# Co-Development of Three Dietary Indices to Facilitate Dietary Intake Assessment of Pediatric Crohn's Disease Patients

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## ABSTRACT

Literature on dietary behaviours of the pediatric Crohn's Disease (CD) population and the relationship between dietary intake and CD activity is limited. Three dietary indices were developed and tested to conduct dietary pattern analysis in pediatric patients with CD consuming a free diet following remission induction via exclusive enteral nutrition ($n$ = 11). Index scores underwent descriptive and inferential analysis. The mean adjusted scores (out of 100) for the *Pediatric Western Diet Index*, *Pediatric Prudent Diet Index*, and *Pediatric-Adapted 2010 Alternate Healthy Eating Index (PA2010-AHEI)* were 29.82 ± 15.22, 34.25 ± 15.18, and 51.50 ± 11.69, respectively. The mean Western-to-Prudent ratio was 0.94 ± 0.55. A significant correlation ($r$ = −0.71) and relationship ($F_{[1, 9]}$ = 9.04, $P < 0.05$, $R^2$ = 0.501) between the Western-to-Prudent ratio and PA2010-AHEI was found. The results suggest participants were not following a Western or Prudent diet, and were consuming foods not captured by the indices. More research is needed to describe dietary intake of individuals with CD, validate dietary indices in diverse samples, and explore the utility of these indices in CD assessment and treatment. The co-authors hope this work will stimulate/inspire subsequent interprofessional, dietitian-led research on this topic.

**Key words:** Crohn's Disease, dietary intake assessment, dietary patterns, dietary pattern analysis, nutrition, pediatrics.

(Can J Diet Pract Res. 2024;00:XX–XX)
(DOI: 10.3148/cjdpr-2024-005)
Published at dcjournal.ca on XX XXXX XXXX

## RÉSUMÉ

La littérature sur les comportements alimentaires de la population pédiatrique atteinte de la maladie de Crohn (MC) et sur la relation entre l'apport alimentaire et l'activité de la MC est limitée. Trois indices alimentaires ont été créés et testés en vue d'analyser les habitudes alimentaires de patients pédiatriques atteints de la MC et ayant une alimentation libre après induction d'une rémission par nutrition entérale exclusive ($n$ = 11). Les scores associés aux indices ont fait l'objet d'une analyse descriptive et inférentielle. Les scores moyens ajustés (sur 100) pour l'Indice pédiatrique d'alimentation occidentale, l'Indice pédiatrique d'alimentation prudente et l'Indice alternatif d'alimentation saine de 2010 adapté pour les enfants (PA2010-AHEI) étaient respectivement de 29,82 ± 15,22, 34,25 ± 15,18 et 51,50 ± 11,69. Le ratio occidentale/prudente moyen était de 0,94 ± 0,55. Une corrélation ($r$ = −0,71) et une relation ($F_{[1, 9]}$ = 9,04, $p < 0,05$, $R^2$ = 0,501) significatives ont été observées entre le ratio occidentale/prudente et le PA2010-AHEI. Les résultats suggèrent que les participants ne suivaient pas une alimentation occidentale ou prudente et qu'ils consommaient des aliments non pris en compte par les indices. Des recherches supplémentaires sont nécessaires pour décrire les apports alimentaires des personnes atteintes de MC, valider les indices alimentaires dans divers échantillons et explorer l'utilité de ces indices dans l'évaluation et le traitement de la MC. Les coauteurs espèrent que ce travail encouragera la tenue d'autres recherches interprofessionnelles menées par des diététistes à ce sujet.

**Mots-clés :** maladie de Crohn, évaluation des apports alimentaires, habitudes alimentaires, analyse des habitudes alimentaires, nutrition, pédiatrie.

(Rev can prat rech diétét. 2024;00:XX–XX)
(DOI: 10.3148/cjdpr-2024-005)
Publié au dcjournal.ca le XX XXXX XXXX

## INTRODUCTION

The role of medical nutrition therapy (MNT) in the modulation of intestinal health in individuals with inflammatory bowel disease (IBD) is supported by the effectiveness of exclusive enteral nutrition (EEN), the administration of a nutritionally complete, liquid formula (most often polymeric, i.e. composed of whole macronutrients) while excluding all other oral intake for 6 weeks or longer [1,2]. In mild to moderate Crohn's Disease (CD), one type of IBD, EEN has been associated with a remission rate of approximately 80% [3–6]. Early relapse upon return to a free diet (food intake ad libitum) following EEN and the ineffectiveness of partial enteral nutrition (PEN; typically 25–75% of total energy requirements) with a free diet as an alternative MNT suggests that the success of EEN is related to exclusion of certain dietary components [6–11]. Recent research has implicated food additives, such as emulsifiers (e.g. carrageenan, carboxymethylcellulose) in impaired intestinal health, including inflammatory changes and degradation of the mucous layer, which separates the intestinal wall from pathogens and commensal microorganisms [12–14]. Other dietary components are thought to have a protective effect on intestinal health. For example, the fermentation of non-digestible carbohydrates (e.g. dietary fibre, resistant starch) produces short-chain fatty acids in the large intestine; these are involved in maintenance of the mucus layer, immune modulation, and decreased intestinal lumen pH, which can inhibit the growth of pathogens [15–17].

Literature on specific dietary components (i.e. nutrients, foods) and intestinal health provides potential insight into CD pathophysiology but relies heavily on animal models, and mechanisms are not fully understood [12–17]. Furthermore, nutrients and foods impact one another, making it difficult to study independent effects. This is relevant to literature interpretation, as individuals eat mixed meals, rather than isolated nutrients/foods [18–20]. Approaching the diet-disease link from the perspective of the overall diet (dietary pattern) can help address these limitations and offers a more practical approach, rationale that has been recognized by several clinical practice guidelines [21–23].

The Western and Prudent dietary patterns have been repeatedly identified and evaluated in the context of chronic disease prevention using *a posteriori* analysis (e.g. factor analysis) [24–26]. The Western pattern is associated with an increased risk of chronic disease associated with an inflammatory response, including IBD [27–30]. It is characterized by a high intake of animal protein, fried and processed foods, additives, refined grains, high glycemic index carbohydrates, high-fat dairy products, and added sugar [20,27,31,32]. Conversely, the Prudent pattern is associated with a decreased risk of chronic disease and is consistent with MNT that have been found to have a positive impact on chronic disease risk and/or inflammatory markers [31,33–38]. It emphasizes vegetables, fruits, legumes, whole grains, nuts, fish, poultry, low-fat dairy products, and is low in processed foods and often high in fibre and resistant starch [20,27,31,39]. Examples of MNT consistent with the Prudent pattern include the Mediterranean Diet and Dietary Approaches to Stop Hypertension.

The CD–dietary pattern relationship has not been fully described. A Canadian case-controlled study in pediatric patients with newly diagnosed CD (n = 149) identified four dietary patterns through factor analysis that explained approximately one-quarter of the variance in the dietary data [31]. A Prudent pattern was identified and was significantly negatively associated with CD development. In girls, a Western pattern was significantly associated with CD development. While a partial Western pattern (lower in animal protein) was identified in boys, there was no significant relationship with CD. Factor analysis using retrospective data on adolescent dietary habits from the Nurses Health Study II had similar results [33]. The Prudent pattern was associated with a decreased risk of CD and no significant relationship with the Western pattern was observed [33]. The Crohn's Disease Exclusion Diet (CDED) is a whole-food dietary treatment for pediatric CD [6,10,40–42]. It excludes or limits certain foods and food additives characteristic of the Western pattern and emphasizes lean protein sources, fibre, and resistant starch [6,10,40]. In a 12-week randomized controlled trial in pediatric patients with mild to moderate CD (n = 74), the CDED with PEN had a remission rate comparable to EEN [6]. Its utility as a mono- or co-first line or rescue therapy has also been described in a recently published case series [40]. The CD treatment-with-eating diet, another novel dietary therapy, aims to recreate EEN using food by excluding certain dietary components and matching macronutrient and micronutrient intake [43]. An open-label trial in pediatric patients with mild to moderate CD found that 60% of participants (n = 5) were in clinical remission after 9 weeks of treatment [43]. Limitations of the literature described above include use of retrospective data and lack of standardized dietary intake assessment tools and protocols.

The observed relationships between dietary patterns and chronic disease and the success of novel dietary therapies in the treatment of pediatric CD highlight the importance of assessing dietary patterns at different points in CD disease course. Therefore, this work had two objectives: (1) develop and evaluate three dietary indices, and (2) using dietary pattern analysis (DPA), describe the dietary patterns of Canadian Maritime pediatric patients with CD after return to free diet post remission induction via EEN [44,45].

## METHODS

### Study design

Dietary intake data from a **m**etagenomic **a**pproach to diagnosis, induction, and maintenance of deep **r**emission following **EEN** in pediatric CD (MAREEN) Study were used to complete observational cross-sectional retrospective DPA.

MAREEN (2014–2017) generated data on a comprehensive clinical-, biomarker-, genetic-, and metagenomic-based approach to diagnosis, remission induction (via EEN), and remission maintenance of pediatric CD [44,45]. Participants starting EEN induction or re-induction therapy (week 0) were followed throughout the treatment course (12 weeks) and to week 96. A polymeric formula was used for EEN (consistent with standard EEN protocol at the treatment site).

The secondary analysis of the MAREEN dietary intake data via DPA is discussed in this paper and was approved by the IWK Health Centre (file number 1016081) and Mount Saint Vincent University (file number 2017-153) Research Ethics Boards.

### Participants

Participants (n = 17) were prospectively recruited via MAREEN in Summer 2016. Participants were receiving care through the IWK Health Centre, including remission induction or re-induction via EEN.

### Data collection and analysis

A 77-item semi-quantitative food frequency questionnaire (FFQ) [46] was used to collect data on dietary intake in the

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previous week. Three dietary indices were developed and used to complete DPA. The Western and Prudent pattern were chosen due to their wide use, acceptance, and role in health and disease literature, and the 2010 Alternate Healthy Eating Index (2010-AHEI) as it considers foods that are associated with favourable health outcomes and has been associated with lower risk of chronic disease [20,27–37,39,47–50]. The development of each index was informed by published dietary indices (Supplementary Table 1), and the most current Canada's Food Guide (2007) at the time of analysis completion [24–26,51]. Components for the Pediatric Prudent Diet Index (PPDI) and the Pediatric Western Diet Index (PWDI) were developed based on the work of Hu et al. [52,53]. The 2010-AHEI was adapted using pediatric nutrient and food group intake guidelines to create the Pediatric Adapted 2010-AHEI (PA2010-AHEI). The dietary indices reflect current (at the time of analysis) MNT for IBD that include serving size guidelines, and school food and nutrition programing guidelines [6,10,54] (see supplementary Tables 2 to 12 for a detailed description of index development, components, and scoring).

The FFQs were analyzed by NutritionQuest [46], and a score for the PPDI, PWDI, and PA2010-AHEI was determined for each participant. The PPDI and PWDI scores were adjusted to be out of 100. The Western-to-Prudent ratio was also calculated for each participant. Scores for each index and the Western-to-Prudent ratio underwent descriptive analysis using IBM® SPSS® Statistics 24.0 (IBM SPSS Statistics for Windows, Version 28.0. Armonk, NY: IBM Corp, 2021). The correlation and relationship between the ratio and PA2010-AHEI scores were investigated using two-tailed Pearson's correlation and simple linear regression, respectively. The assumptions of normality were tested prior to conducting Pearson's correlation by assessing measures of central tendency (mean, median), kurtosis, skewness, and the Shapiro–Wilk test for each index and the ratio. For linear regression, the assumption of linearity and homoscedasticity were tested using plots of standardized residuals against standardized predicted values.

## RESULTS

### Participants

Seventeen participants were enrolled in MAREEN at FFQ administration in Summer 2016. Eleven (three female, eight male) returned a completed FFQ (response rate 64.7%) and were included in the secondary analysis. Respondents were 11–17 years of age and 14–112 weeks from MAREEN baseline (week 0).

### Dietary index scores

Full results for the PPDI, PWDI, and PPDI to PWDI ratio are presented in Table 1.

PPDI: The mean (± standard deviation) adjusted total score (out of 100) was 34.25 ± 15.18 and the scores ranged from 16.50 to 66.33. The fruit component had the highest mean score (9.75 ± 0.58), and the fish component had the lowest mean score (1.00 ± 1.06). The vegetable component had the second highest mean score (4.16 ± 3.28). The maximum score (10) was observed for vegetable, dark yellow vegetable, and fruit. The minimum score (0) was only observed for fish and poultry.

PWDI: The mean adjusted total score (out of 100) was 29.82 ± 15.22. The refined grains component had the highest mean score (8.18 ± 4.05), followed by the high-energy drink component (3.58 ± 3.12). The high-fat dairy component had the lowest mean score (0.00 ± 0.00), as all participant scores were zero. The remaining components had a mean score of less than five. The maximum score (10) was observed for all components except high-fat dairy. The minimum score (0) was observed for all components except lunch meat.

PPDI to PWDI ratio: The mean ratio for the unadjusted total scores was 1.07 ± 0.62, with a range of 1.74 (minimum 0.29, maximum 2.04). For adjusted total scores, the mean was 0.94 ± 0.55 with a range of 1.53 (minimum 0.26, maximum 1.78).

PA2010-AHEI (see Table 2 for full results): The mean total score (out of 100) was 51.50 ± 11.69 and the total scores ranged from 34.19 to 67.81. The fruit component had the highest mean score (9.75 ± 0.58), followed by omega-3 fats (8.29 ± 1.72), polyunsaturated fatty acids (6.59 ± 1.83), and sugar-sweetened beverages (5.11 ± 3.77). Whole grains had the lowest mean score (1.90 ± 1.43). The maximum score (10) was not observed for this component or red/processed meat, trans fat, and polyunsaturated fatty acids. The minimum (0) score was observed for sugar-sweetened beverages, trans fat, and sodium.

### Correlation and regression

The assumptions of normality were not violated by the dietary index score data. A significant ($P < 0.05$) strong negative correlation ($r = -0.71$) between the Western-to-Prudent ratio and the PA2010-AHEI scores was observed. A significant relationship between the ratio and PA2010-AHEI was also seen ($F_{[1, 9]} = 9.04$, $P < 0.05$, $R^2 = 0.501$), and the ratio score explained 50.1% of the variance in the PA2010-AHEI scores. The slope coefficient was −13.27 (95% CI [−23.26, −3.29]) and was significantly different from 0 ($P < 0.05$).

## DISCUSSION

This paper describes the development of three novel dietary indices and presents findings from DPA in a sample of Canadian pediatric patients with CD, following return to free diet after remission induction via EEN. The results suggest that the sample was consuming foods from both the Western and Prudent pattern. The observed non-adherence to either pattern may be due to low intake of certain components. The average component scores from the indices reflected low intake of whole grains, vegetables, lean poultry, fatty fish, legumes and high-fat dairy products, and moderate intake of nuts and red and processed meat.

The sample's intake may be similar to the general Canadian population, with the exception of dairy product

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**Table 1.** Pediatric Prudent Diet Index, Pediatric Western Diet Index, and Pediatric Western Diet Index to Pediatric Prudent Diet Index ratio results.

| Component/Total score | Mean ± SD | Minimum | Maximum | Range |
|---|---|---|---|---|
| **Pediatric Prudent Diet Index** | | | | |
| Vegetables | 4.16 ± 3.28 | 0.55 | 10.00 | 9.45 |
| Dark yellow vegetables | 3.68 ± 3.95 | 0.29 | 10.00 | 9.71 |
| Fruit | 9.75 ± 0.58 | 8.27 | 10.00 | 1.73 |
| Whole grains | 2.10 ± 1.71 | 0.25 | 5.90 | 5.65 |
| Legumes | 2.02 ± 2.58 | 0.02 | 9.29 | 9.27 |
| Fish | 1.00 ± 1.06 | 0.00 | 3.28 | 3.28 |
| Poultry | 1.25 ± 3.01 | 0.00 | 9.53 | 9.53 |
| **Total score**[a] | 23.97 ± 10.63 | 11.55 | 46.43 | 34.88 |
| **Adjusted total score**[b] | 34.25 ± 15.18 | 16.50 | 66.33 | 49.83 |
| **Pediatric Western Diet Index** | | | | |
| Lunch meat | 3.55 ± 2.06 | 0.13 | 6.65 | 6.53 |
| Red meat | 3.09 ± 3.38 | 0.00 | 10.00 | 10.00 |
| Potatoes | 1.81 ± 4.05 | 0.00 | 10.00 | 10.00 |
| High-fat dairy | 0.00 ± 0.00 | 0.00 | 0.00 | 0.00 |
| Eggs | 0.91 ± 3.02 | 0.00 | 10.00 | 0.00 |
| Refined grains | 8.18 ± 4.05 | 0.00 | 10.00 | 10.00 |
| High-energy drinks | 3.58 ± 3.12 | 0.00 | 10.00 | 10.00 |
| French fries | 2.73 ± 4.67 | 0.00 | 10.00 | 10.00 |
| **Total score**[c] | 23.86 ± 12.17 | 3.39 | 44.96 | 41.57 |
| **Adjusted total score**[b] | 29.82 ± 15.22 | 4.24 | 56.20 | 51.96 |
| **Pediatric Western Diet Index to the Pediatric Prudent Diet Index ratio** | | | | |
| Unadjusted total scores | 1.07 ± 0.62 | 0.29 | 2.04 | 1.74 |
| Adjusted total scores | 0.94 ± 0.55 | 0.26 | 1.78 | 1.53 |

SD = standard deviation.
[a]Total score is out of 70.
[b]Total adjusted score is out of 100.
[c]Total score is out of 80.

**Table 2.** Pediatric-Adapted 2010-AHEI results by component and total score.

| Component/Total score | Mean ± SD | Minimum | Maximum | Range |
|---|---|---|---|---|
| Vegetables | 4.16 ± 3.28 | 0.55 | 10.00 | 9.45 |
| Fruit | 9.75 ± 0.58 | 8.27 | 10.00 | 1.73 |
| Whole grains | 1.90 ± 1.43 | 0.22 | 5.06 | 4.84 |
| Sugar-sweetened beverages | 5.11 ± 3.77 | 0.00 | 10.00 | 10.00 |
| Nuts | 4.57 ± 4.44 | 0.08 | 10.00 | 9.92 |
| Red/processed meat | 4.87 ± 2.70 | 1.04 | 9.28 | 8.24 |
| Trans fat | 2.62 ± 2.28 | 0.00 | 5.82 | 5.82 |
| Omega-3 fats | 8.29 ± 1.72 | 4.91 | 10.00 | 5.09 |
| Polyunsaturated fatty acids | 6.59 ± 1.82 | 3.16 | 9.50 | 6.34 |
| Sodium | 3.64 ± 5.05 | 0.00 | 10.00 | 10.00 |
| **Total score**[a] | 51.50 ± 11.69 | 34.19 | 67.81 | 33.62 |

AHEI, Alternate Healthy Eating Index; SD, standard deviation.
[a]Total score is out of 100.

intake [30,55–58]. The average number of servings of milk and alternatives consumed per day by Canadians 2–18 years old is 2.10–3.30 [59]. Fluid milk and fortified soy beverages are an important source of milk and alternatives for this age group, and about one quarter consumed are high in fat and/or sugar [59]. Other high-fat and/or high-sugar dairy products (e.g. cheese, dairy-based desserts) are also major sources of this food group for this age [57]. No participants consumed more than two servings of high-fat dairy products per day. This could indicate intake of mostly low-fat dairy products (not assessed) or an overall low intake of dairy products. Ongoing supplemental EN, as per local protocol, could also contribute to low dairy intake.

Low intake of a variety of foods has been described in individuals with IBD. Tsiountsioura et al. found that compared to healthy controls, Scottish children with CD had a lower daily intake of dairy products, fish, and fruits and vegetables [60]. Maconi et al. found over one-third of adult patients with IBD intentionally changed their diet due to symptoms, including reducing milk, cheese, fat, and high-fibre food intake [61]. Similarly, a review on disordered eating habits in gastrointestinal (GI) disorders found that patients consumed less food than healthy individuals and suggested that reducing food intake was a way to cope with/control symptoms [62]. Evidence of food restriction in GI disorders and the sample's low to moderate intake of the four food groups raises the question of what other foods are being consumed by this population.

It is possible that the Canadian pediatric CD population consumes a high amount of "other foods" (e.g., oils/fats, condiments, snack foods), like the general Canadian population [56]. The previously mentioned study in Scottish children found that children with CD had a higher daily intake of jams, chips, and savoury snacks than controls [60]. In Canadian children with CD, pre-diagnosis dietary patterns high in condiments, desserts, chips, and snack foods have been reported [31]. Since the three indices did not capture intake of these foods, the sample may have had a high intake of "other foods".

Another potential explanation for the observed index scores is high consumption of liquids. A prior analysis of the MAREEN dietary data found that three of the eleven participants were consuming less than 600 g of solid food per day [63]. This suggests the participants had either inadequate intake or were consuming liquids as well. Since ongoing supplemental EN in addition to free diet is recommended as an adjunct therapy for remission maintenance after remission induction via EEN, and the mean scores for the PWDI high energy drinks component and PA2020-AHEI sugar-sweetened beverages component reflect low intake of these liquids (less than one standard pop can per day), it is possible the sample was consuming EN formula and other liquids not captured by the FFQ/indices [64]. For example, a pre-diagnosis dietary pattern with higher liquid consumption has been described in Canadian girls with CD [31].

Despite the observed significant negative correlation and relationship between the Western-to-Prudent ratio and the PA2010-AHEI, only half the variance in the PA2010-AHEI scores was explained by the ratio. This may be due to differences in the components of the three indices. The PA2010-AHEI does not capture four components included in the PWDI (high-fat dairy products, eggs, potatoes) and PPDI (poultry). It also assesses nut and sodium intake, which are not part of the other indices. Variability in the indices' assessment of certain dietary intake (e.g., omega-3) may have impacted correlation. Additionally, the Western-to-Prudent ratio results were interpreted with the assumption that if an individual has a high PWDI score, they have a low PPDI score (and vice versa); this would be violated in the context of high or low intake of foods from both patterns.

The results of the analysis help describe the dietary intake of pediatric patients with CD; however, more research is needed in larger, diverse samples to develop a full understanding of this population's dietary pattern following remission induction via EEN and at other points in disease course. Additional data could assist with development of a standard whole-food-based MNT for pediatric CD, which is an emerging area of research. More information on this population's habitual dietary intake could also help with the implementation of MNT, as patients required to make dietary changes benefit from tailored, comprehensive nutrition education strategies [65,66].

Dietary indices can also be used to assess adherence to MNT for CD, such as the CDED. Using a validated tool to assess adherence to MNT can contribute to evidence for and the understanding of the therapy's effectiveness. Integrating validated measurements of adherence into dietary intervention protocols would also support monitoring and allow for identification of patients who require additional education and/or support to achieve adherence. Since dietary indices do not capture all dietary intake, they should be used to assess/monitor adherence in conjunction with other dietary intake assessment methods and detailed review of intake by a trained clinician within an interdisciplinary setting [67,68].

There are several limitations to this work. The indices did not completely describe the sample's intake, a limitation inherent to *a priori* analysis and FFQs. Recall bias and completion of the FFQ at home without support from clinicians may have impacted data quality. The analysis used a small subsample of the MAREEN Study, and demographic information (except age and sex) and markers of nutrition status and disease activity were not part of the analysis protocol. Therefore, the results may not be representative of the entire MAREEN sample, the Canadian pediatric CD population, or different demographic groups within this population. Dietary intake, and therefore index scores, may vary depending on disease activity and nutrition status. It should be noted that small sample sizes are common in pediatric CD research and the FFQ response rate is similar to those reported in the literature [6,10,69–71]. However, seasonal activities may have impacted the response rate.

## RELEVANCE TO PRACTICE

The results of this work contribute to the existing knowledge of dietary intake of Canadian pediatric patients with CD and demonstrate the PPDI, PWDI, and the PA2010-AHEI have potential utility in dietary assessment of this population. While index validation studies are needed, this work highlights an opportunity to stimulate standardization of dietary assessment in pediatric CD. Rigorous dietary assessment methodology that includes standardized tools and administration protocols has the potential to strengthen data on the diet–CD relationship and further contribute to the prevention and treatment of CD. As dietary assessment is implemented in this population, consultation with appropriate nutrition and foods academics, clinicians, and professionals is needed to ensure appropriate data collection methods and tools are used.

## Supplementary material

Supplementary data are available with the article through the journal Web site at https://doi.org/10.3148/cjdpr-2024-005

### Acknowledgements

The authors thank all participants and their families who made this study possible. The MIRAPeds team was involved in the MAREEN Study implementation and supported the completion of the DPA. Leah Boulos (Maritime SPOR SUPPORT Unit) assisted in the literature review of existing Canadian and American dietary pattern indices.

**Financial support:** The MAREEN Study has received funding from the North American Society for Pediatric Gastroenterology, Hepatology and Nutrition (NASPGHAN) through the NASPGHAN Foundation Young Investigators Development Award (2013–2015.) In addition, JVL was supported by a Canadian Institutes of Health Research (CIHR)-Canadian Association of Gastroenterology-Crohn's Colitis Canada New Investigator Award (2015–2019), a Canada Research Chair Tier 2 in Translational Microbiomics (2018–2019) and a Canadian Foundation of Innovation John R. Evans Leadership fund (awards #35235 and #36764), a Nova Scotia Health Research Foundation (NSHRF) establishment award (2015–2017), an IWK Health Centre Research Associateship, a Future Leaders in IBD project grant, a donation from the MacLeod family, a CIHR-SPOR-Chronic Diseases grant (Inflammation, Microbiome, and Alimentation: Gastro-Intestinal and Neuropsychiatric Effects: the IMAGINE-SPOR Chronic Disease Network), and the Wetenschappelijke Adviesraad of Stichting Steun Emma kinderziekenhuis. SG was supported by a Mount Saint Vincent University New Scholar Grant (grant number 42-0-165426) during the study period. AH received a CIHR Canada Graduate Scholarship for the 2016/2017 academic year. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

**Competing interests:** AH reports travel support from The Wolfson Medical Centre Pediatric Inflammatory Bowel Disease (PIBD) Retreat Grant. JVL reports consulting, travel and/or speaker fees, and research support from AbbVie, Janssen, Nestlé Health Science, Novalac, Pfizer, Merck, P&G, GSK, Illumina, and Otsuka. SG, BM, MP, LC, JC, and AO declare no actual or perceived conflict of interest.

**Note:** A previous version of this article was published with incomplete authorship; the current version is complete and correct.

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