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Review

Dairy intake and type 2 diabetes risk factors: A narrative review

Joanna Mitri [a,*], Barakatun-Nisak Mohd Yusof [b,**], Melinda Maryniuk [c], Cara Schrager [a], Osama Hamdy [a], Veronica Salsberg [a]

[a] Joslin Diabetes Centre, Harvard Medical School, 1 Joslin Place, Boston, MA, 02215, United States
[b] Department of Nutrition & Dietetics and Research Centre (Non-Communicable Chronic Diseases), Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400, Malaysia
[c] Maryniuk & Associates Consulting, United States

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ABSTRACT

Aim: The interest regarding the potential role of dairy products in the prevention of type 2 diabetes (T2D) has emerged. Although results remain mixed, numerous cohort studies have shown that increased dairy consumption is inversely associated with T2D risk. This narrative review evaluates the recent evidence of dairy products intake on T2D risk factors for the prevention of T2D.

Material and method: The review is framed within the systematic review and meta-analyses of cohort studies and the individual randomized controlled trials evidence. We searched for existing meta-analyses of cohort studies that addressed the association of dairy intake with incidence of T2D in adults using the MEDLINE (via PubMed) database. For the interventional studies, the literature searched was conducted using MEDLINE (via PubMed) with the following Medical Subjects Heading (MeSH) terms i.e. dairy OR milk OR cheese OR yogurt AND glucose OR diabetes OR insulin resistance OR insulin sensitivity OR pre-diabetes.

Results: Most of the meta-analyses and systematic reviews of the cohort studies point to a reduced risk of T2D with dairy intake of 3 servings per day. This effect was mainly attributed to low-fat dairy, particularly yogurt and cheese. However, there is no evidence in cohort studies that high-fat dairy intake poses any harm.

Conclusion: Dairy products, when incorporated into a healthy diet, likely do not have detrimental effects on glucose-related outcomes. The potential impact of dairy consumption on glucose tolerance tests, insulin levels, insulin sensitivity measures, and plasma glucose levels warrant future investigation.

1. Background

Lifestyle modification is an integral component of type 2 diabetes (T2D) prevention. It is well established that lifestyle interventions, including managing weight and adopting healthy eating patterns, reduces diabetes incidence by more than 50% in at-risk individuals [1]. However, the impact of specific foods and nutrients on T2D prevention remains the subject of ongoing research. Dairy products such as milk, cheese, and yogurt have long been recommended as part of a healthy meal plan [2,3], particularly for their substantial supply of high-quality protein and dietary calcium. The United States Department of Agriculture (USDA) advises individuals ≥ 9 years of age to consume 3 servings of milk or other equivalent dairy products per day (options listed in Table 1) [3]. Despite this recommendation, the per capita consumption of dairy products in 2012 among the U.S. totaled 1.9 servings per day [4].

Specific recommendations regarding dairy intake for T2D prevention is not available. For people with T2D, guidelines from various U.S. professional associations recognize the importance of dairy products as part of a balanced diet [1,5,6]. However, guidelines differ substantially when it comes to recommending low-fat or non-fat dairy. For example, the USDA Dietary Guidelines, American Heart Association Guidelines, and the National Lipid Association Guidelines recommend dairy products from low-fat or non-fat sources [3,7,8]. In contrast, American Diabetes Association

* Corresponding author.
** Corresponding author.
E-mail addresses: Joanna.Mitri@joslin.harvard.edu (J. Mitri), bnisak@upm.edu.my (B.-N. Mohd Yusof), melinda@melindamaryniuk.com (M. Maryniuk), cara.schrager@joslin.harvard.edu (C. Schrager), Osama.Hamdy@joslin.harvard.edu (O. Hamdy).

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Table 1
Nutrient composition of dairy foods per dairy equivalent serving Sizes.[47]

Dairy foods	Serving Size[a]	Calories	Calcium (g)	Sodium	Carbs (g)	Protein (g)	Saturated fat (g)
Milk, whole	1 cup	149.0	276.0	105.0	12.0	8.0	4.5
Milk, reduced fat (2%)	1 cup	137.0	350.0	145.0	12.0	10.0	3.0
Milk, low-fat (1%)	1 cup	105.0	314.0	127.0	12.0	9.0	1.5
Milk, skim	1 cup	91.0	316.0	130.0	12.0	9.0	0.4
Kefir, low-fat	1 cup	98.0	312.0	96.0	11.0	9.0	1.5
Yogurt, Greek, plain, whole milk	1 cup	190.0	250.0	75.0	9.0	20.0	6.0
Yogurt Greek, plain, non-fat	1 cup	133.0	248.0	81.0	8.0	23.0	0.26
Hard cheese (cheddar)	1.5 oz	172.0	302.0	278.0	1.3	10.0	8.0
Shredded cheese (low-fat mozzarella)	1/3 cup	86.0	203.0	194.0	2.3	7.0	3.2
Processed cheese (American)	2 oz	120.0	281.0	672.0	5.8	8.0	4.4
Cottage cheese, whole milk	2 cups	412.0	348.0	1528.0	14.0	46.0	7.0
Cottage cheese, 1% fat, no added salt	2 cups	326.0	276.0	60.0	12.0	56.0	3.0
Ricotta, whole milk	½ cup	216.0	257.0	104.0	4.0	14.0	10.0
Ricotta, part skim	½ cup	171	337.0	123.0	6.0	14.0	6.0

[a] Serving sizes are based on calcium equivalents/United States Department of Agriculture recommendations.

guidelines refer to the importance of dairy products as part of a healthy meal plan, but do not consistently specify low-fat or non-fat options (Table 2) [1].

Recent research has drawn attention to the potential beneficial effects of dairy products in the prevention of T2D. Previously published reviews of this literature base are limited in that they primarily include cohort studies [9], were not limited to dairy products [10] or looked only at the effect of dairy products in people with diabetes [11]. While greater consumption of regular-fat dairy has been associated with a lower incidence of metabolic syndrome, it was not seen among those at risk of T2D [12]. Weight loss was determined to be the most important contributor to the lifestyle intervention. In the Nurses' Health Study (NHS), increased whole milk intake was associated with less weight gain over 4 years [13]. It has also been shown that, over a period of 11.2 years, the risk of becoming overweight or obese in a prospective cohort of middle-aged and elderly women was lower in the highest quintile of dairy fat intake (hazard ratio [HR] 0.82; 95% confidence interval [CI]: 0.86–0.99) [14]. In a study of 26,930 individuals conducted in Malmö, Sweden, decreased risk of T2D was observed with higher high-fat dairy products from cream, butter, high-fat fermented milk, and cheese over 14 years of follow-up compared to low-fat dairy [15].

To clarify conflicting results from epidemiological studies, we performed an overview of the published systematic review and meta-analyses of cohort studies investigating the association

Table 2
Advisory committee recommendations for fat, saturated fat, and dairy food intake.[2,4–7,48–50]

Organization, Committee	Year	Total fat (%TE)	SFA (%TE)	Level of fat in dairy foods	Recommendation Related to Dairy Intake
Dietary Guidelines for Americans (DGAC/USDA)	2015–2020	None	<10%	Fat free or low-fat	Follow a healthy eating pattern across the lifespan, defined to include: "fat-free or low-fat dairy, including milk, yogurt, cheese and/or fortified soy beverages."
AACE/ACE Clinical Practice Guidelines for Healthy Eating	2013	~30%	<7%	Low-fat	Recommends 3–4 daily servings of low-fat dairy foods.
ADA Standards of Medical Care in Diabetes (ADA)	2018	None	*Follow guidelines for the general population **Focus on reducing saturated fats	*None **Low-fat	*Carbohydrate intake, including dairy products, with an emphasis on foods higher in fiber and lower in glycemic load, should be advised over other sources, especially those containing sugars. **Lifestyle therapy for weight loss, CVD, and lipid management should include low-fat dairy products and increased activity levels.
AHA/ADA Scientific Statement	2015	<30%	<10%	Low-fat	Emphasizes intake of fruits, vegetables, whole grain, reduced saturated fat, and low-fat dairy products in place of other carbohydrate sources
Academy of Nutrition and Dietetics	2014	20%–35%	Goal of <7%, maximum intake 10%	Low-fat	Recommends a food-based approach, including regular consumption of fatty fish, nuts and seeds, lean meat and poultry, low-fat dairy products, vegetables, fruits, and whole grains.
AHA/ACC Lifestyle Management Guideline	2013	None	5%–6%	Low-fat	Consume a dietary pattern that emphasizes intake of vegetables, fruit, whole grains; this includes low-fat dairy products, poultry, fish, legumes, nontropical vegetable oils, and nuts, and limits the intake of sweets, sugar-sweetened beverages and red meats.
Joslin Diabetes Center Nutrition Guidelines	2016	30%–40%	<10%	Saturated fat from dairy foods may be acceptable within the total daily caloric intake	Recommended protein sources include: fish, skinless poultry, lean meat, dairy, nuts, seeds, soy, and legumes Avoid foods high in trans and saturated animal fat, including non-lean beef, pork, lamb, processed meat, and butter and cream

ADA = American Diabetes Association; ACC = American College of Cardiology; AHA = American Heart Association; CVD = cardiovascular disease; DGAC = Dietary Guidelines Advisory Committee; SFA = saturated fatty acids; TE = total energy; USDA = United States Department of Agriculture; *For Diabetes Prevention and Management; **For Cardiovascular, Lipid, and Weight-Loss Management in Diabetes.

between dairy intake and incidence of T2D. Besides, we examined the evidence from interventional studies to better understand the effects of dairy products on T2D risk factors (plasma glucose, glucose tolerance, insulin sensitivity, and circulating insulin levels) in adults at high risk of T2D. Based on the interventional studies, we summarized the effects of dairy intake (high compared with low) with the focus on three categories of dairy products including milk, cheese, and yogurt on T2D risk factors.

2. Methods

We searched for existing meta-analyses of cohort studies that addressed the association of dairy intake with the incidence of T2D in adults using the MEDLINE (via PubMed) database until November 2018. For the interventional studies, the literature searched was done using MEDLINE (via PubMed) with the following Medical Subjects Heading (MeSH) terms i.e. dairy OR milk OR cheese OR yogurt AND glucose OR diabetes OR insulin resistance OR insulin sensitivity OR pre-diabetes. We did not include studies on dairy proteins, such as whey or casein, since the primary goal of this review was to investigate whole dairy foods and not individual nutrients. We then reviewed the studies based on the intervention type and comparator groups. Studies that included another intervention in addition to dairy were excluded.

3. Results

3.1. An overview of systematic review and meta-analyses of cohort studies

The included systematic reviews and meta-analyses were published between 2011 and 2017 [16–22]. The number of studies ranged from 7 to 26 cohort studies with a sample size range from 328,029 to 5,741,718 subjects (Table 3). The reported cases of T2D ranged from 13,078 to 46,905. Of the 7 meta-analyses of cohort studies reported here [16–22], all studies except Schwingshackl et al. [17] were consistently showed an inverse association between total dairy product consumption (per 200–400 g/d) and T2D risk (RR range: 0.86–0.97) (Table 3). When stratified according to the level of fat, 6 out of 7 studies reported a significant inverse association for low-fat dairy products (per 200 g/day) with T2D risk (RR range: 0.82–0.97) (Table 3). For the types of dairy products, 5 out of 7 studies found significant association for yogurt (per 50–244 g/day), and 2 out of 7 studies found significant association for cheese (per 30–50 g/day) with a lower risk of T2D (Table 3). The association for high-fat dairy and milk were consistently neutral.

Soedamah-Muthu and de Goede [16] have recently updated the meta-analyses by Gijsbers et al. [18] by adding another four new cohorts given a total number of 26 cohort studies included in the meta-analyses and consistent results were observed. In summary, they found that total dairy consumption of 200g/day was significantly associated with a 3% lower risk of T2D, and the intake of low fat dairy (per 200 g/day) and yogurt (per 80g/day) reduced T2D risk by 4% and 15% respectively [16]. No associations with full-fat dairy, fermented dairy, milk, and cheese were observed. Similar results were reported by Gijsbers et al. [18] that included 22 cohorts and found that total dairy intake was associated with a 3% lower risk of T2D (RR 0.97, 95% CI: 0.95–1.00; $P = 0.04$) per 200-g/day increment (1.1 serving/day, 7.1 oz/day). There was a linear inverse association with low-fat dairy and T2D risk (RR 0.96 per 200 g/day, 95% CI: 0.92–1.00; $P = 0.072$). A non-linear inverse association was found for yogurt intake (RR 0.86 per 80 g/day, 95% CI: 0.83–0.90; $P < 0.001$). There was no association between other dairy products and T2D risk. High-fat dairy intake was not associated with T2D risk (RR 0.98 per 200 g/day, 95% CI: 0.93–1.04; $P = 0.52$) [18].

Gao et al. [20] performed a meta-analysis of 14 cohort studies and found a significant inverse linear association of total dairy product consumption, in particular low-fat dairy, cheese, and yogurt, and T2D risk. Pooled risk ratios were 0.94 (95% CI: 0.90–0.97) for 200 g/day total dairy; 0.88 (95% CI: 0.84–0.93) for low-fat dairy; 0.80 (95% CI: 0.63–0.93) for 30 g/day of cheese; and 0.91 (95% CI: 0.82–1.00) for 50 g/day of yogurt. The relationship with non-fat dairy was non-linear, with the highest reduction in T2D risk at 300 g/day, while higher intake was not associated with a further risk reduction. Again, high-fat dairy consumption was not associated with T2D risk (RR 0.95, 95% CI: 0.85–1.07) [20]. Similarly, a meta-analysis by Aune et al. [21] showed a 9% decreased risk of T2D incidence per 200 g/day of low-fat dairy and an 8% risk reduction with a 50 g (about 2 oz) daily serving of cheese. There was no risk reduction with high-fat dairy or milk, with a RR of 0.98 (95% CI: 0.94–1.03; $I^2 = 8\%$, where I^2 is total variation explained by between-study variation) per 200 g of high-fat dairy products/day and a RR of 0.87 (95% CI: 0.72–1.04; $I^2 = 94\%$) per 200 g milk/day [21].

A meta-analysis of 7 cohort studies conducted by Tong et al. [22] showed a 14% reduction in T2D risk among a population with the highest consumption of dairy products compared to the lowest consumption. This risk reduction was mainly attributed to low-fat dairy (RR 0.82, 95% CI: 0.74–0.90) and yogurt (RR 0.83, 95% CI: 0.74–0.93). In contrast, intake of high-fat dairy and whole milk had neutral effect. A dose-response analysis showed that T2D risk was lowered by 10% for every 1-serving increment of low-fat dairy [22]. In a meta-analysis that included 459,770 individuals, Chen et al. [19] found no association between total consumption of dairy products and T2D risk (RR 0.98, 95% CI: 0.96–1.01). Nonetheless, there was reduced risk of T2D with yogurt consumption (RR 0.82, 95% CI: 0.70–0.96; $P = 0.003$) [19].

3.2. Interventional studies in those at risk for type 2 diabetes

The literature review identified 15 interventional studies in individuals at risk for T2D; 6 studies due to metabolic syndrome [23–28] and 9 studies due to overweight/obesity [29–37] (Table 4). The number of participants in each study ranged from 14 to 200, with a total of 1034 participants across all studies. Study durations varied from 0.5 to 6 months, including 7 crossover studies with washout periods ranging from 0 to 8 weeks. The studies evaluated the effect of dairy intake in comparison to limited or no dairy on T2D risk factors including glycemic parameters, such as fasting plasma glucose, insulin levels, and insulin resistance measure such as HOMA-IR. The amount of dairy products used in the interventions ranged between 2 and 6 servings per day versus controls with limited dairy ($\leq$2 servings) [24,27,28,32,34,36] or non-dairy products such as lean red meat [30], sugar-sweetened beverages [31,33] or fruit juices [37]. Low-fat dairy products were frequently used in dairy intervention groups (n = 10 studies) [24,25,29,31–34,36,37].

Since weight loss could interfere with outcomes, many studies (n = 8) included a weight-stabilizing diet [23,26,27,29–32,36]. Of these, 9 studies showed that dairy consumption has a neutral effect on body weight [23,27,28,30–33,36,37]. Majority of studies (n = 10) also found a neutral effect of dairy on glycemic [23–26,29,30,33–35,37] and others (n = 5) showed reductions in A1C, plasma glucose, or HOMA IR [27,28,31,32,36].

3.3. Dairy versus non-dairy products

Maki and colleagues [31] found that after 6 weeks of intervention, HOMA-IR improved with consumption of dairy products compared to sugar-sweetened foods in individuals with

Table 3
Summary of meta-analyses of observational cohort studies and the risk of type 2 diabetes.

Author (year)	Number of Cohort studies; N[#]; Diabetes Incidence	Total Dairy Products	Type of Dairy Products			Level of Fat		Summary
			Milk	Cheese	Yogurt	High-Fat Dairy	Low-Fat Dairy	
		RR (95% CI) with significant association						
Soedamah-Muthu and de Goede, 2018	26, N = 5,741,718 Diabetes incidence = 46,905	0.97 (0.95−1.00) per 200 g/d (equal to 1.1 serving/d)	No association	No association	0.94 (0.91−0.97) per 80 g/day	No association	0.96 (0.92−1.00) per 200 g/day	Intake of total dairy, low-fat dairy and yogurt were inversely associated with T2D risk
Schwingshackl et al., 2017	21, N = 566,872 Diabetes incidence = 44,474	0.91 (0.85−0.97) per 200 g/d	NR	NR	NR	No association	0.97 (0.94−1.00) per 200 g/day	Intake of total dairy and low-fat dairy were inversely associated with T2D risk
Gijsbers et al. 2016	22, N = 579,832 Diabetes incidence = 43,118	0.97 (0.95−1) per 200 g/day (equal to 1.1 serving/d)	No association	No association	0.86 (0.83−0.90) per 80 g/day	No association	0.96 (0.92−1.00) per 200 g/day (p = 0.07)	Intake of total dairy, yogurt and low-fat dairy were inversely associated with T2D risk
Chen et al., 2014	14, N = 459,790 Diabetes incidence = 35,863	No association	No association	No association	0.82 (0.70−0.96) per 244 g/day	No association	No association	Intake of yogurt was inversely associated with T2D risk
Gao et al., 2013	14, N = 526,998 Diabetes incidence = 29, 789	0.94 (0.91−0.97) per 200 g/day	No association	0.80 (0.69−0.93) per 30 g/day	0.91 (0.82−1.00) per 50 g/day	No association	0.88 (0.84−0.93) per 200 g/day	Intake of total dairy, low-fat dairy products, cheese, and yogurt were inversely associated with T2D risk
Aune et al., 2013	17, N = 526,482 Diabetes incidence = 30,243	0.93 (0.87−0.99) per 400 g/day	No association	0.92 (0.86−0.99) per 50 g/day	No association	No association	0.91 (0.86−0.96) per 200 g/day	Intake of total dairy, low-fat dairy, and cheese were inversely associated with T2D risk
Tong et al., 2011	7, N = 328,029 Diabetes incidence = 13,078	0.86 (0.79−0.92)	No association	NR	0.83 (0.74−0.93)	No association	0.82 (0.74−0.90)	Intake of total dairy, especially low-fat dairy was inversely associated with T2D risk

CI = confidence interval; HF = high fat; I^2 = the amount of total variation explained by between-study variation; LF = low fat; NA = not applicable; NR = Not reported, RR = relative risk; T2D = type 2 diabetes; [#] Total number of subjects; *significant.

Table 4
Summary of interventional studies investigating the effect of high-dairy, low-dairy (intervention), or limited/no-dairy on glucose-related outcomes in adults.

No	Author (year; country)	N, Patients	Duration (months)	Design	Intervention		Control	Weight-Stable Diet	Body Weight	Outcomes (vs limited/no dairy)	Comments
					High Dairy	Low Dairy	Limited or No Dairy				
1	Raziani et al. (2016; Denmark)	139, MetS	3	II RCT	Regular-fat cheese (80 g/day) or reduced-fat cheese (80 g/day)		No cheese (substituted with non-dairy CHO diet)	Yes	Neutral	Neutral (glucose and insulin)	Dropout rate 15% Other types of dairy (milk and yogurt) were not considered
2	Lee et al. (2016; Korea)	58, MetS	1.5	II RCT	Low-fat milk (400 ml/day)		Relatively low milk intake	–	Increased; not SS	Neutral (glucose and insulin)	Other types of dairy (cheese and yogurt) were not considered Energy intake was not balanced between intervention and control
3	Dugan et al. (2016; USA)	33, MetS	4	X	Low-fat dairy (3 servings/day)		No dairy; CHO control diet	No	Not reported; slight WC reduction in low-fat dairy group, $P = 0.002$)	Neutral (HOMA-IR)	Final analysis excluded participants who were gaining weight Weight reduction in women diluted study outcomes
4	Drouin-Chartier et al. (2015; Canada)	27, OB women	1.5	X	2% milk (3.2 servings/day)		No milk or other dairy	Yes	Reduced in both arms	Neutral (glucose and insulin)	6- to 8-week washout period between regimens Small sample size Relatively short duration
5	Thorning et al. (2015; Denmark)	14, Owt women	0.5	X	Regular cheese (96–120 g/day)		Meat diet CHO diet	Yes	Neutral	Neutral (glucose and insulin)	Short duration and narrow study participants
6	Maki et al. (2015; USA)	34, Owt	6	X; RCT	3 servings/day (2% milk [474 ml/day] and low-fat yogurt [170 g/day])		3 servings/day sugar-sweetened beverages	Yes	Neutral	Reduced with dairy (HOMA-2; not SS)	Dairy intervention combined low- and high-fat dairy foods 100% compliance
7	Tanaka et al. (2014; Japan)	200, MetS	6	X; RCT	Nutrition education + dairy (400 g/day in the form of milk or milk + yogurt)		Nutrition education alone with no dairy	Yes	Reduced in both arms, not SS (more in the control group)	Neutral (fasting glucose)	Source of dairy fat was not reported
8	Rideout et al. (2013; Canada)	23, Owt/OB	6	X	4 servings low-fat dairy/day		2 servings low-fat dairy/day	Yes, limited counseling on how to incorporate in diet	Neutral	Reduced with dairy (HOMA-IR 11% [$P = 0.03$]; plasma insulin 9% [$P \leq 0.05$])	Drop-out rate 41% No washout period Lack of compliance checks (food log and dairy log) Potential bias as dairy was only provided during high-dairy interventional phase
9	Maersk et al. (2012; Denmark)	47, Owt	6	II RCT	Semi-skim milk (1 L/day)		Cola, diet cola, or water	–	Neutral	Neutral	Small sample size
10	Crichton et al. (2012; Australia)	61, Owt/OB	6	X RCT	4 servings reduced-fat dairy/day^		≤1 serving of reduced-fat dairy/day	No energy restriction	Increased, not SS	Neutral (glucose)	High drop-out rate (48%) due to long trial duration No wash-out period <2 servings of dairy at baseline
11	Rosado et al. (2011; Mexico)	139 OB	4	II RCT	3 servings low-fat milk vs 3 servings low-fat milk + micronutrients		Habitual diet	Energy restriction	Reduced in low-fat milk + micronutrients (−5.1 kg vs −3.6 kg low-fat milk; $P = 0.035$)	Neutral between groups but significant within treatment (glucose)	Compliance monitoring scale Excluded those with >3 servings dairy/day at baseline
12	Stancliffe et al. (2011; USA)	40, MetS	3	II RCT	3.5 servings dairy/day		0.5 serving dairy/day	Yes	Neutral	Reduced with dairy (plasma insulin; −3.38 μu/mL, [$P < 0.05$] and HOMA-IR [-0.59, $P < 0.05$])	Data combined for low- and high-fat dairy products

(*continued on next page*)

Table 4 (*continued*)

No	Author (year: country)	N, Patients	Duration (months)	Design	Intervention		Control	Weight-Stable Diet	Body Weight	Outcomes (vs limited/no dairy)	Comments
					High Dairy	Low Dairy	Limited or No Dairy				
13	Van Meijl and Mensink (2011; Netherlands)	35, Owt/OB	2	II RCT	Low-fat dairy (500 ml low-fat milk and 150 g low-fat yogurt)		CHO-rich foods (600 ml fruit juice and 3 biscuits)	No; total energy intake similar between groups	Neutral	Neutral (glucose)	Small sample size
14	Wennersberg et al. (2009; Finland, Norway, Sweden)	121, MetS	6	II RCT	3-5 portions dairy products/day[#]		Habitual diet (≤2 portions dairy products/day)	Dairy included in diet; no other advice Similar energy intake	Neutral	Reduced with dairy (HOMA-IR -0.6, $P = 0.037$)	Data combined for low- and high-fat dairy products (including butter and ice cream) Increased pentadecanoic acid
15	Zemel et al. (2005; USA)	Phase 1; 34, Healthy/OB Phase 2; 29, OB	6 6	II RCT	3 servings low-fat dairy/day; ≥1 in the form of milk		0-1 serving low-fat dairy/day	Yes No (reduced-energy diet)	Neutral Reduced in high-dairy (-11.0 kg) and low-dairy diets (−5.9 kg; $P < 0.01$ for comparison)	Decreased with dairy (plasma insulin; not SS)	Small Study, African American patients No compliance assessment through rigorous methods

II = parallel design; CHO = carbohydrate; HOMA-IR = Homeostatic Model Assessment of Insulin Resistance; MetS = metabolic syndrome; OB = obese; Owt = overweight; serv = servings; SS = statistically significant; SSB = sugar-sweetened beverages; WC = waist circumference; X = cross-over design; ˜reduced fat = 250 ml milk (2.00 g) or 175–200 g yogurt (2.00 g) per each dairy serving; #dairy products = 200 ml milk (1–6 g fat) or 200 g yogurt (2–11 g fat); ˜day.

overweight and obesity [31]. This difference was related to increased insulin concentrations in the control group. Worsened insulin sensitivity may be related to increased carbohydrate and fructose intake in sugar-sweetened foods. In this trial, participants in the dairy arm consumed reduced-fat milk and low-fat yogurt. Pentadecanoic acid (15:0) was increased in the dairy group indicating good adherence to the assigned diet, but changes in milk fat were not associated with changes in HOMA-IR. Saturated fat increased significantly in the dairy group with no effect on lipid profiles [31]. Dugan and colleagues evaluated subjects with metabolic syndrome with low-normal dairy intake in a 6-week crossover study [25]. Compared to a carbohydrate control, 3 servings/day of low fat dairy led to no differences in HOMA-IR but promoted small improvements in fasting plasma glucose in men [25]. In a randomized 12-week crossover study by Drouin and colleagues of 27 women with abdominal obesity [29], 3.2 servings/day of 2% fat milk per 2000 kcal in the context of a prudent diet, compared to a diet with a similar energy profile but lacking in dairy, had no favorable nor deleterious effect on cardiometabolic risk factors, including fasting plasma glucose [29]. Similarly, a 16-week interventional crossover study (N = 35) conducted by Van Meiji and colleagues in patients with metabolic syndrome found that dairy consumption vs carbohydrate control did not affect any of parameters of the metabolic syndrome [37]. Lastly, in a randomized, crossover, open-label intervention of 14 overweight postmenopausal women, there were no differences in fasting glucose, insulin concentrations, or HOMA-IR following 2 weeks of several isocaloric diets: high-cheese (96–120g/day) diet, macronutrient-matched nondairy diet, high meat control diet; and a non-dairy low-fat high-carbohydrate control diet [30].

3.4. High- versus low-dairy diet

Improved insulin sensitivity and reduced circulating insulin levels were observed in 5 out of 15 studies after 6 weeks to 6 months of high total dairy intervention [27,28,31,32,36]. These studies provided relatively higher servings (3–5 servings/day) of dairy products compared to reduced dairy intake (0–2 servings). Three of these studies provided low- or reduced-fat in the dairy arms [31,32,36] while 2 studies combined low- and high-fat dairy in the intervention [27,28]. Stancliffe et al. randomized 48 adults with overweight or obesity with metabolic syndrome to receive adequate dairy (3.5 daily servings) or low-dairy (0.5 daily servings) weight-maintenance diets for 12 weeks [27]. Dairy intake included milk and yogurt. At the end of the study, there was no significant effect on plasma glucose. Nevertheless, the adequate dairy diet resulted in a significant reduction in plasma insulin and improvements in HOMA-IR [27]. This effect was evident after 1 week and was maintained throughout the study. Despite no difference in body weight, fat mass was reduced significantly by an average of 1.7 kg in the adequate dairy group [27].

In a study by Rideout et al., high intake of low-fat dairy products (4 servings/day) improved insulin resistance as measured by HOMA-IR by 11% ($P = 0.03$) and plasma insulin by 9% ($P < 0.05$) compared to low intake of dairy products (1–2 servings/day) over a 6-month period in adults with overweight and obesity, without adverse effects on body weight or lipid profile [32]. Participants were instructed to maintain their usual diet and physical activity levels and were advised to incorporate dairy by substitution so as not to increase energy intake. In this study, incomplete diet records did not enable accurate evaluation of actual dairy compliance [32].

Lee and colleagues randomized participants with metabolic syndrome from South Korea (N = 58) to either 2 servings of low-fat milk or regular diet for 6 weeks [24]. They found no significant changes in insulin levels, fasting glucose, or hemoglobin A1C levels

between both groups [24]. Similarly, in a 12-month crossover trial, Crichton and colleagues found no difference in fasting plasma glucose between a diet high in dairy (4 servings/day) versus a diet low in dairy (1 serving/day) in overweight or obese individuals [34]. Despite being asked to incorporate dairy by substitution with other foods, there was an increase in energy intake and weight in the high-dairy group versus the low-dairy group. However, the weight difference was not significant, nor the changes in body composition [34].

In the first of two interventions designed to evaluate calcium intake among African-Americans, Zemel et al. found that a weight-maintenance, high-dairy diet providing 3 daily servings resulted in significantly lower circulating insulin levels over 24 weeks, compared to a low-dairy diet [36]. Although body weight remained stable; total body fat decreased significantly, and lean mass increased significantly in the high-dairy group. In the second intervention, a caloric restriction of 500 kcal per day resulted in weight loss in both low-and high-dairy groups over 24 weeks but weight and fat loss were twofold higher ($P < 0.01$), and loss of lean body mass was significantly reduced in the high-dairy group [36].

Wennergsberg et al. randomized 121 patients with metabolic syndrome from Finland, Norway, and Sweden to 3–5 portions of dairy products per day or habitual diet for 6 months [28]. Dairy product choices were milk 0.5%–3.0% fat, yogurt 1.0%–5.4% fat, cream 40% fat, cheese 15%–30% fat, and butter 40%–80% fat. Increased levels of pentadecanoic acid (15:0) in the dairy group confirmed dietary adherence. HOMA-IR increased in the control group (≤2 dairy servings per day) but there were no differences in body weight or body composition between the 2 groups. In a subgroup analysis of participants with low calcium intake, there was a decrease in waist circumference among the dairy group (102.1 ± 10.2 cm at baseline; 99.3 ± 10.8 cm at 6 months; $P = 0.003$). Based on a 3-day food log, participants in the dairy group had a higher energy intake, mainly attributed to greater consumption of protein and fat, including saturated fat coming from dairy products [28].

4. Discussion

This literature review suggests a 2–15% decreased risk of T2D with dairy intake of ≥3 servings per day. This effect can be primarily attributed to low-fat dairy and yogurt in particular. The neutral effect of dairy intake on body weight and body fat suggests the possibility of dairy restricting body-fat accumulation [28]. However, the studies reviewed herein were too small to detect changes in cardiometabolic measures.

Several mechanisms may contribute to the beneficial effect of dairy products on T2D risk. Dairy-derived fatty acids may have a protective effect [38,39]. For example, dairy products that have undergone fermentation are associated with reduced T2D risk, similarly high serum phospholipid *trans*-palmitoleic acid (*trans* 16:1n-7), which is found in dairy fat, was associated with lower incidence of insulin resistance [39]. Also, higher consumption of dairy fat as measured by *trans*-16:1n-7, pentadecanoic acid (15:0), and heptadecanoic acid (17:0) (which are also circulating biomarkers of dairy fat) has been inversely associated with fasting plasma glucose and positively associated with lower glucose levels in an oral glucose tolerance test, as well as higher systemic and hepatic insulin sensitivity [40]. In a prospective cohort study (N = 594), these biomarkers were not associated with stroke and in another large, prospective cohort (N = 3,333) they were associated with lower incidence of diabetes [41]. In comparison with the lowest quartile, individuals in the highest quartile of plasma 15:0, 17:0, and *trans*-16:1n-7 had a 44% (HR 0.56, 95% CI: 0.37–0.86; *P*-trend = 0.01), 43% (HR 0.57, 95% CI: 0.39–0.83; *P*-trend<0.01), and 52% (HR 0.48, 95% CI: 0.33–0.70; *P*-trend <0.001) lower risk of diabetes mellitus, respectively [28].

Several potential limitations to the currently available data should be noted. There is methodological heterogeneity between studies, which precludes firm conclusions. Most of the reviewed cohort studies that evaluated association of dairy and T2D risk used validated food-frequency questionnaires, which would mitigate measurement error and potential sources of bias. In general, any inverse association between dairy intake and T2D risk should be interpreted with caution, as these findings may be a result of unmeasured or residual confounding. A high total dairy intake and perhaps in particular low-fat dairy, may be associated in the same individuals with other healthy behaviors, including higher levels of physical activity, higher intake of dietary fiber and whole grains, lower prevalence of smoking, lower prevalence of overweight or obesity, and reduced intake of red and processed meat. In addition, dairy intake is frequently associated with other factors linked to lower rates of obesity and cardiometabolic disease, such as higher socio-economic status and higher educational level Although many analyses adjusted for known confounding factors (such as age, BMI, family history, fiber and energy intake, body weight, and smoking), other covariates may exist, making it difficult to draw conclusions from observational studies alone. Thus, whether or not the observed association is due to dairy itself or other lifestyle aspects is not clear. Additionally, some crossover studies had no washout period, making it difficult to evaluate whether the effects of any pre-intervention dietary factors carried-over into the study. This effect, however, was reduced with longer-duration studies [34]. Moreover, the dairy products provided in some studies might not be easy to incorporate into individual diets. It is not clear whether providing patients with different or desirable dairy products would alter energy intake.

4.1. Clinical applications

Overall, evidence supporting the role of dairy products in T2D prevention is growing. Additional research is needed to identify the mechanisms whereby dairy products exert their effects, as well as the role of total dairy products in modulating T2D risk. Registered dietitians and other healthcare providers can support their patients who may have prediabetes or risk factors for T2D by emphasizing dietary changes associated with diabetes prevention. Recommendations may include, encouraging patients to ensure a regular intake of unsweetened dairy products, such as yogurt, milk as well as cheese if their usual intake is less than 3 servings/day. There is little evidence showing harm with high-fat dairy intake, if it is within total daily caloric intake. Dietitians can use this as an opportunity to further educate their patients on how fats, particularly from dairy, can fit into their healthy diet. Because the glycemic index of dairy foods is low (<55), they are a good option for individuals looking to manage their blood glucose levels. It is important to note that research has not included alternative dairy beverages such as soy, nut and rice beverages.

For individuals with T2D, some dairy products will need to be counted as a carbohydrate food (ie, milk and yogurt), while others (cheese) is considered a protein food. These foods are also excellent sources of vitamins and minerals. It is imperative for dietitians to explain the importance of a high-quality meal plan to individuals at risk for or who already have T2D. For example, a breakfast including whole-milk yogurt with fruit contains fat and protein that may provide enough satiety to keep an individual satisfied until lunchtime, thereby helping that individual to avoid eating a less healthful morning snack. A dietary strategy may start by assessing an individual's usual dairy consumption and overall diet quality. If the individual is agreeable to changing their dairy intake, providing

guidance on how to add or increase dairy products as part of other healthy dietary changes may be beneficial, particularly if that individual is at risk for developing T2D.

5. Summary

Meta-analyses and systematic review of the cohort studies suggest possible decreased risk of T2D with dairy consumption, which might be attributed primarily to a low-fat dairy, yogurt and possibly to cheese. The findings of these observational studies were supported by several meta-analyses, although most of them included the same cohort studies. Dairy products, as part of a healthy diet plan, likely do not have harmful effects on glycemic parameters. The potential benefits of dairy consumption on plasma glucose levels, insulin level, and insulin sensitivity measures warrant future investigation. There is a need for long-term, well-designed clinical trials to evaluate the effect of dairy products on other diabetes-related outcomes. There is also need for randomized clinical studies that differentiate the impact of low- versus high-fat dairy intake on metabolic syndrome progression and type 2 diabetes development.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dsx.2019.07.064.

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