healthy lifestyle behaviors: 10-year health outcomes from a health promotion program. Am J Prev Med 2016;51(6):1027–37.
50. Sugimori H, Miyakawa M, Yoshida K, Izuno T, Takahashi E, Tanaka C, Nakamura K, Hinohara S. Health risk assessment for diabetes mellitus based on longitudinal analysis of MHTS database. J Med Syst 1998;22(1):27–32.
51. Uemura M, Yatsuya H, Hilawe EH, Li Y, Wang C, Chiang C, Otsuka R, Toyoshima H, Tamakoshi K, Aoyama A. Breakfast skipping is positively associated with incidence of type 2 diabetes mellitus: evidence from the Aichi Workers' Cohort Study. J Epidemiol 2015;25(5):351–8.
52. van der Heijden AA, Hu FB, Rimm EB, van Dam RM. A prospective study of breakfast consumption and weight gain among U.S. men. Obesity (Silver Spring) 2007;15(10):2463–9.
53. Uzhova I, Fuster V, Fernandez-Ortiz A, Ordovas JM, Sanz J, Fernandez-Friera L, Lopez-Melgar B, Mendiguren JM, Ibanez B, Bueno H, et al. The importance of breakfast in atherosclerosis disease: insights from the PESA study. J Am Coll Cardiol 2017;70(15):1833–42.
54. St-Onge MP, Ard J, Baskin ML, Chiuve SE, Johnson HM, Kris-Etherton P, Varady K, American Heart Association Obesity Committee of the Council on Lifestyle and Cardiometabolic Health, Council on Cardiovascular Disease in the Young, Council on Clinical Cardiology, et al. Meal timing and frequency: implications for cardiovascular disease prevention: a scientific statement from the American Heart Association. Circulation 2017;135(9):e96–e121.
55. Kollannoor-Samuel G, Chhabra J, Fernandez ML, Vega-Lopez S, Perez SS, Damio G, Calle MC, D'Agostino D, Perez-Escamilla R. Determinants of fasting plasma glucose and glycosylated hemoglobin among low income Latinos with poorly controlled type 2 diabetes. J Immigr Minor Health 2011;13(5):809–17.
56. Li Y, Nemoto T, Tobimatsu S, Saito M, Ebata M, Munakata H, Nakajima K. Relationship between skipping breakfast and impaired fasting glucose along with cardiovascular and pre-diabetes condition risk factors in apparently healthy subjects. Endocrinol Stud 2011;1(e17):76–80.
57. Deshmukh-Taskar P, Nicklas TA, Radcliffe JD, O'Neil CE, Liu Y. The relationship of breakfast skipping and type of breakfast consumed with overweight/obesity, abdominal obesity, other cardiometabolic risk factors and the metabolic syndrome in young adults. The National Health and Nutrition Examination Survey (NHANES): 1999–2006. Public Health Nutr 2013;16(11):2073–82.
58. Iqbal K, Schwingshackl L, Gottschald M, Knuppel S, Stelmach-Mardas M, Aleksandrova K, Boeing H. Breakfast quality and cardiometabolic risk profiles in an upper middle-aged German population. Eur J Clin Nutr 2017;71(11):1312–20.
59. Flegal KM, Shepherd JA, Looker AC, Graubard BI, Borrud LG, Ogden CL, Harris TB, Everhart JE, Schenker N. Comparisons of percentage body fat, body mass index, waist circumference, and waist-stature ratio in adults. Am J Clin Nutr 2009;89(2):500–8.
60. Seo DC, Choe S, Torabi MR. Is waist circumference >/ = 102/88cm better than body mass index >/ = 30 to predict hypertension and diabetes development regardless of gender, age group, and race/ethnicity? Meta-analysis. Prev Med 2017;97:100–8.
61. Higgins JPT, Green S, editors. Cochrane handbook for systematic reviews of interventions. Version 5.1.0 [updated March 2011]. The Cochrane Collaboration. Available from: www.handbook.cochrane.org.