International Dairy Journal 122 (2021) 105159

Contents lists available at ScienceDirect

International Dairy Journal

journal homepage: www.elsevier.com/locate/idairyj

Higher yogurt intake is associated with lower blood pressure in hypertensive individuals: Cross-sectional findings from the Maine–Syracuse longitudinal study

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ARTICLE INFO

Article history:
Received 7 April 2020
Received in revised form
7 July 2021
Accepted 7 July 2021
Available online 16 July 2021

ABSTRACT

Associations between fermented dairy products and blood pressure are unclear. The current study therefore examined the association between yogurt and blood pressure in hypertensive and non-hypertensive individuals. Cross-sectional analyses were undertaken on 915 community-dwelling adults from the Maine–Syracuse Longitudinal Study. Habitual yogurt consumption was measured using a food frequency questionnaire. The primary outcomes were systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), and pulse pressure. Secondary outcomes included BMI (kg m^{-2}), total cholesterol (mg dL^{-1}), glucose (mg dL^{-1}), HDL (mg dL^{-1}), LDL (mg dL^{-1}), triglycerides (mg dL^{-1}), and plasma homocysteine (μmol L^{-1}). Multivariable regression analyses revealed significant inverse associations between yogurt and both SBP ($p < 0.05$) and MAP ($p < 0.05$) in hypertensive ($n = 564$) but not non-hypertensive participants ($n = 351$). Future observational and intervention studies should continue to focus on at-risk individuals to examine the potential benefits of yogurt.

1. Introduction

Cardiovascular diseases (CVDs) are the leading cause of death worldwide (WHO, 2014). As the population ages, the incidence CVD is expected to increase (Heidenreich et al., 2011). To reduce the burden of CVD, attention is being directed towards long-term interventions targeting modifiable risk factors.

High blood pressure is the leading modifiable risk factor for CVD (WHO, 2011). Recent investigations, including an umbrella review of meta-analyses, provide convincing evidence of the association between total dairy intake and decreased risk of elevated blood pressure, CVD, and CVD mortality (Crichton, Elias, Dore, Abhayaratna, & Robbins, 2012; Drouin-Chartier et al., 2016; Godos et al., 2020; Guo et al., 2017; Lee, Lee, & Kim, 2018; Qin et al., 2015; Wang, Fox, Troy, Mckeown, & Jacques, 2015).

Dairy foods contain a range of micronutrients, including calcium, magnesium, and potassium, which are involved in the regulation of blood pressure (Chrysant & Chrysant, 2013). Additionally, probiotic fermented dairy products, such as yogurt, contain bacteria which lead to enzymatic release of antihypertensive peptides (Rai, Sanjukta, & Jeyaram, 2017). Therefore, yogurt may have a greater cardiovascular benefit than non-fermented dairy products. A meta-analysis of short-term clinical trials reported that probiotic fermented milk products were associated with a reduction of 3 mmHg in systolic blood pressure and 1 mmHg in diastolic blood pressure when compared with a milk-based reference group (Dong et al., 2013). The meta-analysis also found that the association was marginally greater in hypertensive individuals.

An investigation by Buendia et al. (2018a) employing The Nurses' Health Study cohort reported an association between yogurt intake and risk of myocardial infarction in persons with hypertension. The authors observed that hypertensive individuals consuming ≥2 servings of yogurt per week experienced 17–21% lower risk of developing CVD than those consuming <1 serving of yogurt per month. However, the Nurses' Health Study relied upon self-report of hypertension and did not include blood pressure outcomes. It is therefore unknown whether improvements to blood pressure were responsible for reductions in CVD risk. Moreover, the study did not include a reference group of individuals with normal

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https://doi.org/10.1016/j.idairyj.2021.105159
0958-6946/

blood pressure. Thus, it is not clear whether yogurt was beneficial to hypertensive individuals specifically, or whether yogurt could be beneficial regardless of the disease process. In another study, Buendia et al. (2018b) also reported that higher dairy consumption, especially in the form of yogurt, was associated with lower risk of new cases of hypertension (incident hypertension). While this is an important longitudinal study, the authors, as in the first study (Buendia et al., 2018a) employed self-report of hypertension (Buendia et al., 2018b). In the current study, we aimed to extend these findings of the potential benefit of habitual yogurt consumption by examining the association between yogurt intake and blood pressure measures in both hypertensive and non-hypertensive individuals.

To extend the findings of The Nurses' Health Study investigation (Buendia et al., 2018a, b) we utilised objective measures of blood pressure and hypertension. As a secondary research question, we also aimed to evaluate whether yogurt intake is associated with other indicators of cardiovascular health, such as hypertriglyceridemia, low HDL cholesterol, BMI, and elevated fasting plasma glucose. Based on previous studies of fermented dairy food intake and cardiovascular outcomes (Buendia et al., 2018a, b; Dong et al., 2013), we hypothesized that yogurt consumption would be inversely associated with blood pressure in hypertensive but not non-hypertensive individuals. We predicted that the restricted range of blood pressure values in non-hypertensive individuals would be unlikely to change as a function of yogurt intake.

2. Methods

2.1. Participants

Data were collected from participants enrolled in the Maine–Syracuse Longitudinal Study (MSLS), a multi-wave longitudinal cohort study of cardiovascular and cognitive function (http://MSLSperspectives.net). Use of the MSLS data set for the current study was approved by the University of Maine Institutional Review Board. Written informed consent was obtained from all subjects upon enrollment. A description of the study and a list of published papers can be found at http://MSLSperspective.net.

Community-dwelling adults living in Central New York were recruited through public advertisements in local print media, flyers, posters, and community presentations for studies of aging and hypertension. Participant data were collected approximately every five years from 1975 (Wave 1) to 2010 (Wave 7). The current cross-sectional investigation has drawn data from Wave 6, collected between 2001 and 2006, when dietary measures and data on multiple cardiovascular risk factors were collected. Due to a change in grant-related objectives in Wave 7 (funding for the nutrition aspect of the MSLS studies ended after Wave 6), we limited our analyses to only include participants in Wave 6.

Participants were excluded from this analysis for the following reasons: acute stroke ($n = 28$), probable dementia ($n = 8$), renal dialysis treatment ($n = 5$), inability to read English ($n = 1$), prior alcohol abuse ($n = 1$), and incomplete data for any of the nutrition and health variables included in this study. This left a sample of 915 participants from Wave 6 with complete demographic, nutrition, and health data for these reported variables. Acute stroke was defined as an acute onset focal neurological deficit persisting for more than 24 h and was based on self-report confirmed by hospitalization, medical records confirmed by record review, or both. Probable dementia was determined by committee using the National Institute of Neurological and Communicative Diseases and Stroke/Alzheimer's Disease and Related Disorders (NINCDS-ADRA) Alzheimer's criteria, along with MSLS cognition data, diagnostic records, and medical review data. Diagnosis or probable dementia were made by intensive case review by a multidisciplinary team representing medicine and psychology, including geriatrics and gerontology.

2.2. Procedure

At Wave 6, participants completed the Nutrition and Health Questionnaire (Kaaks & Riboli, 1997) in the two weeks preceding their laboratory visit. After an overnight fast, participants underwent a blood draw by a licensed phlebotomist. After a light breakfast, including decaffeinated tea or coffee, participants underwent a physical examination, measures of anthropometry and blood pressure and a battery of cognitive tests (not employed in the present study).

2.3. Blood pressure measurement

For the current study blood pressure parameters were the primary outcome of interest. Systolic blood pressure (SBP), diastolic blood pressure (DBP), pulse pressure, and mean arterial pressure (MAP) were measured as in all previous waves of the MSLS. We employed a clinical grade automated blood pressure monitor (GE DINAMAP 100DPC-120XEN, GE Healthcare). Blood pressure measurements were taken from the right arm after supine rest of 15 min, using the optimal cuff size for each participant. Five measurements were taken for each reclining, sitting, and standing positions, with a 5-min rest period between each set of measures. Hypertension was defined as systolic blood pressure $\geq$140 mmHg or diastolic blood pressure $\geq$90 mmHg, or the use of antihypertensive medications.

2.4. Secondary outcomes

Secondary outcomes included indices of cardiovascular risk: BMI (kg m^{-2}), total cholesterol (mg dL^{-1}), HDL (mg dL^{-1}), LDL (mg dL^{-1}), triglycerides (mg dL^{-1}), glucose (mg dL^{-1}) and plasma homocysteine (μmol L^{-1}). Standard assay methods are described elsewhere (Elias et al., 2006, 2008).

Diabetes mellitus was determined through self-report confirmed either by a diagnosis in the endocrine diabetes clinic at the New York State University, or a fasting blood glucose level $\geq$126 mg dL^{-1}. Prevalent CVD was determined through self-reported history and was defined as coronary artery disease, myocardial infarction, heart failure, transient ischemic attack, or angina pectoris, confirmed by medical records.

2.5. Assessment of yogurt intake

Dietary intake data was collected at Wave 6 using the Nutrition and Health Questionnaire (NHQ). The NHQ asks participants to indicate how frequently they consume particular foods including fruit, vegetables, meat, fish, eggs, breads, cereals, rice and pasta, legumes, dairy foods, nuts, other snack-type foods, and beverages including alcohol. For each food participants answered whether their habitual consumption was never, seldom, once per week, 2–4 times per week, 5–6 times per week, or one or more times per day. Average weekly and daily food intakes were estimated by converting response options to the median score. For example, 2–4 times per week was estimated as 3 times per week. The item 'yogurt and dairy desserts' was used to determine habitual intake of yogurt. As dairy desserts likely have a different nutrient composition to yogurt, our statistical analysis (described below) was designed to remove the effect of dairy desserts.

2.6. Statistical analysis

All statistical analyses were performed in R (R Core Team, 2019). Analysis of variance (ANOVA) analyses were performed using the Car package (Fox & Weisberg, 2019). Preliminary analyses were conducted to compare demographic characteristics of participants across yogurt intake categories. One-way ANOVAs were used to compare continuous variables and Chi-square tests of independence were used to compare differences between groups for categorical variables.

For the primary analysis, separate multiple linear regressions were used to assess the relationship between yogurt intake and blood pressure variables. For these analyses, yogurt intake was treated as a continuous variable. To adjust for the effect of ‘dairy desserts’ in the survey item ‘yogurt and dairy desserts’, cottage cheese (servings per day), cakes/pudding/pie (servings per day), ice cream (servings per day) were included as covariates. Additional covariates were informed by The Nurses' Health Study investigation (Buendia et al., 2018a) and previous MSLS analyses (Crichton et al., 2012), and were included if a significant association ($p < 0.05$) was reported in Table 1 or 2. Covariates were organized into five sets (models) as follows:

Model 1: no covariates included (yogurt and dairy desserts only; never, < 1 time per week, 1 time per week, 2–4 times per week, 5–6 times per week, ≥ 1 time per day);
Model 2: model 1 + cottage cheese (servings per day), cakes/pudding/pie (servings per day), ice cream (servings per day);
Model 3: model 2 + age, gender, education;
Model 4: model 3 + recommended food score (RFS), physical activity (MET hours), alcohol (g wk^{-1}), total intake (servings per day), cigarettes (per week);
Model 5: model 4 + diabetes (yes/no), tHCY (μmol L^{-1}), antihypertensive medications (yes/no), triglycerides (mg dL^{-1}), glucose (mg dL^{-1}), HDL (mg dL^{-1}), BMI (kg m^{-2}), cholesterol medications (yes/no).

The same models were used to examine blood pressure in hypertensive and non-hypertensive participants separately, and to analyze secondary outcomes. Our focus was on blood pressure as an outcome variable and thus we do not offer specific hypotheses as to yogurt and these outcomes, but we report them are risk factors that are related to hypertension and thus may be associated with yogurt consumption. The use of antihypertensive medication was not included in Model 5 for non-hypertensive participants. Non-BP cardiovascular risk factors, such as plasma homocysteine, were removed from the model when assessing their independent association with yogurt. For all analyses, a p-value of <0.05 was considered statistically significant.

2.6.1. Sensitivity analysis with the new definition of blood pressure

The American Heart Association has recently updated the criterion for hypertension to SBP ≥130 mmHg or DBP ≥80 mmHg (Arnett et al., 2019). We therefore performed a sensitivity analysis according to this new definition. For primary analyses, we retained the previous definition of hypertension (i.e., 140/90) to reflect the longstanding and traditional definition of hypertension.

3. Results

Self-reported intake of yogurt consumption, demographic variables and health characteristics of the full sample (n = 915) are reported in Tables 1 and 2. Approximately one half of the sample either reported never consuming yogurt (28.7%) or consuming yogurt less than once per week (25.4%). The remaining participants reported consuming yogurt once per week (16.5%), 2–4 times per week (19.0%), 5–6 times per week (6.7%), or one or more times per day (3.7%). To simplify the presentation in Tables 1 and 2, the level of yogurt intake was consolidated into three categories. After consolidating, approximately one quarter of the sample (28.7%) reported never consuming yogurt. Over one third (41.9%) reported consuming yogurt less than or equal to once per week, and the remaining participants (29.4%) reported consuming yogurt twice or more per week.

Participants who consumed higher intakes of yogurt were younger, had more years of education and were more likely to be female ($p < 0.05$). Participants who consumed more yogurt also had lower SBP, lower DBP, lower pulse pressure, lower MAP, higher HDL cholesterol, lower triglycerides, lower fasting glucose, lower

Table 1
Demographic and health characteristics for whole sample (n = 915) according to level of yogurt intake.[a]

Parameter	Yogurt intake categories								P
	All (n = 915)		Never (n = 263)		≤week^{-1} (n = 383)		≥2/week^{-1} (n = 269)		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Age (years)	62.1	12.8	63.9	12.9	61.1	12.4	61.7	13.0	<0.05
Education (years)	14.7	2.7	14.2	2.6	14.8	2.7	15.0	2.7	<0.01
Mean SBP (mmHG)	130.8	21.8	136.0	22.3	130.6	21.8	126.1	20.2	<0.01
Mean DBP (mmHG)	70.4	10.0	72.6	10.7	70.5	9.6	68.1	9.4	<0.01
Pulse Pressure (mmHg)	60.5	17.0	63.4	18.0	60.1	17.2	58.1	15.5	<0.01
MAP (mmHg)	90.6	12.7	93.7	13.0	90.5	12.4	87.4	11.9	<0.01
Total cholesterol (mg dL^{-1})	200.4	39.1	200.6	39.3	199.2	40.8	202.1	36.2	0.66
LDL (mmol L^{-1})	3.1	0.9	3.1	0.9	3.1	0.9	3.2	0.8	0.70
HDL (mmol L^{-1})	1.39	0.4	1.36	0.4	1.38	0.4	1.44	0.4	<0.05
Triglycerides (mg dL^{-1})	130.7	69.7	139.4	71.0	131.3	70.7	121.5	66.1	<0.05
Glucose (mg dL^{-1})	98.57	27.9	103.3	36.2	98.2	26.3	94.5	18.5	<0.01
tHCY (μmol L^{-1})	9.9	3.6	11.0	4.5	9.5	3.1	9.4	3.2	<0.01
BMI (kg m^{-2})	29.4	6.0	29.9	5.7	29.6	6.5	28.6	5.3	<0.05
Physical Activity (MET hours per week)	20.1	26.5	15.6	19.4	21.3	26.4	22.8	31.7	<0.01
Total energy intake (serves per day)	14.7	4.5	14.4	4.8	14.2	4.4	15.8	4.2	<0.01
Alcohol intake (g wk^{-1})	36.0	69.6	52.3	90.9	32.4	67.2	25.0	40.1	<0.01
Cigarettes per week	7.5	31.1	11.8	39.1	6.3	29.4	5.0	23.2	<0.05
Recommended food score	10.7	3.0	9.6	3.1	10.8	2.8	11.7	2.7	<0.01

[a] One-way ANOVAs were used to compare continuous variables and Chi-square tests of independence were used to compare categorical variables.

Table 2
Demographic and health characteristics for whole sample (n = 915) according to level of yogurt intake.[a]

Parameter	Yogurt intake categories				
	All (n = 915)	Never (n = 263)	≤week^{-1} (n = 383)	≥2/week^{-1} (n = 269)	*P*
	n (%)	n (%)	n (%)	n (%)	
Gender					<0.01
male	369 (40)	145 (55)	154 (40)	70 (26)	
Female	546 (60)	118 (45)	229 (60)	199 (74)	
Ethnicity					0.34
African American	68 (7)	18 (7)	34 (9)	16 (6)	
Other	847 (93)	245 (93)	349 (91)	253 (94)	
Hypertension	564 (62)	192 (73)	234 (61)	138 (51)	<0.01
Antihypertensive Meds	459 (50)	150 (57)	200 (52)	109 (41)	<0.01
Diabetes	113 (12)	41 (16)	50 (13)	22 (8)	<0.05
Diabetes Meds	94 (10)	36 (14)	38 (10)	20 (7)	0.06
Cardiovascular disease	137 (15)	47 (18)	54 (14)	36 (13)	0.29
Cholesterol Meds	254 (28)	90 (34)	98 (26)	66 (25)	<0.05

[a] One-way ANOVAs were used to compare continuous variables and Chi-square tests of independence were used to compare categorical variables.

plasma homocysteine, lower BMI, consumed more energy, exercised more, consumed less alcohol, smoked fewer cigarettes, and were less likely to have hypertension and diabetes (all $p < 0.05$). Across the whole sample, SBP ranged from 81 mmHg to 226 mmHg. DBP ranged from 45 mmHg to 128 mmHg. Within hypertensives (n = 564) SBP ranged from 87 mmHg to 226 mmHg and DBP ranged from 46 mmHg to 128 mmHg. Within non-hypertensives (n = 351) SBP ranged from 81 mmHg to 140 mmHg and DBP ranged from 45 mmHg to 90 mmHg.

3.1. Individuals with hypertension

Table 3 presents the association between yogurt intake and the blood pressure variables for hypertensive individuals. After controlling for all covariates (model 5), significant inverse linear trends were observed for SBP ($b = -1.44$, CI = [−2.71, −0.17], $p < 0.05$) and MAP ($b = -0.89$, CI = [−1.65, −0.14], $p < 0.05$) but not for DBP ($b = -0.62$, CI = [−1.25, 0.01], $p = 0.05$) nor pulse pressure ($b = -0.83$, CI = [−1.84, 0.19], $p = 0.11$).

3.2. Non-hypertensive individuals

Table 4 presents the association between yogurt intake and blood pressure for non-hypertensive individuals. No significant differences were observed across groups for SBP, DBP, pulse pressure, or MAP before and after adjusting for covariates (all $p > 0.05$).

3.3. Non-blood pressure parameters

Table 5 summarizes findings for non-blood pressure parameters related to yogurt consumption in hypertensive individuals. No significant associations were observed between yogurt intake and

Table 3
Cross–sectional associations between yogurt and blood pressure in sample of persons (n = 564) with hypertension.[a]

Parameter	Model	*b*	95% CI		*β*	*R*^{2}	*p*
			Lower	Upper			
Systolic blood pressure (mmHg)	1	−1.83	−3.09	−0.58	−2.51	0.01	<0.01
	2	−1.90	−3.18	−0.62	−2.60	0.02	<0.01
	3	−1.69	−2.97	−0.41	−2.32	0.08	<0.05
	4	−1.49	−2.83	−0.15	−2.05	0.09	<0.05
	5	−1.44	−2.71	−0.17	−1.98	0.21	<0.05
Diastolic blood pressure (mmHg)	1	−1.08	−1.68	−0.48	−1.48	0.02	<0.01
	2	−0.96	−1.57	−0.35	−1.31	0.03	<0.01
	3	−0.76	−1.37	−0.15	−1.04	0.08	<0.05
	4	−0.56	−1.20	0.08	−0.77	0.11	0.09
	5	−0.62	−1.25	0.01	−0.85	0.16	0.05
Pulse pressure (mmHg)	1	−0.75	−1.80	0.30	−1.03	0.00	0.16
	2	−0.94	−2.00	0.12	−1.29	0.02	0.08
	3	−0.93	−1.94	0.07	−1.28	0.17	0.07
	4	−0.93	−2.00	0.13	−1.28	0.18	0.08
	5	−0.83	−1.84	0.19	−1.13	0.26	0.11
Mean arterial pressure (mmHg)	1	−1.33	−2.05	−0.61	−1.83	0.02	<0.01
	2	−1.27	−2.01	−0.53	−1.74	0.03	<0.01
	3	1.07	−1.82	−0.32	−1.46	0.04	<0.05
	4	−0.87	−1.66	−0.08	−1.19	0.06	<0.05
	5	−0.89	−1.65	−0.14	−1.22	0.16	<0.05

[a] Models are: 1, yogurt (never, < 1 time per week, 1 time per week, 2–4 times per week, 5–6 times per week, ≥ 1 time per day); 2, model 1 + cottage cheese (servings per day), cakes/pudding/pie (servings per day), ice cream (servings per day); 3, model 2 + age, gender, education; 4, model 3 + recommended food score (RFS), physical activity (MET hours), alcohol (g wk^{-1}), total intake (serves per day), cigarettes (per week); 5, model 4 + diabetes (yes/no), tHCY (μmol L^{-1}), antihypertensive medications (yes/no), triglycerides (mg dL^{-1}), glucose (mg dL^{-1}), HDL (mg dL^{-1}), BMI (kg m^{-2}), cholesterol medication (yes/no). R^2 value represents overall model R^2; *p*-value is for the effect of yogurt (not the overall model).

Table 4
Cross−sectional associations between yogurt and blood pressure in sample of persons (n = 351) with normal blood pressure.[a]

Parameter	Model	*b*	95% CI		*β*	R^2	*p*
			Lower	Upper			
Systolic blood pressure (mmHg)	1	−0.57	−1.51	0.37	−0.83	0.00	0.23
	2	−0.59	−1.54	0.35	−0.87	0.03	0.22
	3	0.12	−0.78	1.01	0.17	0.20	0.80
	4	0.41	−0.51	1.33	0.60	0.22	0.38
	5	0.73	−0.17	1.62	1.07	0.30	0.11
Diastolic blood pressure (mmHg)	1	−0.45	−1.04	0.15	−0.66	0.01	0.14
	2	−0.37	−0.98	0.23	−0.54	0.02	0.23
	3	0.02	−0.58	0.62	0.03	0.10	0.95
	4	0.08	−0.55	0.70	0.11	0.12	0.81
	5	0.22	−0.40	0.84	0.33	0.16	0.48
Pulse pressure (mmHg)	1	−0.12	−0.80	0.57	−0.17	0.00	0.73
	2	−0.22	−0.91	0.46	−0.33	0.04	0.52
	3	0.10	−0.52	0.71	0.14	0.28	0.76
	4	0.33	−0.29	0.96	0.49	0.32	0.30
	5	0.50	−0.12	1.12	0.74	0.37	0.11
Mean arterial pressure (mmHg)	1	−0.49	−1.14	0.16	−0.72	0.01	0.14
	2	−0.45	−1.11	0.22	−0.65	0.02	0.19
	3	0.05	−0.60	0.70	0.07	0.12	0.88
	4	0.19	−0.49	0.86	0.28	0.14	0.59
	5	0.39	−0.27	1.05	0.58	0.21	0.24

[a] Models are: 1, yogurt (never, < 1 time per week, 1 time per week, 2−4 times per week, 5−6 times per week, ≥ 1 time per day); 2, model 1 + cottage cheese (servings per day), cakes/pudding/pie (servings per day), ice cream (servings per day); 3, model 2 + age, gender, education; 4, model 3 + recommended food score (RFS), physical activity (MET hours), alcohol (g wk^{-1}), total intake (serves per day), cigarettes (per week); 5, model 4 + diabetes (yes/no), tHCY (μmol L^{-1}), antihypertensive medications (yes/no), triglycerides (mg dL^{-1}), glucose (mg dL^{-1}), HDL (mg dL^{-1}), BMI (kg m^{-2}), cholesterol medication (yes/no). R^2 value represents overall model R^2; *p*-value is for the effect of yogurt (not the overall model).

Table 5
Cross−sectional associations between yogurt and non-blood pressure parameters in sample of persons (n = 564) with hypertension.[a]

Parameter	Model	*b*	95% CI		*β*	R^2	*p*
			Lower	Upper			
BMI (kg m^{-2})***	5	−0.10	−0.47	0.27	−0.14	0.26	0.59
Cholesterol (mg dL^{-1})	5	−0.16	−2.14	1.82	−0.22	0.45	0.88
HDL (mg dL^{-1})***	5	−0.01	−0.04	0.01	−0.02	0.36	0.18
LDL (mg dL^{-1})	5	0.00	−0.05	0.05	−0.00	0.22	0.89
Triglycerides (mg dL^{-1})***	5	−1.07	−5.71	3.57	−1.47	0.17	0.65
Glucose (mg dL^{-1})***	5	−1.19	−2.85	0.48	−1.62	0.40	0.16
tHCY (μmol L^{-1})***	5	−0.08	−0.31	0.16	−0.11	0.17	0.51

[a] Models are: 1, yogurt (never, < 1 time per week, 1 time per week, 2−4 times per week, 5−6 times per week, ≥ 1 time per day); 2, model 1 + cottage cheese (servings per day), cakes/pudding/pie (servings per day), ice cream (servings per day); 3, model 2 + age, gender, education; 4, model 3 + recommended food score (RFS), physical activity (MET hours), alcohol (g wk^{-1}), total intake (serves per day), cigarettes (per week); 5, model 4 + diabetes (yes/no), tHCY (μmol L^{-1}), antihypertensive medications (yes/no), triglycerides (mg dL^{-1}), glucose (mg dL^{-1}), HDL (mg dL^{-1}), BMI (kg m^{-2}), cholesterol medication (yes/no). R^2 value represents overall model R^2; *p*-value is for the effect of yogurt (not the overall model); measures for BMI, HDL, triglycerides, glucose and tHCY not included in the model when the DV.

BMI, total cholesterol, HDL, LDL, triglycerides, fasting glucose, or tHCY (all $p > 0.05$). Table 6 summarizes findings for non-blood pressure parameters in non-hypertensive individuals. In the non-hypertensive sample, no significant associations were observed between yogurt intake and BMI, total cholesterol, HDL, LDL, triglycerides, fasting glucose, or tHCY (all $p > 0.05$).

3.4. Sensitivity analysis

Our sensitivity analysis based on the updated definition of hypertension as (SBP ≥ 130 mmHg or DBP ≥ 80 mmHg) revealed essentially the same pattern results as in the primary analysis (Supplementary material Tables S1 and S2). Significant inverse associations were observed for SBP, DBP, and MAP. The most notable change was that the relationship between yogurt and DBP was significant in model 5 when using the updated definition ($p < 0.05$) but not the older definition ($p = 0.05$). Sensitivity analyses were not performed for non-hypertensive individuals due to the limited sample size.

Table 6
Cross−sectional associations between yogurt and non-blood pressure parameters in sample of persons (n = 351) without hypertension.[a]

Parameter	Model	*b*	95% CI		*β*	R^2	*p*
			Lower	Upper			
BMI (kg m^{-2})	5	−0.21	−0.56	0.14	−0.31	0.23	0.24
Cholesterol (mg dL^{-1})	5	−0.59	−3.06	1.87	−0.87	0.37	0.64
HDL (mg dL^{-1})	5	0.01	−0.02	0.03	0.01	0.40	0.51
LDL (mg dL^{-1})	5	−0.02	−0.08	0.05	−0.02	0.14	0.63
Triglycerides (mg dL^{-1})	5	−0.98	−4.91	2.96	−1.44	0.25	0.62
Glucose (mg dL^{-1})	5	−0.56	−1.62	0.49	−0.83	0.53	0.29
tHCY (μmol L^{-1})	5	−0.06	−0.30	0.17	−0.09	0.19	0.59

[a] Models are: 1, yogurt (never, < 1 time per week, 1 time per week, 2−4 times per week, 5−6 times per week, ≥ 1 time per day); 2, model 1 + cottage cheese (servings per day), cakes/pudding/pie (servings per day), ice cream (servings per day); 3, model 2 + age, gender, education; 4, model 3 + recommended food score (RFS), physical activity (MET hours), alcohol (g wk^{-1}), total intake (serves per day), cigarettes (per week); 5, model 4 + diabetes (yes/no), tHCY (μmol L^{-1}), antihypertensive medications (yes/no), triglycerides (mg dL^{-1}), glucose (mg dL^{-1}), HDL (mg dL^{-1}), BMI (kg m^{-2}), cholesterol medication (yes/no). R^2 value represents overall model R^2; *p*-value is for the effect of yogurt (not the overall model); measures for BMI, HDL, triglycerides, glucose and tHCY not included in the model when the DV.

4. Discussion

The current study examined the association between yogurt intake, blood pressure and cardiovascular risk factors commonly associated with hypertension. Higher yogurt consumption was associated with modestly lower SBP, DBP (significant when using the updated definition of hypertension), and MAP in hypertensive but not non-hypertensive adults. This was true with adjustment of demographic, cardiovascular, and lifestyle factors.

Our study builds upon previous research reporting associations between yogurt consumption and health outcomes in individuals at risk of CVD. An investigation of The Nurses' Health Study cohort demonstrated that higher yogurt consumption was associated with reduced risk of CVD in hypertensive individuals (Buendia et al., 2018a). Our findings provide new evidence, demonstrating that the consumption of yogurt is related to positive blood pressure outcomes for hypertensive but not non-hypertensive individuals.

We did not find evidence of an association between yogurt consumption and blood pressure in non-hypertensive individuals. We propose that higher blood pressure is more likely to respond to dietary factors with the potential to improve endothelial health and function. On the other hand, normal blood pressure is indicative of healthy endothelial functioning and blood pressure regulation. It is therefore unlikely that yogurt consumption would be capable of improving blood pressure if it is not already elevated. Blood pressure is also susceptible to a 'floor effect', meaning that it cannot decrease past a certain range. Further, the range of BP values was narrower for normal blood pressure individuals, restricting the potential magnitude of change.

The mechanism through which yogurt influences blood pressure is theorized to be multimodal. Yogurt contains bioactive nutrients, including calcium, whey protein and peptides, and lactic acid bacteria, with independent and combined effects on a range of physiological functions (Fernandez, Panahi, Daniel, Tremblay, & Marette, 2017). Calcium homeostasis is closely linked with blood pressure and a calcium-deficient diet leads to a hormonal response aimed at preserving calcium within cells. The reactionary influx of calcium within vascular cells then promotes contraction and increases resistance, indirectly promoting hypertension (Zemel, 2001). By providing additional dietary calcium, yogurt has the potential to reverse this process. Further, milk fermentation and probiotic bacteria found within yogurt lead to the production of angiotensin converting enzyme inhibitory (ACE-I) peptides, which have antihypertensive properties (Rai et al., 2017). Buendia et al., 2018a, b hypothesized that yogurt may work its positive effects on blood pressure via casein-derived peptides. They further point out that these substances lower blood pressure in humans and animals due to the renal angiotensin system. This hypothesis gains support from a review of the literature (Xu, Qin, Wang, Li, & Chang, 2008).

Recently, Wade et al. (2018) reported that a Mediterranean diet with 3 daily serves of dairy foods, including yogurt, led to improvements in systolic blood pressure in a sample at risk of CVD. The Mediterranean diet and the Dietary Approaches to Stop Hypertension (DASH) diet are high in fruits, vegetables and fish (Appel et al., 1997; Davis, Bryan, Hodgson, & Murphy, 2015). Due to synergistic relationships between foods, yogurt consumed within a Mediterranean or DASH diet may have greater benefit than when consumed within a diet low in processed and discretionary foods. Future studies should continue to evaluate the benefit of yogurt in conjunction with other healthy foods, to determine whether a more pronounced reduction in blood pressure will be seen.

The current study has several limitations that should be taken into consideration. Firstly, the cross-sectional design limits our ability to infer causative relationships between yogurt and health outcomes. Further, we are unable to make conclusions regarding change over time. Secondly, the NHQ used to collect dietary intake data relies on self-report and has a limited number of items related to yogurt consumption, which likely limited the accuracy of our results. Participants were asked 'how often' they consumed yogurt and dairy desserts, but were not required to specify serving size, which is likely to differ between individuals. Moreover, participants were not required to specify the fat or sugar content of yogurt consumed, which reduced our capacity for additional analyses. Thirdly, our sample of hypertensive adults ($n = 564$) was larger than our sample of non-hypertensive adults ($n = 351$). While a smaller number of subjects could account for non-significant differences, it is clear from the confidence intervals (see Table 3) that the associations between yogurt and blood pressure values were not approaching statistical significance. Further, our data indicate less variability in SBP across yogurt intake categories for non-hypertensive individuals compared with hypertensive individuals.

Notwithstanding these limitations, our study offers valuable insight into the association between yogurt and blood pressure outcomes. Based on model 5 for SBP, increasing yogurt consumption by one level corresponds to a 1.44 mmHg reduction in SBP. While this may seem small, a change in blood pressure of this magnitude could lead to significant differences at the population level. Indeed, a meta-analysis examining the relationship between blood pressure and vascular mortality reported that a reduction of 2 mmHg in SBP translates to 10% lower risk of stroke and cardiovascular mortality (Prospective Studies Collaboration, 2002).

5. Conclusions

The current study has provided evidence for the inverse association between yogurt consumption and blood pressure, adjusting for demographic, lifestyle, cardiovascular, and dietary variables. Our findings suggest that the relationship between yogurt consumption and blood pressure is beneficial for individuals with hypertension. While limited to a cross–sectional association, these findings provide further support for the potential cardiovascular benefits of yogurt consumption in hypertensive individuals and highlight the need to target at-risk individuals in future intervention studies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The Maine Syracuse Longitudinal Study was supported by research grants R01HL067358, and R01HL081290 from the National Heart, Lung and Blood Institute, National Institutes of Health (USA), and research grant R01AG03055 from the National Institute on Aging, National Institutes of Health (USA). The funding sources had no involvement in the study design, data collection, writing or decision to submit for publication. ATW was supported by an Australian Government Research Training Program Scholarship.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.idairyj.2021.105159.

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