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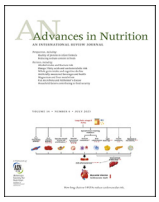

Review

The Relationship of Ready-to-Eat Cereal Intake and Body Weight in Adults: A Systematic Review of Observational Studies and Controlled Trials

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A B S T R A C T

Results from observational studies indicate that consumption of ready-to-eat cereal (RTEC) is associated with higher diet quality and lower incidence of overweight and obesity in adults compared with other breakfasts or skipping breakfast. However, randomized controlled trials (RCTs) have had inconsistent results regarding effects of RTEC consumption on body weight and composition. This systematic review aimed to evaluate the effect of RTEC intake on body weight outcomes in observational studies and RCTs in adults. A search of PubMed and Cochrane Central Register of Controlled Trials (CENTRAL) databases yielded 28 relevant studies, including 14 observational studies and 14 RCTs. Results from observational studies demonstrate that frequent RTEC consumers (usually ≥4 servings/wk) have lower BMI, lower prevalence of overweight/obesity, less weight gain over time, and less anthropometric evidence of abdominal adiposity compared with nonconsumers, or less frequent consumers. RCT results suggest that RTEC may be used as a meal or snack replacement as part of a hypocaloric diet, but this approach is not superior to other options for those attempting to achieve an energy deficit. In addition, RTEC consumption was not associated with significantly less loss of body weight, or with weight gain, in any of the RCTs. RTEC intake is associated with favorable body weight outcomes in adults in observational studies. RTEC does not hinder weight loss when used as a meal or snack replacement within a hypocaloric diet. Additional long-term RCTs (≥6 mo) in both hypocaloric and ad libitum conditions are recommended to evaluate further the potential effects of RTEC consumption on body weight outcomes. PROSPERO (CRD42022311805).

Keywords: ready-to-eat cereal, breakfast, body weight, BMI, body fat, adult

Statement of Significance

This systematic review provides an updated analysis of the most recent literature examining the relationship between ready-to-eat cereal (RTEC) consumption and body weight–related outcomes in adults. The current review includes 7 new controlled trials and 5 observational studies that have been published since the last reviews in 2014–2016, and unlike previous reviews, includes studies of RTEC intake outside of the breakfast occasion.

Abbreviations used: CENTRAL, Cochrane Central Registry of Controlled Trials; FM, fat mass; PICO, population, intervention, control, and outcome; RCT, randomized controlled trial; RTEC, ready-to-eat cereal.

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Introduction

Breakfast consumption has long been considered a key component of a healthy diet, yet ~25% of United States adults skip breakfast, primarily to maintain or lose weight [1]. Interestingly, this practice contradicts the published literature results suggesting an association of regular breakfast consumption with lower body weight and BMI (in kg/m^2) [1–6]. Additionally, consumption of ready-to-eat cereals (RTECs), a common breakfast food, has also been associated with lower BMI, lower incidence of overweight/obesity, and less weight gain over time in adults [3,5,7–9]. In fact, 90% of participants in the National Weight Control Registry—who have maintained ≥13.6 kg (30 lb) of weight loss for ≥1 y—reported eating breakfast most or all days of the week, and ~60% of individuals who report eating breakfast usually or always chose cereal for breakfast [10].

Adults who regularly consume RTEC are more likely to meet daily intake requirements for several vitamins and minerals and have a higher quality diet, as assessed by the Healthy Eating Index [8,11]. In addition, RTEC consumers also typically have higher dietary fiber and whole grain intakes as RTEC is an important source of both dietary components [6,8,11,12]. These nutritional benefits may contribute to the observed associations with favorable body weight–related outcomes. However, questions remain about the potential health benefits of RTEC as observational data also show RTEC consumers have higher intakes of total and added sugars, although this does not consistently correlate with increased energy intake [8,11,12].

Previous systematic reviews have examined the relationship between RTEC consumption and body weight in adults, but these either examined RTEC at breakfast only [7,12] or included hot cereals and porridge in the assessment [8]. Additionally, 7 new randomized controlled trials (RCTs) and 5 observational studies have been published since the latest review [12]. Therefore, this systematic review aims to provide an updated assessment of the observational studies and controlled trials examining the relationship of RTEC intake with body weight and body composition outcomes.

Materials and Methods

Literature search

PRISMA guidelines [13] were utilized for this systematic review, and it was registered with PROSPERO (CRD42022311805). In addition, a comprehensive literature search was conducted using PubMed and Cochrane Central Register of Controlled Trials (CENTRAL) databases to identify publications of observational studies and controlled trials examining RTEC intake (excluding hot cereals) and body weight–related outcomes in adults and children. The search was limited to English language publications from 2000 through February 2022. This article reports findings in adults, and a second publication includes findings in children. Full search terms are provided in (Supplemental Table 1).

Inclusion and exclusion criteria

Inclusion criteria consisted of the prospective cohort, cross-sectional, and controlled studies in humans, where the intervention arm (controlled trials) or primary exposure variable (observational studies) was RTEC. Retrospective, case-control, and single-arm (no control) studies were excluded, as were studies conducted in vitro or in all species of animals. Studies were also required to include a body weight or body composition outcome (for example, BMI, waist circumference, weight loss, percent body fat, etc.). Exclusion criteria included studies in pregnant or lactating women and in individuals with a chronic disease, except for overweight/obesity, metabolic syndrome, prediabetes, or type 2 diabetes. Intervention studies in participants taking medications that may impact weight or those with a history of surgical weight loss interventions were excluded. Studies prior to the year 2000 or including interventions or exposures to hot cereal, were also excluded. Hot cereals were excluded as they are not considered RTECs.

Screening and data extraction

Titles and abstracts obtained in the search were screened for inclusion, and full texts of potentially eligible publications were obtained and reviewed by a research team member (LMS). The inclusion of publications was evaluated by 2 reviewers (LMS and MRD). Excluded publications and publications that were unclear regarding eligibility were discussed among the research team to confirm inclusion or exclusion. Population, intervention, control, and outcome (PICO) data from included manuscripts were extracted into a database by 1 researcher (LMS) and verified for accuracy by a second researcher (MRD). Discrepancies were resolved by discussion with the research team and referencing the original article.

Assessment of study quality

Risk of bias for each trial was assessed with the Cochrane Risk-of-Bias tool (Cochrane, version 2) for randomized trials (all trials were randomly assigned), using the appropriate tools for parallel and cross-over studies [14]. In addition, risk of bias for observational studies was evaluated using the NIH quality assessment tool (https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools). The NIH assessment tool uses the terms "good," "fair," and "poor" to indicate study quality. To maintain consistency in this article, the terms in the Cochrane risk of bias tool were used instead (for example, "good" = "low" risk of bias, "fair" = "some concerns," "poor" = "high" risk of bias).

Results

A flow diagram summarizing the review process is shown in Figure 1. After the title and abstract review, 91 full-text articles were identified, and an additional 36 articles were found in reference lists of full-text publications and systematic reviews. Fifty-one publications met the inclusion/exclusion criteria. Excluded publications and reason for exclusion are included in Supplemental Table 2. Twenty-eight publications included adults and are reviewed in this publication. The remaining publications on children and/or adolescents are reviewed in a separate publication [15]. In addition, 2 papers included data on children and adults and are included in both reviews.

There were 14 observational studies [4,5,9,16–26] and 14 RCTs [27–40] evaluating the relationship of RTEC with body weight outcomes. Most observational studies were cross-sectional in design, with only 3 prospective analyses from

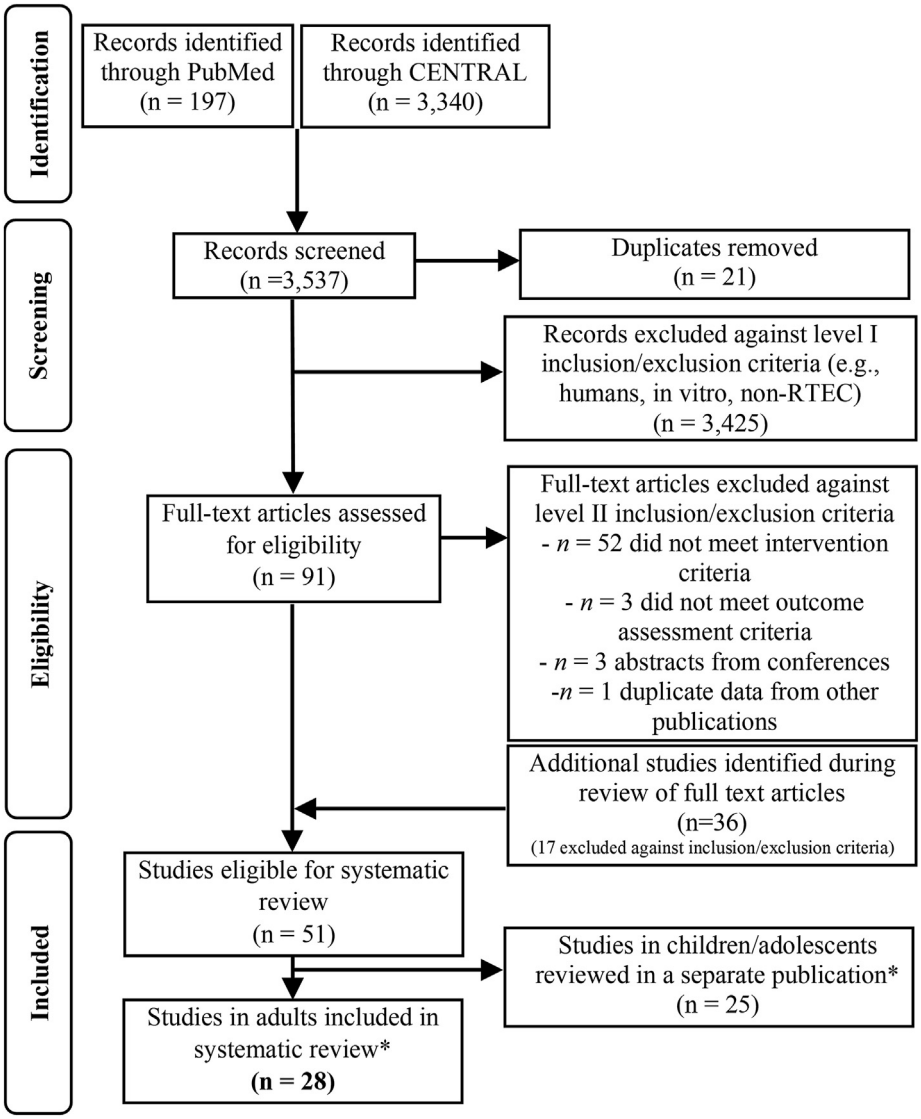

FIGURE 1. Flow chart of study selection. CENTRAL, Cochrane Central Registry of Controlled Trials; RTEC, ready-to-eat cereal. *Two publications contained data on adults and children and were included in both reviews.

cohorts or longitudinal RCTs [9,22,23]. All RCTs employed parallel designs.

RTEC intake and body weight outcomes in observational studies in adults

Twelve cross-sectional analyses in the United States and Canadian populations reported an inverse relationship between RTEC intake and body weight–related outcomes in adults [3–5,9,16–20,23–25] (Table 1). Only 1 study reported no association between RTEC consumption and BMI compared with nonconsumers in the Canadian population [26]. No studies reported a positive (adverse) association between RTEC and body weight or body composition outcomes. The study designs varied substantially, with some studies comparing RTEC consumers to nonconsumers; RTEC breakfasts compared with non-RTEC breakfasts compared with breakfast skippers; breakfast patterns including RTEC compared with patterns excluding RTEC; and tertiles or quartiles of the amount of RTEC or frequency of consumption. The predominant outcome measure was BMI, but some studies also included prevalence of overweight/obesity, OR for overweight/obesity, and waist circumference. Fewer studies included body weight outcomes, waist:hip ratio, and measures of fat mass (FM).

Compared with non-RTEC breakfasts, consumers of RTEC breakfasts consistently have a lower BMI [5,18,21,25], and all but 2 studies [18,26] found consumers of RTEC have a lower BMI compared with nonconsumers-or-breakfast-skippers [4,5,20,25]. Song et al. [25] found this relationship in females but not males. Cho et al. [20] reported that consumers of RTEC breakfasts have a lower BMI than consumers of meat and egg breakfasts but not other breakfasts such as bread, fruits and vegetables, sweets, or dairy foods. In a similar study, when breakfasts were divided into 12 different patterns, RTEC breakfasts, but not noncereal breakfasts, were associated with a lower BMI than skipping breakfast [4]. This study also evaluated the sugar content of cereals in relation to BMI and reported that consumers of both

TABLE 1
Summary of observational studies in adults

Reference	Design	Population	Data set and location	Risk of bias	Groups	Outcomes	Key findings
Albertson et al. [16]	Cross-sectional	2926 adults >12 y	National Eating Trends Database and NHANES 1999–2004 Canada	High	1) 0–1 svg RTEC/ 7 d 2) 2–3 svgs RTEC/7 d 3) 4+ svgs RTEC/ 7 d	BMI % ow/ob	- RTEC frequency is inversely associated with BMI in males but not females - Lower BMI in males consuming 4+ svgs RTEC/ 7 d compared with 0–1 svg RTEC/7 d - RTEC frequency is inversely associated with the % of ow/ob in the total population and males - % ow/ob lower in 4+ svgs RTEC/7 d and 2–3 svgs/d compared with 0–1 svg/d in total population
Albertson et al. [17]	Cross-sectional	1759 adults ≥55 y	National Eating Trends Database and NHANES 1999–2004 United States	High	1) 0 svg/14 d 2) 1–3 svgs/14 d 3) 4–7 svgs/14 d 4) ≥8 svgs/14 d	BMI % ow/ob % obesity	- RTEC frequency is inversely associated with BMI in males, but females only approached significance ($P = 0.06$) - In males, BMI is lower in ≥8 svg/14 d compared with 0 svg and 1–3 svg/ 14 d - RTEC frequency is inversely associated with % ow/ob in males - % ow/ob lower in males with ≥8 svgs/14 d and 4–7 svgs/14 d compared with 0 svg or 1–3 svg/14 d - No relationship of RTEC frequency to % obesity
Barr et al. [18]	Cross-sectional	12,337 adults ≥18 y	Canadian Community Health Survey Cycle 2.2, 2004 Canada	Low	1) RTEC bf consumers 2) Non-RTEC bf consumers 3) Bf skippers	BMI % ow/ob OR ow/ob	- RTEC consumers had lower BMI than non-RTEC bf (association also in subgroups of age 51+ but not younger age groups; associations also in the female but not male) - RTEC consumers 18–30 y had a lower % of ow/ob than bf skippers - RTEC consumers 18–30 y had lower odds of ow/ob compared with bf skippers
Bazzano et al. [9]	Prospective analysis of RCT	17,881 male adults 40–84 y 8 y and 13 y follow-up	Physician's Health Study 1982–1995 United States	Some concerns	1) Rarely/no RTEC 2) 1 svg RTEC/wk 3) 2–6 svgs RTEC/wk 4) ≥1 svg RTEC/d Total, WG, RG RTEC	BMI Weight gain % ow/ob RR overweight RR obesity	- RTEC frequency inversely associated with BMI (total, WG, and RG RTEC) - RTEC frequency is inversely associated with weight gain at 8 y and 13 y - WG and RG RTEC frequency inversely associated with weight gain at 8 y only - RTEC frequency inversely associated with % ow/ob (total, WG, and RG RTEC) - RTEC frequency inversely associated with RR overweight and RR obesity at 8 y and 13 y
Bertrais et al. [19]	Cross-sectional	5039 adults 35–60 y	SU.VI.MAX cohort 1994–2002 France	Some concerns	1) RTEC nonconsumers 2) Occasional RTEC consumers (2–5 d out of 12)	BMI Waist:hip	- RTEC frequency is inversely associated with BMI for males but females only approached significance ($P = 0.08$) - RTEC frequency inversely associated with waist:hip in males and females

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TABLE 1 (*continued*)

Reference	Design	Population	Data set and location	Risk of bias	Groups	Outcomes	Key findings
					3) Regular RTEC consumers (6–9 d of 12) 4) Heavy RTEC consumers (10–12 d of 12)		
Cho et al. [20]	Cross-sectional	16,452 adults ≥18 y	NHANES III 1988–1994 United States	Low	10 different categories of bf based on predominant item consumed, with RTEC being 1 category	BMI	RTEC consumers had lower BMI than bf skippers and meat + egg bf
Deshmukh-Taskar et al. [3]	Cross-sectional	5316 young adults 20–39 y	NHANES 1999–2006 United States	Low	1) Bf skippers 2) RTEC bf 3) Non-RTEC bf	BMI Body weight Waist circumference Triceps skinfold % abdominal obesity OR abdominal obesity % ow/ob OR ow/ob	- RTEC bf consumers had lower BMI, body weight, waist circumference, triceps skinfold, % abdominal obesity, OR abdominal obesity, % ow/ob, and OR ow/ob compared with bf skippers and non-RTEC bf
Koh-Banerjee et al. [22]	Prospective	27,082 adult men 40–75 y 8 y follow-up	Health Professionals Study 1986–1994	Some concerns	Unspecified but mentions svgs/day WG (≥51%), WG (25%–50%), and RG	Weight gain	- Greater intake of WG RTEC (≥51% WG) associated with less weight gain at 8 y - Greater intake of WG RTEC (25%–50%) marginally associated with less weight gain at 8 y ($P = 0.05$) - Greater intake of RG RTEC positively associated with weight gain at 8 y
Linde et al. [23]	Cross-sectional and prospective analysis of longitudinal RCT	1000 adults with ow/ob ≥18 y 2 y follow-up	Weigh-to-be weight loss study United States	High	Study examined several foods in the diet, including high-fiber/bran RTEC	BMI Change in BMI	- High-fiber RTEC is inversely associated with BMI in females but not males - Increased intake of high-fiber RTEC over 2 y associated with reductions in BMI in males and females
Liu et al. [24]	Cross-sectional analysis of prospective study	86,190 adult men 40–84 y	Physician's Health Study 1982 United States	Some concerns	1) Rarely/no RTEC 2) 1 svg RTEC/wk 3) 2–6 RTEC/wk 4) ≥1svg RTEC/d Total, WG, RG RTEC	BMI (baseline) % ow/ob	- RTEC frequency inversely associated with BMI (total, WG, and RG) - RTEC frequency inversely associated with % ow/ob (total, WG, and RG)
McGill et al. [5]	Cross-sectional	14,316 adults 19–50 y 51–70 y	NHANES 2001–2008 United States	Low	1) Bf skippers 2) RTEC bf 3) Non-RTEC bf	BMI Body weight Waist circumference OR ow/ob	- RTEC bf consumers had lower BMI and body weight compared with non-RTEC bf and bf skippers - 19–50 y RTEC bf consumers had lower waist circumference compared with non-RTEC bf and bf skippers - 19–50 y RTEC bf consumers had lower OR ow/ob compared with bf skippers

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TABLE 1 (*continued*)

Reference	Design	Population	Data set and location	Risk of bias	Groups	Outcomes	Key findings
O'Neil et al. [4]	Cross-sectional	18,988 adults ≥19 y	NHANES 2001–2008 United States	Low	20 different patterns, which included: 1) Presweetened RTEC (≥6 g/svg) + low-fat milk 2) Non-presweetened RTEC (<6 g/svg) + low-fat milk, whole fruit, and/or fruit juice 3) Bf skipper	BMI Waist circumference % ow/ob OR ow/ob	- Presweetened and non-presweetened RTEC consumers had lower BMI, waist circumference, % ow/ob, and OR ow/ob compared with bf skippers
Song et al. [25]	Cross-sectional	4218 adults ≥19 y	NHANES 1999–2000 United States	Low	1) RTEC bf consumers 2) Non-RTEC bf consumers	BMI OR ow/ob	- RTEC consumption inversely related to BMI in females - Female RTEC consumers had lower OR ow/ob compared with female non-RTEC consumers - No relationship in males
Vatanparast et al. [26]	Cross-sectional	19,677 adults ≥18 y	Canadian Community Health Survey 2015 Canada	Low	1) RTEC consumers 2) RTEC nonconsumers	BMI	- No effect of RTEC on BMI

Abbreviations: bf , breakfast; ow/ob, overweight/obese; RCT, randomized control trial; RG, refined grain, RR, relative risk; RTEC, ready-to-eat cereal; SU.VI.MAX, Supplementation en Vitamines et Mineraux Antioxydants; svg, serving, WG, whole grain.

presweetened RTEC (≥6 g/serving) and non-presweetened RTEC (<6 g/serving) breakfasts had lower BMI compared with breakfast skippers. Some studies also reported age differences, but the results were inconsistent, with 1 study [18] reporting lower BMI with RTEC consumption in older adults (≥51 y) but not younger adults, whereas another study reported lower BMI in RTEC consumers aged 19–50 y, but not older adults [5].

Five studies reported an inverse relationship between the amount or frequency of RTEC consumption and BMI [9,16,17,19,24]; 2 studies included only male participants [9,24], and 2 studies reported an inverse relationship in males only but not females [17,19]. In a study in the Canadian population, Albertson et al. [16] found that males consuming ≥4 servings of RTEC over a week had significantly lower BMI than males consuming 1 serving or no RTEC over a week. Similar results were found when the study design was applied to the United States population [17]. Linde et al. [23] found that high-fiber RTEC intake was associated with lower BMI in females but not males. In addition to the frequency of total RTEC intake, Liu et al. [24] and Bazzano et al. [9] also found inverse relationships of BMI to whole grain and refined-grain RTEC.

All studies that examined the prevalence of overweight/obesity and/or the odds of overweight/obesity in adults found an inverse association with RTEC intake [3–5,9,16–18,24,25] (Table 1). Three studies reported a lower prevalence of overweight/obesity in RTEC consumers than in breakfast skippers [3,4,18] and non-RTEC breakfasts [3]. Barr et al. [18] found this relationship only in young adults aged 18–30 y, but not older adults. Four papers also reported an inverse relationship between the prevalence of overweight/obesity and increasing servings of RTEC intake in all adults [16] or in males only [9,17,24]. Two of these also reported that the prevalence of overweight/obesity was significantly less in the highest quartile of RTEC intake (~4 servings/wk) compared with the lowest quartile (0–1 servings/wk) [16,17]. Five papers reported RTEC consumers had lower odds of overweight/obesity compared with breakfast skippers [3–5,18] and non-RTEC breakfasts [3,5,25], but this relationship was only found in young to middle-aged adults and not older adults in 2 studies [5,18]. Additionally, Song et al. [25] reported lower odds of overweight/obesity in females but not males. One study assessed the sugar content of RTEC and found no difference in prevalence or odds of overweight/obesity based on sugar content [4]. Similarly, Liu et al. [24] assessed whole-grain content and found similar declines in the prevalence of overweight/obesity with increasing frequency of whole grain and refined-grain RTEC consumption.

Only 3 prospective studies in adults have assessed the relationship of RTEC intake to weight change over 2–13 y [9,22,23] and included an assessment of either the fiber content or the whole-grain content of the cereal. Bazanno et al. [9] examined the relationship between the frequency of RTEC consumption and weight gain in >17,000 males over 8 y and 13 y of follow-up in the Physician's Health Study. Regardless of RTEC type, increasing frequency of RTEC consumption (from rarely to ≥1 serving/d) was associated with less weight gain over 8 y and 13 y. When examined by type, whole grain and refined-grain RTEC consumption were associated with less weight gain over 8 y, but the relationships were not observed at 13 y follow-up, although it approached significance in the whole-grain RTEC group ($P = 0.08$). A similar study in >27,000 male adults in the Health Professionals Study also demonstrated an inverse relationship between servings of ≥51% whole-grain RTEC and weight gain over 8 y that was only marginally significant for lower whole-grain RTEC (25%–50% whole grain) [22]. However, there was a positive relationship between refined-grain RTEC intake and weight gain over 8 y. Linde et al. [24] performed a secondary prospective analysis of a 24-mo, longitudinal RCT and reported an increase in high-fiber RTEC intake was associated with a decrease in BMI. Unfortunately, the authors did not assess the intake of low-fiber RTEC.

RTEC intake and body weight outcomes in RCTs in adults

Fourteen RCTs examined the impact of RTEC on body weight and/or body composition outcomes in adults [27–40] (Table 2). Most studies were short in duration (≤12 wk) [28,30–35,37–40], with 3 studies conducted for 4–6 mo [27,29,36]. Unlike observational studies, RCTs were conducted in several countries, including India, Australia, the United States, United Arab Emirates, and the United Kingdom. Seven studies evaluated RTEC in the context of a hypocaloric, weight loss diet [29,30,33,34,36–38], either using RTEC as a meal replacement [30,34,36,38], comparing types of RTEC [33,37], or comparing RTEC to non-RTEC breakfasts [29]. Four additional studies included RTEC as meal or evening snack replacements with ad libitum consumption for the remainder of the diet [27,32,35,39]. Studies consistently reported significant within-treatment weight loss and improvements in body composition (that is, waist circumference, percentage body fat, FM, or lean mass) in participants consuming RTEC within the context of a hypocaloric diet [29,30,33,34,36–38]. Studies including RTEC without a hypocaloric diet had mixed results, with 3 studies reporting significant within-treatment weight loss when RTEC was utilized as a meal or evening snack replacement [32,35,39], whereas another study reported only modest and nonsignificant weight loss with RTEC consumption [27].

The comparator diet was different between studies and may have influenced the outcomes. When compared with a usual diet without caloric restriction, individuals consuming a hypocaloric diet with RTEC as a meal replacement had significantly greater weight loss and lower waist circumference, percentage body fat, or FM [34,36,38]. However, results were mixed when the comparator diet was also hypocaloric [29,30,36]. Kuriyan et al. [30] reported greater weight loss and a smaller waist, hip, and abdominal circumference in women on a hypocaloric diet with RTEC as a meal replacement compared with a control hypocaloric diet. However, Melanson et al. [36] and Keogh et al. [29] reported no difference in weight loss between hypocaloric diets with and without RTEC. Studies comparing types of RTEC reported no difference in weight loss between high-fiber and low-fiber RTEC consumed within a hypocaloric diet [33,37]. Maki et al. [33] reported a smaller waist circumference in adults consuming high-fiber, whole-grain RTEC than low-fiber RTEC. Two studies comparing a single RTEC compared with a variety of RTECs as a meal replacement reported mixed results, with 1 study

TABLE 2
Summary of randomized control trials in adults

Reference	Population	Location	Risk of bias	Treatment	Comparator	Duration	Outcomes	Key findings
Boutelle et al. [27]	30 adult parents Any age	United States	Some concerns	RTEC bf 5 d/wk	2 egg bf 5 d/wk	120 d (~4 mo)	BMI	No difference in BMI within or between treatments
Geliebter et al. [40]	36 adults with overweight 18–65 y	United States	Low	Presweetened RTEC bf + low-fat milk daily	1) Oatmeal + whole milk 2) Water daily	30 d (~1 mo)	Body weight Weight change Waist circumference Waist:hip FM FFM	- Body weight lower and weight change greater with water compared with RTEC and oatmeal - No difference between oatmeal and RTEC for any outcomes
Jarrar et al. [28]	81 healthy adults fasting during Ramadan 18–65 y	United Arab Emirates	Low	High-fiber RTEC bf	Normal diet	20 d	Body weight BMI Waist circumference % body fat	- Both diets resulted in weight loss and lower BMI - No difference between treatments for body weight or BMI - No difference within a treatment or between treatments for waist circumference or % body fat
Keogh et al. [29]	76 adults with ow/ob >18 y	Australia	Low	RTEC bf 5 d/wk + wt loss diet	2 egg bf 5 d/wk + wt loss diet	180 d (~6 mo)	Weight loss	- Both treatments lost weight over 6 mo - No difference between treatments
Kuriyan et al. [30]	101 females with ow/ob 18–44 y	India	High	Low-fat RTEC bf and lunch	Dietary advice for weight loss	14 d	Weight loss Change in BMI Waist circumference Abdominal waist circumference Hip circumference	- RTEC treatment lost more weight, had a greater change in BMI, and greater reductions in the waist, abdominal waist, and hip circumference than the comparator
Lattimore et al. [31]	123 normal weight females or females with overweight 20–40 y	United Kingdom	Low	Low-fat RTEC + whole wheat toast bf	Chocolate chip muffin bf	7 d	Body weight	- No within-treatment changes in body weight (between treatment changes not assessed)
Lightowler et al. [32]	41 adults with ow/ob 20–60 y	United Kingdom	High	Single RTEC variety bf and lunch (first 2 wk), bf only (4 wk)	Variety RTEC bf and lunch (first 2 wk), bf only (4 wk)	42 d (6 wk)	Weight loss % change in body weight Waist circumference Hip circumference FM % body fat	- Significant weight loss within both treatments at 2 wk - Significant weight loss within a variety of treatments only at 6 wk - Weight loss and % change in body weight were greater with a variety of RTEC vs. single RTEC - Waist circumference lower within both treatments at 6 wk - Hip circumference and FM lower within a variety of RTEC treatments only at 6 wk - No between-treatment comparisons of the waist, hip circumference, or % body fat

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TABLE 2 (*continued*)

Reference	Population	Location	Risk of bias	Treatment	Comparator	Duration	Outcomes	Key findings
Maki et al. [33]	144 adults with ow/ob and mild/moderate hypercholesterolemia 20–65 y	United States	Low	High-fiber RTEC twice daily + wt loss diet	Low-fiber RTEC and snacks + wt loss diet	84 d (~3 mo)	Weight loss Waist circumference Triceps skinfold	- Significant weight loss in both treatments - No difference in weight loss between high-fiber and low-fiber RTEC - Waist circumference was lower with high-fiber RTEC treatment compared with low-fiber RTEC
Mattes [34]	109 adults with ow/ob 20–60 y	United States	Low	1) Single RTEC bf twice daily (2 wk) + volumetric diet (4 wk) 2) Variety RTEC bf twice daily (2 wk) + volumetric diet (4 wk)	1) Volumetric diet 2) Usual diet	RTEC groups 42 d (6 wk) Volumetric and usual diet 28 d (4 wk)	Weight loss FM	- Single RTEC and variety RTEC groups both lost weight over the first 2 wk and 6 wk - Both RTEC diets lost more weight than the usual diet - Single RTEC lost more weight than volumetric diet - Single RTEC and variety RTEC groups both lost FM over the first 2 wk and 6 wk - RTEC diets lost more FM than usual diets but not volumetric
Matthews et al. [35]	70 adults with overweight and habitual evening snackers 18–55 y	United Kingdom	Low	RTEC once daily after the evening meal	Usual diet	42 d (6 wk)	Body weight Body fat Waist circumference Hip circumference	- Significant weight loss and lower waist circumference with RTEC treatment - No difference between RTEC and usual diet for all outcomes
Melanson et al. [36]	126 sedentary adults with overweight 18–70 y	United States	Low	WG RTEC twice daily (12 wk), once daily (12 wk) + exercise + wt loss diet	1) Exercise + wt loss diet 2) Exercise + usual diet	168 d (~6 mo)	Body weight BMI	- Significant weight loss in both hypocaloric diets compared with exercise alone - No difference in weight loss between the WG RTEC diet and weight loss diet + exercise
Stefoska-Needham et al. [37]	56 adults with ow/ob 18–65 y	Australia	Low	High-fiber RTEC twice daily	Low-fiber RTEC twice daily	84 d (~3 mo)	Weight change BMI change Waist circumference % body fat	- Significant reductions in weight, BMI, waist circumference, and % body fat in both treatments - No difference between RTEC treatments
Vander Wal et al. [38]	133 adults with ow/ob 18–65 y	United States	Low	1) Low-fat RTEC twice daily 2) Low-fat RTEC + bar each once daily	Usual diet	28 d (~1 mo)	Weight change BMI change Waist, hip, and thigh circumference % body fat	- Significant reductions in weight, BMI, waist, hip, thigh circumference, and % body fat compared with the usual diet

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TABLE 2 (*continued*)

Reference	Population	Location	Risk of bias	Treatment	Comparator	Duration	Outcomes	Key findings
Waller et al. [39]	58 adults with ow/ob and habitual evening snackers 18–65 y	United States	Low	RTEC once daily as an evening snack	Usual diet	28 d (~1 mo)	Weight change	- Significant weight loss in RTEC group only in compliant participants (20 of 28 d RTEC consumption) - No difference in weight loss compared with the usual diet

Abbreviations: bf, breakfast; FFM, fat free mass; ow/ob, overweight/obese; RTEC, ready-to-eat cereal; WG, whole grain; wt, weight.

demonstrating greater weight loss in the various group compared with a single RTEC [32], whereas another study showed similar weight loss between the single RTEC group and variety group [34]. Studies without hypocaloric conditions reported no differences in weight loss or body composition between RTEC and non-RTEC interventions [27,35,39].

Results from 3 other short-term studies did not show differences in body weight or body composition between an RTEC intervention and other types of breakfasts [28,31,40]. In addition, 2 papers did not report a difference in body weight or body composition outcomes when RTEC was compared with other types of breakfasts [31,40]; however, 1 study was only 1 wk in duration, and a change in body weight was not the intended outcome [31]. The other study was also short in duration (1 mo) and reported no change in body weight or body composition between RTEC and a hot cereal intervention [40]. Finally, a study evaluating the digestive health impact of once-daily high-fiber RTEC during Ramadan demonstrated significant weight loss in the RTEC intervention, similar to the control condition without RTEC [28].

Although not all studies provided details on the type of RTEC used in the intervention, most studies provided non-presweetened RTEC. Therefore, it was not possible to assess the potential impact of sugar content on body weight and body composition outcomes.

Study quality

Half of the observational studies in adults had a low risk of bias, and half had some concerns or high risk. Two studies evaluated as having a high risk of bias used different data sets to estimate intake and portion size and also included self-reported body weight [16,17]. Another study considered a high risk of bias lost >40% of individuals during follow-up who were younger, less educated, and had a higher BMI than those retained through the follow-up period [23]. Studies with some concerns about risk of bias either used self-reported body weights [9,22,24] or were unclear if covariates were included in the analysis [19]. Removing high-risk bias studies from consideration does not substantially change the overall outcome because of the consistency of the inverse relationship of RTEC intake and body weight–related outcomes across all observational studies.

Eleven RCTs were determined to have a low risk of bias, whereas 3 were considered to have some concerns or high risk. The high risk of bias was because of the possibility of selective reporting, such as within-group rather than between-group analyses, or presenting intent-to-treat but not per-protocol analyses [30,32]. In addition, 1 study experienced high attrition (40%), so there were some concerns about missing outcome data [27]. However, removing the high-risk bias studies from consideration would not substantially change the overall results because there are 6 similar studies with a low risk of bias that reported weight loss when RTEC was consumed within the context of a hypocaloric diet. However, Kuriyan et al. [30] were 1 of only 3 studies to report a weight loss benefit of RTEC within a hypocaloric diet that was greater than a control hypocaloric diet. The remaining 2 studies reported no difference in weight loss between hypocaloric diets with or without RTEC. Further details on risk of bias analysis are in Supplemental Table 3.

Although not formally evaluated in standardized risk of bias assessments, funding source was also considered. Eleven

observational studies were funded by the food industry, and 3 were funded through governmental organizations (for example, NIH and USDA). Of the food industry-funded studies, 91% reported inverse associations of RTEC and body weight outcomes, whereas 100% of studies funded by government sources reported inverse associations of RTEC and body weight outcomes. Thirteen of the 14 RCTs were funded by the food industry, and 8 reported a neutral effect of RTEC on body weight outcomes.

Discussion

The results of this systematic review demonstrate consistent evidence from observational studies that adults consuming RTEC have lower BMI, lower prevalence and odds of overweight/obesity, less weight gain over time, and less anthropometric evidence of abdominal adiposity. RCT results suggest that RTEC can be incorporated as a meal or snack replacement in a hypocaloric diet without hindering weight loss but doing so did not generally provide additional weight loss benefits beyond similar hypocaloric diets without RTEC. Consumption of RTEC in ad libitum conditions does not appear to contribute to changes in body weight or body composition compared with usual diets without RTEC. These results are consistent with those from previous systematic reviews [7,8,12], although the current review included several more RCTs because of more recent publications in the last 7 y and broader inclusion criteria, such as RTEC interventions outside of the breakfast occasion.

Although the observational data are more consistent regarding associations of RTEC consumption for body weight and composition, important limitations should be considered, such as residual confounding and reverse causality. For example, individuals with a higher BMI may decide to start skipping breakfast to control caloric intake, possibly contributing to the higher BMI observed in breakfast skippers compared with RTEC consumers. Additionally, RTEC consumption has been associated with many healthy behaviors in adults, such as increased physical activity, greater vegetable and dairy consumption, and a lower likelihood of smoking [9,25,41], which may confound observational analyses. Almost all studies attempt to correct for some of these potential confounders in their analyses and other covariates, such as age, sex, race/ethnicity, socioeconomic status, marital status, and energy intake, but such adjustments cannot always eliminate residual confounding [42]. Observational studies also typically rely on self-reported food intake from 24 h recalls or FFQs, which are prone to measurement error and may not always accurately reflect intake. Most observational studies assessed were cross-sectional, which examines relationships between RTEC intake and outcomes at a single point in time but cannot assess changes over time. The 3 prospective studies that followed participants for 2–13 y reported inverse relationships of high fiber and/or whole-grain RTEC consumption with BMI and weight gain over time.

There were similar numbers of RCTs and observational studies in adults. However, most of the RCTs were conducted in the context of a hypocaloric, weight loss diet rather than ad libitum intake, which would be more reflective of the conditions in observational studies. Studies that evaluated RTEC as a substitute meal or snack in an ad libitum diet did not report any differences in body weight or body composition compared with a usual meal or snack [27,35,39], although 3 studies reported significant within-treatment weight loss with RTEC consumption [32,35,39].

A reduction in energy intake is one of the primary mechanisms proposed for how RTEC may contribute to a healthier body weight, and RCTs utilizing RTEC as a meal replacement generally support this mechanism. However, observational data have been mixed on the relationship between RTEC consumption and energy intake, with most systematic reviews reporting no relationship between RTEC to energy intake [7,8,12]. In the current review, not all studies assessed energy intake, but those that did report either a positive association of RTEC frequency and energy intake [16,17,19] or greater daily energy intake in RTEC consumers compared with breakfast skippers, but not non-RTEC breakfasts [3,4,18,20,25]. Despite increased energy intake, most of these studies reported an inverse relationship between RTEC intake and body weight or body composition, suggesting other mechanisms, such as those affecting energy expenditure, may need to be considered. In addition, RTEC consumers are more likely to be physically active, which may make it difficult to ascertain the direct effects of RTEC on energy expenditure. Song et al. [25] also reported that breakfast consumers are more likely to attempt to control their weight, suggesting RTEC and breakfast consumption may be indicators of an overall health-focused lifestyle that contributes to healthy body weight.

Previous systematic reviews have identified the need for additional RCTs evaluating the impact of RTEC on body weight outcomes, and in recent years there have been several new RCTs published that are included in the present review. For individuals seeking to lose weight, the RCT results suggest RTEC as a meal or snack replacement may be used to limit energy intake, although based on the available data, this approach is not superior to other options for those attempting to achieve an energy deficit. Meal replacements have become popular as a convenient and effective way to control portions and calories within a weight loss plan [43,44]. RTEC is readily available and comes in many varieties, which may help to avoid monotony. Lightowler et al. [32] evaluated a single RTEC meal replacement compared with a variety of RTEC meal replacements and found that individuals consuming the variety of RTEC lost more weight over 6 wk than those consuming a single RTEC. Another publication reported no body weight differences between single and variety RTEC consumption, but the RTEC was only consumed for 2 wk [34]. In addition, RTEC may be fortified with fiber, vitamins, and minerals that can positively impact nutrient intake, which is particularly important when food intake is reduced. In fact, 2 studies in the current review reported improvements in nutrient intake and diet quality when RTEC was used as a meal replacement, compared with the usual diet or another hypocaloric diet [20,36].

Most studies evaluating RTEC as a meal replacement used RTEC to replace 2 meals each day for a duration of 2–12 wk. Although this generally resulted in significantly greater weight loss than the non-RTEC diet, replacing only 1 meal or snack each day with RTEC did not result in greater weight loss than a non-RTEC diet [27,35,39]. This may be partial because of insufficient caloric restriction with only 1 meal or snack, or it may be because of insufficient length of the intervention. The 2 studies evaluating the replacement of RTEC for an evening snack

demonstrated trends toward greater weight loss compared with the usual diet after 4–6 wk of intervention, and the authors suggest a longer study may have been more likely to show a significant effect of RTEC on body weight [35,39]. Substituting 1 meal or snack each day instead of 2 may be more sustainable for weight maintenance over a longer term, whereas substitution of >1 meal might help accelerate initial weight loss and motivate individuals to pursue further weight loss, although these hypotheses remain to be tested in larger and longer-term studies.

Few studies evaluated types of RTEC, but most evaluating high-fiber or whole-grain RTEC did not find differences in body weight compared with low-fiber or refined-grain RTEC. However, 2 of 3 observational studies reported significantly lower BMI and less weight gain over time with increasing frequency of both whole grain and refined-grain RTEC [9,24]. This was also confirmed in 2 RCTs [33,37] comparing high-fiber, whole-grain RTEC to low-fiber whole-grain RTEC, although Maki et al. [33] reported smaller waist circumference in a high-fiber, whole--grain RTEC intervention compared with a low-fiber, refined--grain RTEC. Lightowler et al. [32] included several high-fiber varieties of cereals in the intervention, but it is difficult to determine if the improvement in weight loss was because of the fiber content or the greater variety of cereals (including high-fiber options) in the diet. Dietary fiber may help contribute to decreased appetite and increased satiety over the long term, which could assist in energy restriction during weight loss and prevent excess caloric intake during weight loss maintenance [12,33,36]. Small effects of RTEC consumption on energy intake (and/or expenditure) could produce differences in weight trajectory over time, which would be consistent with results from observational studies, although this would require a large sample to evaluate in an RCT.

Most studies were at low risk of bias or had some concerns. The high risk of bias in observational and RCTs was because of high loss to follow-up, self-reported body weight, possible selective reporting, and lack of statistical consideration for potential confounding variables. Removing high-risk bias studies from the assessment did not materially change the overall results but did strengthen the finding that RTEC within the context of a hypocaloric diet does not provide additional weight loss benefits beyond a control hypocaloric diet. There is the possibility of publication bias within observational studies as most report inverse relationships between RTEC and body weight outcomes. RCTs were more balanced in reporting favorable and neutral findings. Industry funding did not appear to influence the outcome of studies, as a similar portion of industry-funded and government-funded observational studies reported inverse relationships between RTEC and body weight outcomes. The majority of RCTs were supported by industry, yet most of them reported no differences in body weight between RTEC and control diets.

Future studies on RTEC use in managing body weight and body composition in adults should consider the context of the diet (ad libitum compared with hypocaloric), the duration of the intervention, and minimizing potential sources of bias. As previously mentioned, most clinical trials evaluated RTEC in the context of a hypocaloric diet, which does not reflect the ad libitum conditions of observational studies. To better test the hypotheses generated by associations in observational studies, RCTs should include RTEC consumption in the context of an ad libitum diet over longer time periods to evaluate possible effects on body weight outcomes. Longer duration RCTs with hypocaloric diets are also warranted. Most clinical trials were <12 wk in duration with only 1 intervention of 6 mo. It would be ideal to have studies of ≥6 mo in duration. It may also be interesting to examine the impact of RTEC consumption on weight maintenance after initial weight loss. Researchers should also try to eliminate or minimize potential sources of bias by utilizing standardized objective procedures for measuring body weight rather than relying on self-reports, and reporting all data, even if supplemental materials for publications are necessary.

The strengths of this systematic review include broad inclusion criteria (for example, the inclusion of weight loss studies) to capture as many studies as possible, the inclusion of the most recent studies (2000–present), and risk of bias analysis. The search was limited to English language publications which may have indirectly limited the geographical locations as most observational studies reviewed were from North America and Europe. However, RTEC is not as frequently consumed in some other countries, and other countries without national dietary intake databases or large cohorts may also have limited observational data available for analysis. Another limitation of this review is heterogeneity in study designs that make direct comparisons between studies difficult. For example, observational studies categorized RTEC intake differently (for example, frequency, amount, RTEC at breakfast compared with breakfast skippers compared with non-RTEC breakfasts). Likewise, the comparator diet in RCTs varied considerably, including egg-based breakfasts, usual diets, hypocaloric diets, or alternative hot/cold cereals. There were also few RCTs with RTEC interventions in the context of ad libitum intake, which is more reflective of observational studies, and therefore limits the comparison of observational studies and RCTs.

In conclusion, evidence from cross-sectional and prospective studies support the view that adults who consume RTEC more frequently (typically ≥4 servings/wk) have a healthier mean BMI, lower prevalence of overweight/obesity, gain less weight over time, and have improved markers of adiposity, such as waist circumference and percentage body fat. RCT results support the conclusion that weight loss can be achieved within a hypocaloric diet when RTEC is used as a meal replacement, but the inclusion of RTEC does not appear to contribute to greater weight loss than achieved with other hypocaloric diets over the timeframes studied. Including RTEC in the diet without energy, restriction did not conclusively demonstrate benefits for body weight or body composition compared with usual diets but did not contribute to weight gain. Additional studies utilizing RTEC within the context of an ad libitum diet and studies incorporating RTEC in energy-restricted diets over longer timeframes (≥6 mo) should be pursued. Investigators planning additional studies should also consider eliminating or minimizing potential sources of bias, utilizing greater RTEC variety, and including higher-fiber and whole-grain RTEC within interventions, as these may help prevent monotony and improve satiety, thereby potentially contributing to improvements in body weight and body composition outcomes.

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Data availability

Data reviewed during this systematic review is available from the corresponding author upon reasonable request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.advnut.2023.05.001.

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