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Original article

Diet patterns in an ethnically diverse pediatric population with celiac disease and chronic gastrointestinal complaints

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SUMMARY

Introduction: Celiac disease (CD) is an autoimmune disease requiring lifelong adherence to the gluten-free diet (GFD). The GFD has significant nutritional limitations which may result in poor diet quality (DQ). We hypothesized that biopsy-proven children with CD (CCD) would have dietary patterns characterized by high saturated fat/simple sugar intake with a low micronutrient density contributing to lower DQ when compared to children with mild-gastrointestinal complaints (GI-CON). In addition, we hypothesized that ethnicity may further impact DQ.
Methods: Socio-demographic (age, CD duration, parent/child ethnicity, education), household characteristics, anthropometric, dietary intake (24-h recalls), gastrointestinal pain and adherence was collected in CCD (n = 243) and GI-CON (n = 148). Dietary patterns were determined using k-mean Cluster Analysis.
Results: GI-CON had significantly lower DQ than CCD ($p < 0.001$). Most CCD and GI-CON (>80%) had dietary patterns characterized by1) *Western Diet* (Cluster 1: %BMR: 110–150, low DQ, high fat, moderate CHO, high sodium) and 2) *High Fat-Western Diet* (Cluster 2: %BMR:130–150, low DQ, high Fat, high processed meats, high fat dairy products, CHO. Fewer children (<20%) had *Prudent*, *Lower Fat/High Carbohydrate dietary patterns* (% BMR:100–150, higher DQ, lower fat/sodium, higher CHO) with a greater proportion of non-Caucasian CCD consuming a Prudent dietary pattern. Seventy-seven percent and 37.5% of CCD and GI-CON, respectively, did not meet estimated average requirements for folate ($p < 0.001$).
Conclusions: CCD and GI-CON have predominantly Western dietary patterns with low DQ, particularly GI-CON. Non-caucasian CCD consume more prudent dietary patterns with higher DQ. Nutrition education is warranted to ensure optimal DQ in children with chronic gastrointestinal diseases.

1. Introduction

The gluten free diet (GFD) has become increasingly popular, with over 29% of the Canadian public or approximately 10 million Canadians consuming the diet [1,2]. This has been attributed to the GFD's perceived health benefits and incidence of food intolerance (wheat, gluten) by the general public. The GFD is medically indicated for the treatment of Celiac Disease (CD), an autoimmune disease whereby the consumption of gluten triggers intestinal villous atrophy. While perceived as a healthy diet alternative by many, those following a GFD may rely on processed and packaged gluten-free (GF) food which are often higher in simple sugars, glycemic index (GI), glycemic load (GL) and saturated fat than their gluten containing counter-parts [3–6]. In addition, lack of uniform policies regarding nutrient fortification in GF grains in Canada often

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place individuals consuming the GFD at risk for developing sub-optimal micronutrient intake [6,7]. The nutritional quality in a GFD may be even more impaired when combined with other diet patterns, such as plant-based diets or lactose-restricted diets. Such restricted diets are more common in ethnically diverse populations and may further compound the potential nutritional limitations of the GFD. To date no study has examined the nutritional consequences of a GFD in an ethnically diverse population.

This study describes the dietary patterns of an ethnically diverse population of children with celiac disease (CCD) on the GFD and children with mild chronic gastrointestinal complaints (GI-CON). We hypothesized that CCD would have dietary patterns characterized by high saturated fat/high simple sugar intake with a low micronutrient density contributing to overall lower DQ when compared to intake in GI-CON.

2. Methods

A cross-sectional multicenter study was conducted at three Canadian sites: Stollery Children's Hospital (Edmonton, Alberta), The Hospital for Sick Children (Toronto, Ontario), and McMaster Children's Hospital (Hamilton, Ontario). CCD (2–18 years) with biopsy proven CD (n = 243) and youth (2–18 years; n = 148) with minor gastrointestinal complaints (GI-CON), such as functional constipation, who had a diagnosis of CD ruled out by routine serological testing/small bowel biopsy were enrolled (Supplementary Fig. 1) [8]. Participants with additional specialized diets or with diagnoses known to influence dietary intake (Type 1 Diabetes; n = 4), or controls that were later diagnosed with CD (n = 3), or who consented, but were lost to follow-up (n = 11 CD, n = 1 GI-CON) were excluded; leaving a total of 228 CCD and 144 GI-CON [8].

Informed consent/assent was obtained from participants and their parents/responsible caregivers prior to enrollment. Ethics approval was obtained from the Human Research Ethics Board (REB) at the University of Alberta (Pro00033867), The Hamilton Integrated REB (#1107) and The Hospital for Sick Children REB (#1000048112).

2.1. Anthropometric, socio-demographic, histology and biochemical data

Data regarding anthropometric (weight, weight-z, height, height-z) and socio-demographic data (gender, CD/GI-CON diagnosis, CD duration, parent-child [education, ethnicity, age, location of birth], household characteristics [size, number of children (±CD), number/member in household consuming the GFD, urban/rural, income] were collected according to standard methodologies [8]. Marsh Criteria Ranking and serology (anti-tissue transglutaminase IgA or TTG) concentrations were collected at time of diagnosis/recruitment from medical records [9]. All GI-CON had TTG <1 U/L at time of recruitment [8]. The PedsQL Gastrointestinal Symptom Scale 1.0 was used to evaluate functional gastrointestinal symptoms [10]. No significant differences in age between GI-symptoms (as assessed by PedsQL Gastrointestinal Symptom Scale 1.00) were reported between children > and <10 years in both groups (data not shown) [8].

2.2. Dietary intake assessment and adherence to the GFD

Dietary intake was assessed using two 24 h recalls (1 weekday, 1 weekend day) using the multi-pass technique [11,12]. Diet records were reviewed with patient and families by trained research personnel. Macro-and-micronutrient intake was analyzed using Food Processor (2015 ESHA® Research, version 10.15.4, Salem, OR, USA). Brand names of foods consumed were collected to ensure a comprehensive and accurate analysis of the nutrient content of foods consumed and information regarding micronutrient supplement use (type, amount) were recorded. Non-adherence to the GFD for CD participants was determined in three ways: abnormal TTG serology (>7 IU/mL), b) self-report from the Kindl® questionnaire (yes/no) [13], and c) gluten intake (>10 mg/d) [8]. Intake was categorized into food groups based on the Alberta Nutrition Guidelines for Children and Youth (ANGCY) and Canada's Food Guide for Healthy Eating for age and gender [14]. GI and GL were calculated according to the mixed meal methodology [15,16]. Gluten intake was calculated according to the Osborne method [8,17].

2.3. Dietary pattern analysis

Diet patterning was assessed using i) dietary quality (DQ) indices (Health-Eating Index-2010 [HEI-C] & Dietary Approaches to Stop Hypertension [DASH]), and ii) cluster analysis (including subcategorization of food group types) [18,19]. These two methods enable assessment of diet patterns by the assessment of total DQ, components of DQ related to dietary adequacy, moderation and variety, as well as dietary patterns (Cluster Analysis). The HEI-C were subcategorized based on the components of adequacy (number of food servings in each food group, max score 50); moderation (sum of saturated fat, cholesterol and foods in the 'other category, max score 40); and variety (max score is 10) [20]. The max HEI-C score is 100, with scores ≥80 signifying excellent overall DQ, scores of 51–80 indicating 'needs improvement' and scores ≤50 indicating poor DQ. A maximum scores of 80 points is possible for the DASH DQ tool, 65–80 signifying 'good' DQ and <65 signifying 'needs' improvement [19]. The final food categorizations were expressed as percentage (%) of energy intake to ensure normalization of the data prior to performing cluster analysis [21,22]. Food categorizations that had a % of energy intake less than 0.5%, and/or had less than 5% of the entire cohort consuming specific food items within the categorizations were removed from the cluster analysis. The final categorizations resulted in 65 different items under the 8 different categorizations (Supplementary Table 1).

Cluster analysis was performed to enable the determination of dietary patterns. Using this analysis, k-means clusters of 2–5 clusters were considered using the Calinski-Harabaz Stopping Rule. This rule enables the examination of between-and-within-cluster variances to ensure the most distinct clustering of k-means [23]. This was conducted using the FAST Clust Procedure of SAS (Version 9.4; SAS Institute Inc, Cary NC, USA). To assess validity of the clusters, a repeat analysis of a random sample of patients within each cluster was re-run and agreement determined. Agreement (intra-class correlations or ICC) was determined using the Kappa statistic and standard-cut-offs (ICC≤ 0.4, poor-fair]; 0.41–0.60, fair-moderate; 0.61–0.8, moderate-good;] and 0.81–1, [excellent] agreement) [24]. Agreement in the three CD clusters ranged between moderate-good categories for CD; and fair to moderate for GI-CON.

The resulting clusters (n = 3 for CD; n = 3 GI-CON) were given provisional identifiers based upon the % energy contribution of individual food items to overall energy intake, dietary macronutrient distribution ranges for age-and-gender [14,25,26] and the contribution of processed meats, snack foods, processed grains, higher fat dairy and types of added oils to the overall diet [27]. Cluster analysis included the evaluation of the following dietary patterns: Western Diet (higher energy [>130% BMR]/fat (>35%), high simple sugar (>10% added sugar) and sodium intake [>30% AI]), Prudent Diet (moderate energy [±130% BMR], lower fat [25–35%]/lower sodium [≤AI] balanced diet) and the Mediterranean meal pattern (moderate energy [± 130BMR], lower fat [25–35%]/higher MUFA [12–20%]) [27].

2.4. Statistical analysis

Data analysis was completed using the SAS 9.0 statistical software (SAS, Version 9.4; SAS Institute Inc., Cary, NC, USA). Data were expressed as mean ± standard deviation (SD) or median and interquintile range (IQ), unless otherwise specified. The Shapiro-Wilk test was conducted to assess the normality of distribution. Nonparametric data underwent logarithmic transformation. Independent t-tests or Kruskalis Wallis tests with post-hoc Dunn tests to compare anthropometric and demographic differences between groups was used. Chi-square/Fisher exact tests were used to measure differences in categorical data. Multivariate analysis (ANOVA) were conducted to examine the potential interrelationships between adherence to the GFD (categorical and continuous), dietary patterns (clusters) and socio-demographic/socio-economic factors. A p-value ≤0.05 was considered significant.

3. Results

3.1. Anthropometric and demographic data

Anthropometric, demographic, socio-economic, histopathology and serology data have been reported [8]. Mean age in the entire cohort was 10.7 ± 3.9 years (CCD: 10.4 ± 4.1; GI-CON 10.9 ± 4.0 p = 0.54). With the exception of lower weight-z and height-z scores, there were no differences in anthropometric or demographic features between groups [8]. Households were located in urban centers (n = 93.8% [CCD] vs 86.7% [GI-CON]; p = 0.02), with parents (19–68 years) of predominantly Caucasian ancestry (81.9% Caucasian, 19.1% non-Caucasian), university educated (76.2%%) and two children per household (n = 2.4 ± 1), with total household incomes ranging between $51,853-191,634 (Canadian $) [8]. Overall adherence to the GFD in CCD by serum TTG, self-report and estimate gluten intake was 76.3%, 86.4% and 100%, respectively.

3.2. Macro-and-micronutrient intake (CCD vs GI-CON)

Although the absolute intake of energy, protein, fat and carbohydrate was higher in CCD than GI-CON, no major differences in macronutrient distribution was observed between groups (Supplementary Table 2). CCD had diets characterized by higher sugar and GL and lower folate, selenium and calcium than GI-CON, with only 23% of CCD meeting the estimated average requirement (EAR) for folate. Few children (<5%) in either group met the EAR for vitamin D by diet alone. The presence of gastrointestinal pain was associated with lower folate (p = 0.02), selenium (p < 0.001) and vitamin A (p = 0.02) intake in CCD.

3.3. Food groups (FG) intake

CCD consumed more Fruits & Vegetables (F/V) and Milk and alternatives (Milk) than GI-CON (p < 0.05) (Supplementary Table 2). Factors influencing FG servings consumed included paternal/maternal ethnicity, presence of gastrointestinal symptoms, maternal/paternal education and parental/child birth place (grains only). Specifically children with parental Caucasian ancestry consumed more servings of F/V (CCD: (5.9 ± 2.6 [Caucasian] vs 3.6 ± 2.4 [non-Caucasian]; GI-CON: (4.4 ± 2.7 [Caucasian] vs 3.1 ± 1.6 [non-Caucasian]; p < 0.05) and fewer grain servings/d (CCD: 5.1 ± 2.4 [Caucasian] vs 5.1 ± 2.4 [non-Caucasian]; GI-CON (5.2 ± 2.2 [Caucasian ancestry] vs 6.7 ± 2.1 [non-Caucasian]; p < 0.05). Maternal education (≥university) was associated with higher F/V and grain consumption. In contrast gastrointestinal symptoms was associated with reduced intake of F/V servings (4.3 ± 2.6 [+gastrointestinal symptoms] vs 5.4 ± 2.9 [-gastrointestinal symptoms]; p < 0.05) and MP (2.2 ± 1.3 [+gastrointestinal symptoms] vs 2.8 ± 1.3 servings/d [-gastrointestinal symptoms]; p = 0.006) in both groups. GFD adherence, income, or other household characteristics were not associated with FG servings consumed in both groups.

3.4. Diet quality

DASH (total) scores were indicative of a ‘needs improvement in 93% and 95% for GI-CON and CCD, respectively (p > 0.05). GI-CON had lower total HEI-C scores and lower sub-set scores related to variety and adequacy (Fig. 1). Younger children (<10 years) had higher DQ scores than older children (>10 years; p = 0.04), but no effects of gastrointestinal pain (p = 0.37), GFD adherence (p = 0.64), gluten intake (>and <10 mg/d; p = 0.85), TTG concentrations (p = 0.79), paternal (p = 0.21)/maternal (p = 0.25)/child (p = 0.17) ethnicity or maternal/paternal education (p = 0.87) was observed between groups. In contrast, higher HEIC (≥80) was associated with higher incomes ($ 99,979 [$84,807-$128,156]) vs lower HEI-C (<80; ($87788 [$81,836-$103,837]) (p = 0.04). Higher household incomes were also significantly related to HEI-C variety subset scores (p = 0.03), but not to subset HEI-C scores related to moderation (p = 0.16) or adequacy (p = 0.39).

3.5. Dietary patterns: Western Diets vs Prudent Diet Patterns

Three clusters/group were identified, but none fell within the Mediterranean or DASH definitions. Two clusters were characterized by low DQ (Western Diet (Cluster 1) and the Higher Fat Western Diet (Cluster 2)); while the third cluster followed a Prudent Diet dietary pattern. Both Cluster 1 and 2 were very similar in terms of macronutrient distributions (higher energy (130–150% BMR)/higher fat (33–37%)/lower CHO distribution (59-52%) and higher sodium (>AI). However, there were differences in the ‘types of foods’ consumed in Cluster 1 vs Cluster 2 which impacted micronutrient and fat intake consumed. In contrast the Prudent Diet Pattern represented a lower fat (20–25%)/higher CHO diet (60–62%), higher GI/lower sodium diet pattern (Table 1). Except for maternal/paternal ethnicity where the proportion of individuals with non-Caucasian ancestry was highest in Cluster 3 and longer CD duration (Cluster 1 vs Cluster 2 and 3), no major differences between anthropometric, demographic, GFD adherence and household characteristics were observed between clusters (Table 2).

3.6. Nutritional and food intake considerations with dietary patterns

3.6.1. Western Diet (Cluster 1) vs higher-fat Western Diet (Cluster2)

The major nutritional differences between Cluster 1 and 2 was micronutrient consumption and total fat intake. Children in Cluster 2 consumed significantly lower amounts of vitamin D and calcium as reflective in reduced consumption of Milk (low fat milk and yogurt, increased high-fat cheese) and lower riboflavin (Supplementary Table 3). This was particularly evident in GI-CON, where overall consumption of MP was significantly lower when compared to CCD (p < 0.05). Cluster 1 children were more likely to consume daily micronutrient. In this cluster, CCD were more likely to take either a single vitamin D preparation (n = 48 [CCD] vs n = 6 [GI-CON]; p = 0.04) containing 400–1000 IU/D + a multivitamin preparation (n = 29 [CCD] vs n = 2 [GI-CON]; p = 0.03) than GI-CON. Socio-demographic factors associated with higher micronutrient supplement use included maternal ethnicity (Caucasian), parental education (university or higher), positive CD family history and household size (# children). No associations between CD duration, gastrointestinal symptoms, other socio-demographic factors (birth

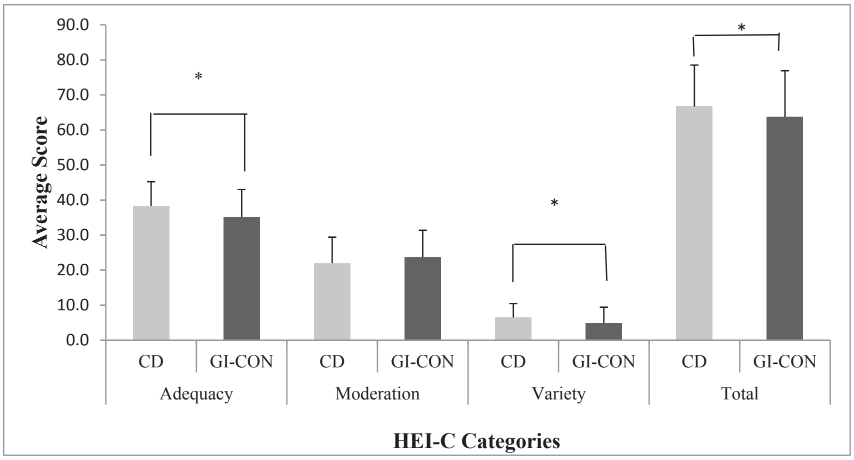

Fig. 1. Differences in Diet Quality between Children with Celiac Disease (CD) and children with chronic gastrointestinal complaints (GI-CON) as determined by the Healthy Eating-Index Score (HEI-C). The HEI-C were subcategorized based on the components of adequacy (based on the number of food servings in each food group; max score 50), moderation (sum of saturated fat, cholesterol and foods in the 'other category; max score 40) and variety (max score is 10) within the HEI-C [20]. The max HEI-C scores is 100 with scores ≥80 signifying excellent overall DQ; scores of 51–80 indicating 'needs improvement' and scores ≤50 indicating poor DQ. Data are mean ± with standard deviation (SD). Values with a superscript are significantly different at $p \leq 0.05$.

place, geographical residence or income), GFD adherence and micronutrient supplement use were observed.

The higher fat intake in Cluster 2 was reflective of higher intakes of cheese (high fat choices ~10% of kcal intake) and processed red meats (>30% of meat and alternative kcals); particularly in the CCD. While no differences in the number of F/V and grains servings consumed occurred between Cluster 1 and 2, fewer CCD met the folate EAR (18.3% [CCD] vs 64% [GI-CON]; $p < 0.001$) and folate RDA (4% [CCD] vs 44% [GI-CON]; $p < 0.001$) than GI-CON. Cluster 1 This was related to the low intakes of folate-rich green leafy vegetables (<10% of vegetable intake) and the lower folate content of GF-grains consumed. No relationships between child/parental ethnicity, age, education, household characteristics (income, size, rural/urban), adherence and the macro-micronutrient intake between clusters 1 vs 2 were observed.

3.6.2. Cluster 3 (prudent diet)

With the exception of the number of meat and alternative servings, the total number of grain servings was higher and the F/V servings consumed was lower in Cluster 3 in both groups when compared to intake in the other clusters (Table 1). This was likely due to higher intakes of whole grains (>50% of grain intake) with rice as the predominant grain source (>75% of grain intake), particularly in the GI-CON. CCD and GI-CON had the lowest folate intake, which was likely due to significantly lower intakes of folate-rich green leafy vegetables and higher intakes of rice flours and brown rice ($p < 0.05$). More CCD children of non-Caucasian ancestry had dietary patterns reflective of Cluster 3 (38.4%) vs Clusters 1 (14%) and Cluster 2 (14.8) ($p < 0.001$).

4. Discussion

Little is known regarding the dietary patterns of CCD consuming the GFD and whether differences in macro-nutrient, micronutrient intake or DQ may be observed in children of different ethnicities. Studying children's diets from a food based dietary pattern method may inform dietary recommendations. This is important to ensure effective dietetic education to meet the unique and specialized nutritional needs of CCD consuming the GFD in multi-cultural environments. The main finding was that DQ in GI-CON was significantly lower than CCD. Surprisingly, overall DQ in CCD was not impacted by GFD adherence, sex, maternal/paternal ethnicity/education, or positive family CD history and is similar to what is reported in healthy children [5,20,28,29]. Maternal ethnicity and positive family CD history was also associated with micronutrient supplement use. CCD had diets higher in fat, total sugar and GL than GI-CON and folate was a micronutrient of major concern [5,6,30]. Amongst CCD, DQ was higher in younger children (<9 years) and in households with higher incomes, particularly in relation to the variety of foods consumed, but no effects of ethnicity on DQ was observed. Regardless, it is interesting that GI-CON actually had the lowest overall DQ, driven by the presence of gastrointestinal symptoms negatively impacting intake of F/V and dairy products. These differences translated to lower intakes of fiber, calcium and vitamin A in GI-CON children. It would be interesting to explore the contribution of dietary education for CCD related to the impact on the higher DQ scores than the GI-CON.

To address the potential socio-demographic, anthropometric and medical factors that may impact food selection, diets were analyzed according to 'dietary patterns'. Three diet patterns were identified. None of these dietary patterns were nutritionally 'ideal' and none of the patterns reflected a DASH or Mediterranean diet pattern. Two out of the three dietary patterns identified were reflective of a Western Diet pattern (Western Diet and a Higher Fat/Lower Dairy version of the Western Diet) and represented >80% of CCD and GI-CON. A third more prudent dietary pattern (Lower Fat/Higher CHO diet) with higher total DQ scores was also identified. CCD of non-caucasian ancestry consumed diets more reflective of the Prudent Dietary Pattern. Within the same individual diet patterns, there were no major differences in macronutrient distribution between CCD and GI-CON, but some distinct differences in energy density, GL, fiber and micronutrient intake was observed between groups within the same dietary cluster. For example, CCD's diets were characterized by high energy density, higher fiber, GL and selenium intakes when compared to GI-CON.

Insufficient dietary folate was a common theme in the GFD in all three dietary patterns, particularly in the CCD. This was likely due to the high intake of GF processed foods (>30% kcal), lower folate content in GF-grains and the low intake of folate-rich foods (green leafy vegetables, beans and lentils) consumed. CCD consumed rice (>75%) as the main grain in the Prudent Dietary pattern, but also had low intake of folate-rich foods along with a significantly lower intake of high-fat dairy products (cheese and milk), juices and snacks. This translated to the lowest intakes of folate and calcium in

Table 1
Macro-and micron-nutrient content of three dietary patterns in youth with Celiac Disease (CD) and Mild Chronic Gastrointestinal Controls (GI-CON) by Diet Pattern Type.

Nutrients of Concern[a]	Cluster 1 (Western Diet-Supplement Users)			Cluster 2 (Higher Fat, Western Diet)			Cluster 3 Prudent Diet (Lower Fat)			
	CD (n = 104)	GI-CON (n = 25)	P-value (group)	CD (n = 47)	GI-CON (n = 81)	P-value (group)	CD (n = 26)	GI-CON (n = 2)	P-value (group)	P-value (Cluster)
Energy (kcal)	1863 ± 436	1485 (1208–1886)	0.001	1899 (1468–2310)	1674 ± 555	0.04	1772 ± 446	1461 ± 496	0.42	0.47
Protein (g)	75 ± 23	66 ± 22.8	0.09	65 (57–89)	64 (51–86)	0.18	66 (57–86)	58 ± 12	0.47	0.37
% EI/BMR	147 (124–173)	108^{a} (101–136)	<0.001	153 (129–188)	132^{b} (105–167)	0.007	158 (133–177)	101^{ab} (61–141)	0.1	0.29
% Protein	16 ± 3	17 ± 4	0.12	16 ± 4	16 ± 4	0.94	16 ± 4	17 ± 9	0.93	0.98
Fat (g)	71 ± 23^{a}	57 ± 22^{b}	0.009	78 (50–98)^{a}	58 (42–75)^{b}	0.005	49.7 ± 16.4^{c}	36 ± 25c	0.42	0.007
% Fat	34 ± 7^{a,b}	33 ± 8^{a,b}	0.59	36 ± 7^{a}	32 ± 6^{b}	0.002	25 ± 6^{c}	21 ± 8^{b,c}	0.47	<0.001
Sat Fat (g)	25 (20–31)^{a}	21 ± 9	0.009	28 (19–34)^{a}	19 (13–28)	0.004	17 ± 7^{b}	10 ± 6	0.09	<0.001
% Sat Fat	13 ± 3	12 ± 4	0.58	13 ± 3	11 ± 3	0.001	10 (7–11)	6 ± 1	0.21	<0.001
PUFA (g)	7.7 (5.4–11.7)^{a}	9.4 ± 5.5	0.66	11.1 ± 7.6^{a}	9.1 (6.7–13.3)	0.91	4.8 (3.7–7.6)^{b}	7.8 ± 8.1	0.93	<0.001
% PUFA	4.0 (2.7–5.6)^{a}	5.3 ± 2.4	0.03	5.0 ± 2.6^{a}	5.3 (4.2–6.5)	0.30	2.5 (2.0–3.2)^{b}	4.2 ± 3.6	0.65	<0.001
MUFA (g)	19 ± 8^{a}	19.9 ± 9.4	0.91	23.2 ± 12.8^{a}	20.8 ± 9.2	0.51	12.0 ± 4.7^{c}	12.6 ± 4.0	0.85	<0.001
% MUFA	9.5 ± 3.5^{a}	11.4 ± 4.0	0.01	10.9 ± 3.8^{a}	11.0 ± 2.6	0.49	6.2 ± 2.6^{b}	7.8 ± 0.1	0.21	<0.001
Carbohydrate (g)	239 ± 62	194 ± 49	0.001	227 ± 76	221 ± 74	0.57	263 ± 75	227 ± 89	0.72	0.02
% Carbohydrate	52 ± 7^{a}	51 ± 9	0.67	49 ± 10^{a}	49 ± 10	0.002	60 ± 8^{b}	62 ± 3	0.53	<0.001
GI	55 ± 6^{a}	50 ± 5	<0.001	54 ± 5^{a}	53 ± 7	0.02	57 ± 7^{b}	51 ± 19	0.72	0.0004
GL	132 ± 39	97 ± 25	<0.001	118 (91–139)	106 (90–133)	0.19	147 ± 54	123 ± 88	0.68	0.004
Fiber (g)	17 ± 6	13 ± 4.8	0.01	18 ± 8	15 (11–19)	0.02	17 ± 6	16 ± 9	0.59	0.76
Total sugar (g)	102 ± 40	79 ± 26	0.007	98 (70–129)	89 ± 40	0.1	81 (65–106)	61 ± 68	0.62	0.35
% Sugar	22 ± 6	21 ± 7	0.68	22 ± 7	22 ± 8	0.88	19.9 ± 5.2	14 ± 14	0.72	0.2
Gluten (mg)	3.2 ± 1.5	8962 ± 4908^{ab}	<0.001	3.1 ± 1.5	11,913 ± 6179^{a}	<0.001	3.9 ± 1.6	279 ± 394^{b}	1.0	<0.001
Micronutrients										
Vitamin A (RAE)	775 ± 394^{a}	495 (307–638)	0.007	685 ± 401^{a}	522 ± 284	0.02	394 ± 212^{b}	327 ± 335	0.72	<0.001
Vitamin B1 (mg)	0.8 (0.6–1.2)	1.2 (0.9–1.7)	0.002	0.8 ± 0.3	1.4 (1.0–1.7)	<0.001	0.9 ± 0.5	0.7 ± 0.1	0.89	0.006
Vitamin B2 (mg)	1.7 ± 0.6^{a}	1.4 (1.0–2.1)	0.42	1.4 (1.0–1.7)^{b}	1.4 (1.1–2.0)	0.38	1.5 (1.2–1.8)^{a,b}	0.9 ± 0.3	0.05	0.02
Vitamin B3 (NE)	22.5 ± 8.8	26.9 ± 11.1	0.09	18 (15–29)	25 (21–31)	0.03	22 ± 9.2	22.9 ± 5.8	0.67	0.16
Vitamin B6 (mg)[a]	1.3 (1.0–1.6)	1.1 (0.8–1.5)	0.12	1.1 (0.9–1.5)	1.1 (0.9–1.4)	0.77	1.5 ± 0.7	1.4 ± 0.3	0.99	0.03
Vitamin B12 (μg)	3.9 (2.9–5.0)	3.5 ± 1.6	0.15	3.6 (2.2–5.3)	2.9 (1.7–4.1)	0.03	3.7 (2.4–4)	2.6 ± 0.9	0.26	0.003
Vitamin C (mg)	92 (59–139)^{a,c}	60 (39–167)	0.83	114 ± 59^{a}	94 ± 71	0.11	79 (21–93)^{c}	67 ± 47	0.04	0.15
Vitamin D (μg)	4.1 (3–6)^{a}	3.7 (2.4–5.3)	0.27	3.7 (1.7–5.0)^{b}	2.8 (2.1–4.7)	0.67	3.6 ± 2.0$^{a.b}$	2.4 ± 3.0	0.53	0.009
Vitamin E (mg)	4.1 (3–6)^{a}	3.4 (2.6–4.9)	0.21	4.8 (3.4–7.3)	4.1 (2.7–6.5)^{a}	0.23	3.3 (1.8–5.2)^{b}	4.5 ± 0.5	0.33	0.1
Folate (DFE)	160 (122–203)	284 (192–365)	<0.001	172 (116–256)	335 (200–436)	<0.001	135 (76–225)	103 (54–153)	0.53	<0.001
Calcium (mg)	998 (796–1297)^{a}	779 (528–930)	0.004	866 (587–1157)^{b}	780 (564–1020)	0.26	826 (505–1188)^{a,b}	488 (199–776)	0.18	0.005
Iron (mg)	9.3 (7.5–11.8)	10.8 (8.5–12.7)	0.16	9.6 (6.9–12.8)	11.1 (8.9–15.3)	0.01	9.6 (7.4–15.6)	8.6 ± 0.4	0.53	0.11
Selenium (μg)	49 (33–67)	69 (59–105)	0.001	42 (32–68)	77 (59–116)	<0.001	41 (29–59)	63 (39–87)	0.33	0.003
Sodium (mg)	2202 (1818–3039)^{a}	2168 (1383–2846)	0.37	2289 (1491–2692)^{a,b}	2166 (1461–2921)	0.57	1391 (971–2722)^{b}	942 (185–1700)	0.37	0.002
Potassium (mg)	2512 (1866–3000)	2107 (1575–2787)	0.09	2245 (1791–2769)	2017 (1466–2406)	0.18	2219 (1658–2691)	1837 (1700–1973)	0.53	0.002
Zinc (mg)	8.9 ± 3.5	9.0 ± 3.4	0.92	8.1 (6.1–12.3)	7.8 (5.9–11.1)	0.39	7.5 (5.6–9.0)	10.1 ± 5.7	0.66	0.30
Diet Quality Indices and Food Groups										
DASH Total	40 ± 12	34 ± 9	0.008	37 ± 13	36 ± 13	0.79	38 ± 13	50 ± 14	0.21	0.27
HEI-C Total	65.4 ± 10.9^{a}	60.9 ± 12.7	0.02	64.4 ± 12.7^{a}	64.8 ± 12.9	0,95	73.5 ± 11.3^{b}	68.3 ± 0.1	0.30	0.006
Adequacy[a]	38.7 ± 6.3	34.3 ± 6.7	0.003	38.0 ± 7.8	35.3 ± 8.3	0.06	37.4 ± 7.6	34.5 ± 8.9	0.65	0.26
Moderation	21.0 ± 6.3^{a}	21.6 ± 7.6	0.94	19.8 ± 7.5^{a}	24.1 ± 7.5	0.001	29.6 ± 7.1^{b}	33.8 ± 8.8	0.49	<0.001
Variety	6.4 ± 3.9	5 ± 4.8	0.21	10.0 (3.3–10.0)	5.0 (0.0–10.0)	0.07	5.0 (5.0–10.0)	0.0 ± 0.0	0.04	0.65
Food Groups										
Grains	4.8 ± 2.3^{a}	4.4 ± 1.9	0.48	5.1 ± 2.2^{a}	5.2 (4.1–7.1)	0.27	7.3 ± 2.3^{b}	7.1 ± 1.6	0.85	<0.001
Fruits and Veg	5.9 ± 2.6^{a}	4.4 ± 2.5	0.03	5.4 ± 2.6^{a,b}	4.3 ± 2.7	0.009	3.9 ± 2.9^{b}	4.5 ± 2.1	0.59	0.002
Milk and Alt.	2.8 ± 1.4^{a}	2.0 ± 1.2	0.01	2.2 ± 1.0^{b}	1.8 (1.1–2.5)	0.07	2.4 ± 1.2b	0.7 ± 0.9	0.05	0.007
Meat and Alt.	2.1 ± 1.2	1.9 ± 1.0^{a}	0.52	2.8 ± 1.8	2.2 ± 1.2^{a}	0.06	2.1 ± 1.0	1.4 ± 0.6^{b}	0.34	0.5

[a] Values are expressed as mean ± SD or as median (25% Q1 − 75% Q3). Values with different superscripts represent significant differences within the same group (CD vs GI-CON) across the clusters. P-group represent differences Abbreviations: CD, celiac disease; GI-CON, gastrointestinal disease control; Sat Fat, saturated fat; PUFA, polyunsaturated fatty acids; MUFA, monounsaturated fatty acids; GI, glycemic index; GL, glycemic load; DASH, dietary approaches to stop hypertension; HEI-C, Healthy Eating Index Canada; Alt: Alternatives. Cluster analysis performed using k-means procedure. DFE; Dietary Folate Equivalents; RAE; retinol active equivalent, NE; niacin equivalents. EI: energy intake; BMR: estimated basal energy requirements using Schofield equations. Values with different superscripts represent within group comparisons between clusters. Post-hoc between group comparisons within individual clusters (P-group) and between cluster differences (P-cluster) were also performed to determine significant differences in nutrient content between and within groups/clusters. Statistical significance was determine at a p value < 0.01.

Table 2
Demographic information for youth with Celiac Disease (CD) and Mild Chronic Gastrointestinal Controls (GI-CON) by Diet Pattern Type.

Demographics	Cluster 1 (Western Diet-Supplement Users)			Cluster 2 (Higher Fat Western Diet)			Cluster 3 (Prudent Diet, Lower Fat)			
	CD (n = 104)	GI-CON (n = 25)	P-values (group)	CD (n = 47)	GI-CON[13] (n = 81)	P-values (group)	CD (n = 26)	GI-CON (n = 2)	P-values (group)	P value cluster
Gender (M:F)[c]	32:72	9:16	0.61	16:31	32:49	0.53	10:16	0:2	0.21	0.62
Age (yr)[a,b]	10.9 (8.2–13.6)	12.9 (8.6–15.7)	0.28	10.5 (6.8–14.2)	10.0 (7.1–14.0)	0.78	8.9 (6.3–11.2)	11.6 (8.2–15.0)	0.52	0.15
Duration of CD (yr)	1.9 (1.0–3.6)[a]	0.0 ± 0.0	<0.001	1.3 (0.9–2.3)[b]	0.0 ± 0.0	<0.001	1.3 (0.8–2.1)[a,b]	0.0 ± 0.0	<0.001	0.009
GI symptoms (Y:N)	65:39	25:0	0.002	26:21	79:0	<0.001	18:8	2:0	0.35	0.04
Family history (Y:N)	44:45	5:7	0.61	12:31	9:26	0.83	9:12	0:1	0.39	0.01
Child Ethnicity[c,d]										
Caucasian	88	7	0.63	36	22	0.21	15	0	–	0.0001
South Asian	11	1		3	0		9	1		
West Asian	1	0		0	1		0	0		
Other	3	1		4	5		1	0		
Mother Ethnicity										
Caucasian	89	7	0.009	37	23	0.07	14	0	0.065	<0.001
South Asian	9	1		4	0		9	1		
West Asian	3	0		0	1		1	0		
Other[e]	0	1		2	5		1	0		
Father Ethnicity										
Caucasian	88	9	–	36	23	0.27	15	0	–	<0.001
South Asian	10	1		3	0		9	1		
West Asian	3	0		1	1		0	0		
Other[e]	0	0		2	4		1	0		
Mother Education[c]										
High School	10	7	0.01	10	22	0.11	6	1	–	0.06
University	60	6		22	21		11	0		
College	27	8		12	31		5	1		
Registered Apprenticeship	2	1		1	3		0	0		
Father Education[c]										
High School	13	6	0.08	5	16	0.002	5	1	0.006	0.06
University	54	6		23	15		11	0		
College	27	6		14	18		5	0		
Apprenticeship	3	2		2	23		0	1		
# of children in home[f]	2.0 (2–3)[a,c]	2.0 (2–3)	0.81	3.0 (2.-3.0)[a]	2.0 (2–3)	0.05	2.0 (2.0–2.0)[c]	4.0 ± 14	0.007	0.59
# of people on GFD[g]	1.0 (1.0–2.0)	0.0 ± 0.0	–	1.0 (1.0–2.0)	0.0 ± 0.0	–	1.0 (1.0–2.0)	0.0 ± 0.0	–	0.78
Serum ATTG U/L	3 (2–8)[ac]	1 (1–1)	<0.001	2 (1–5)[a]	1 (1–1)	<0.001	4 (2–10)[c]	1 (1–1)	0.02	<0.001
Household income	$99979 (81,836–112,216)	$81836 (81,836-10837)	0.13	$99979 (81,836-10387)	$81836 (81,348–103836)	0.27	$81836 (81,836–90908)	$104752 (81,348–128,156)	0.99	0.19
Height (cm)[h]	142.7 ± 21.7	147.1 ± 22.4	0.29	140.5 ± 24.1	141.5 ± 23.6	0.73	132.7 ± 23.5	150.2 ± 15.8	0.24	0.11
Height z-score[i]	0.2 (−0.4–0.9)	0.3 (−0.7–1.1)	0.63	0.2 (−0.7–0.8)	0.3 (−0.3–1.0)	0.27	−0.3 (−1.6–0.2)	1.0 (−0.04–1.9)	0.18	0.07
Weight (kg)[h]	35 (25.3–50.9)	45.6 ± 20.1	0.21	31.9 (22.8–48.4)	38.3 (23.2–55.7)	0.47	27.3 (20.8–37.7)	51.0 (35–67)	0.1	0.52
Weight z-score[i]	0.1 (−0.5–0.9)	0.5 (−0.02–1.0)	0.27	0.2 (−0.4–0.9)	0.5 (−0.4–1.3)	0.25	−0.2 (−0.8–0.5)	1.5 (1.2–1.8)	0.04	0.22

[a] Values are expressed as mean ± SD.
[b] Values are expressed as median (25% Q1 - 75% Q3).
[c] Values are expressed as categorical variables.
[d] Child, maternal and paternal ethnicity is defined from.Stats Canada (http://www.statcan.gc.ca).
[e] "Other" ethnic group includes Chileans and First Nation Cree. Abbreviations: CD, celiac disease; GI-CON, gastrointestinal disease control; M, male; F, female; Y, yes; N, no; GI, gastrointestinal; GFD, gluten free diet; cm, centimetres; kg, kilograms; yr, years. Values with different superscripts represent within group differences across the clusters.
[f] The number of children in the household was recorded for families.
[g] The number of people eating a GFD was documented.
[h] Height and weight at time of visit were obtained from patient's clinic chart or from health care provider.
[i] Z-scores determined using World Health Organization (WHO) anthropometric calculator (Canada, 2014 revision) [1].

the Prudent Dietary Pattern. Fewer GI-CON children had challenges meeting their folate requirements related to the folate content of the grains predominantly consumed (wheat).

Study limitations include the inability to determine in-depth socio-cultural determinants related to food intake, and the smaller sample size related to ethnicity. However, a post-hoc analysis revealed sufficient power ($\beta > 0.8$) to detect differences in ethnicity (Caucasian vs non-Caucasian ancestry), dietary patterns and nutrient intake across the three Clusters in the CCD. While this was also the case for the GI-CON for Clusters 1 and 2, the sample size of GI-CON in Cluster 3 was insufficient to draw any major conclusions regarding dietary patterns or the influence of ethnicity on food intake. Underestimation of the variability in food intake using multiple 24 h recalls was unlikely to be a major factor in this analysis, as within-subject variability was similar to that reported in other studies comparing food intake in children with CD on the GFD with healthy children and children with CD ± Type 1 Diabetes [5,31]. This is likely due to the fact that children consuming the GFD have limitations in access to diverse GF food, particularly in the school setting and hence have less variability in food intake.

Inclusion of GI-CON had some potential limitations related to the influences of gastrointestinal symptoms on food intake between groups as not all CCD experienced symptoms (<50%). Differences in fruit and vegetable and dairy intake due to the presence of gastrointestinal symptoms were observed, which may have impacted the overall assessment of DQ and dietary patterns in both groups. However, GI-CON had similar gastrointestinal symptoms as the CCD (e.g constipation, gas, mild abdominal pain) with no differences between groups in severity of gastrointestinal symptoms, and no differences in anthropometric or socio-demographic features and more importantly had a potential diagnosis of CD ruled out. In addition, no differences in gastrointestinal symptoms and age (>and <10) were observed in both groups. None of these children were on prescribed therapeutic diets (lactose restricted) and few were on plant-based diets (<5%).

Another potential limitation is the lack of consistent knowledge about micronutrient supplement use (dose/type/frequency) consumed by GI-CON. In contrast, the majority of CCD in Cluster 1 consumed either daily single vitamin D preparations and/or multivitamin preparations. This appeared to be related to positive family CD history, maternal/paternal ethnicity and education and may reflect increased CCD family knowledge regarding GFD nutritional limitations. Interestingly, this did not translate to an increased consumption of fruits and vegetables or dairy products and/or reductions in foods in the ‘other category’ consumed. Nor was there any indication that folate intake, a nutrient at risk for CCD, was a ‘driver’ for the type of micronutrient supplements use since the most commonly used preparations were single vitamin D preparations. Micronutrient supplement use in CCD has been related to the potential ‘perceived health benefits’ related to supplement use by parents and/or based on health care provider (HCP) recommendation [31]. These findings highlight the importance of HCP recommendation to ensure nutritional adequacy in CCD and GI-CON.

The majority of children had dietary patterns with significant nutritional limitations and low DQ, particularly the GI-CON [5,18]. Children predominantly consumed dietary patterns reflective of a typical Western diets characterized by higher fat/simple sugar intakes, with fewer children consuming more prudent diets. Lower DQ in the GI-CON was driven by gastrointestinal symptoms and was associated with lower intakes of F/V and dairy foods. Adherence to the GFD and ethnicity did not influence DQ. CCD of non-caucasian ancestry consumed more prudent dietary patterns, but still had low folate intakes, particularly related to GF-grains. These findings have strong policy implications for the need for routine folate fortification in GF grains and highlight the need for the development of evidenced based nutrition guidelines for children with CD and GI-CON.

Author contribution statement - Authors roles and responsibilities

1) Diana R Mager PhD RD: Responsible for study design/inception, supervision of data collection at all sites, PI on all grants associated with project, data analysis and intellectual/scientific interpretation, wrote manuscript, approved final manuscript.
2) Margaret Marcon MD FRCPC: Supervision of data collection at The Hospital for Sick Children, intellectual/scientific interpretation, approved final manuscript.
3) Herbert Brill MD FRCPC: Supervision of data collection at McMaster Children's Hospital, contributed to intellectual/scientific interpretation of data, approved final manuscript.
4) Amanda Liu BSc MSc (cand): collected data at The Hospital for Sick Children, contributed to intellectual/scientific interpretation, approved final version of manuscript.
5) Kristin Harms BSc; collected data at University of Alberta, contributed to data analysis, intellectual/scientific interpretation, approved final version of manuscript.
6) Heather Mileski RD: collected data at McMaster Children's Hospital, contributed to intellectual/scientific interpretation, approved final version of manuscript.
7) Jenna Dowhaniuk MD FRCPC: collected data at McMaster Children's Hospital, contribute to intellectual/scientific interpretation; approved final manuscript.
8) Roseann Nasser: contributed to intellectual/scientific interpretation, approved final manuscript.
9) Matthew Carroll MD: supervised data collection at Stollery Children's Hospital, contributed to intellectual/scientific interpretation, approved final manuscript.
10) Rabin Persad MD: contributed to study design, supervised data collection at Stollery Children's Hospital, contributed to intellectual/scientific interpretation, approved final manuscript.
11) Justine Turner PhD MBBS FRCPC: contributed to study design, supervised data collection at Stollery Children's Hospital, contributed to intellectual/scientific interpretation, approved final manuscript.

Author disclaimers

None to report.

Conflicts of interest

None declared.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clnesp.2019.02.004.

Abbreviations

AI	Adequate Intake
ANGCY	Alberta Nutrition Guidelines for Children and Youth
TTG	Anti-tissue transglutaminase
BMR	Basal Metabolic Rate
BMI	Body Mass Index
CD	Celiac Disease
(CCD)	Children with Celiac Disease
DASH	Dietary Approaches to Stop Hypertension
DFE	Dietary Folate Equivalents
DQ	Diet Quality
EAR	Estimated Average Requirement
FG	Food guide
F/V	Fruits and Vegetables
HEI-C	Healthy Eating Index-Children
Height-z	Height z scores
GI	Gastrointestinal
GI-CON	Gastrointestinal Controls
GSS	Gastrointestinal Symptom Scale
GF	Gluten Free
GFD	Gluten Free Diet
GI	Glycemic Index
GL	Glycemic Load
Milk	Milk and Alternatives
RDA	Recommended Daily Allowance
T1D	Type 1 Diabetes
Weight-z	Weight z scores
WHO	World Health Organization

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