CORA Cork Open Research Archive
Cartlann Taighde Oscailte Chorcaí

Title	Research gaps in diet and nutrition in inflammatory bowel disease. A topical review by D-ECCO Working Group (Dietitians of ECCO)
Authors	Sigall-Boneh, Rotem;Levine, Arie;Lomer, Miranda;Wierdsma, Nicolette;Allan, Philip;Fiorino, Gionata;Gatti, Simona;Jonkers, Daisy;Kierkuś, Jarosław;Katsanos, Konstantinos H.;Melgar, Silvia;Yuksel, Elif Saritas;Whelan, Kevin;Wine, Eytan;Gerasimidis, Konstantinos
Publication date	2017-08-10
Original Citation	Sigall-Boneh, R., Levine, A., Lomer, M., Wierdsma, N., Allan, P., Fiorino, G., Gatti, S., Jonkers, D., Kierkuś, J., Katsanos, K. H., Melgar, S., Yuksel, E. S., Whelan, K., Wine, E. and Gerasimidis, K. (2017) 'Research gaps in diet and nutrition in inflammatory bowel disease. A topical review by D-ECCO Working Group (Dietitians of ECCO)', Journal of Crohn's and Colitis, 11(12), pp. 1407-1419. doi:10.1093/ecco-jcc/jjx109
Type of publication	Article (peer-reviewed)
Link to publisher's version	10.1093/ecco-jcc/jjx109
Rights	© 2017, European Crohn's and Colitis Organisation (ECCO). Published by Oxford University Press. All rights reserved. This is a pre-copyedited, author-produced version of an article accepted for publication in Journal of Crohn's and Colitis following peer review. The version of record is available online at: https://doi.org/10.1093/ecco-jcc/jjx109
Download date	2026-11-07 08:17:53
Item downloaded from	https://hdl.handle.net/10468/4768



University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

Manuscript Doi: 10.1093/ecco-jcc/jjx109

Title: Research Gaps in Diet and Nutrition in Inflammatory Bowel Disease. A Topical Review by D-ECCO Working Group (Dietitians of ECCO)

Rotem Sigall-Boneh, Arie Levine, Miranda Lomer, Nicolette Wierdsma, Philip Allan, Gionata Fiorino, Simona Gatti, Daisy Jonkers, Jarosław Kierkuś, Konstantinos H. Katsanos, Silvia Melgar, Elif Saritas Yuksel, Kevin Whelan, Eytan Wine, Konstantinos Gerasimidis*

***Corresponding author**

Dr Konstantinos Gerasimidis
Human Nutrition
School of Medicine
College of Medical, Veterinary and Life Sciences
University of Glasgow
New Lister Building
Glasgow Royal Infirmary
Glasgow
UK
G31 2ER
Tel: 0044 141 201 8689
Email: konstantinos.gerasimidis@glasgow.ac.uk

Accepted Manuscript

Authors' contributions

All authors drafted the individual sections of the manuscript which were grouped under three thematic areas by AL, ML, RSB. KG collated the individual sections and produced the first complete draft with the assistance of RSB. KW critically edited the manuscript. RSB & KG were the project coordinators. All authors and the Governing Board of ECCO approved the final version for submission.

Copyright © 2017 European Crohn's and Colitis Organisation (ECCO). Published by Oxford University Press. All rights reserved. For permissions, please email: journals.permissions@oup.com

Manuscript Doi: 10.1093/ecco-jcc/jjx109

Contents

Abstract 3
Introduction 4
Methodology 5
1. Role of diet as an environmental factor in IBD aetiology 6
1.1 Diet, Microbiota and Pathogenesis of IBD 6
1.2 Effect of Diet on Rodent Models and Cell Lines 8
1.3 Epidemiology Linking Diet with risk of IBD 10
2. Diet as induction and maintenance therapy in IBD 13
2.1Exclusive Enteral Nutrition in Management of IBD 13
2.2 Partial Enteral Nutrition in Management of IBD 16
2.3 Elimination Diets in Management of IBD 18
3. Assessment of nutritional status and supportive nutritional therapy in IBD 20
3.1 Assessment of Nutritional Status 21
3.2 Supportive therapy in Short Bowel Syndrome in IBD 22
3.3 Supportive nutritonal therapy for functional bowel symptoms in IBD 24
Conclusions 27
DISCLAIMER TEXT 27
CONFLICT OF INTEREST 27
Participant list with full affiliations 27
References 29

Accepted Manuscript

Manuscript Doi: 10.1093/ecco-jcc/jjx109

Abstract

Although the current doctrine of IBD pathogenesis proposes an interaction between environmental factors with gut microbiota in genetically-susceptible individuals, dietary exposures have attracted recent interest and are, at least in part, likely to explain the rapid rise in disease incidence and prevalence. The D-ECCO working group along with other ECCO experts with expertise in nutrition, microbiology, physiology and medicine reviewed the evidence investigating the role of diet and nutritional therapy in the onset, perpetuation and management of IBD. A narrative topical review is presented where evidence pertinent to the topic is summarized collectively under three main thematic domains: i) the role of diet as an environmental factor in IBD aetiology; ii) the role of diet as induction and maintenance therapy in IBD; and iii) assessment of nutritional status and supportive nutritional therapy in IBD. A summary of research gaps for each of these thematic domains is proposed which is anticipated to be agenda setting for future research in the area of diet and nutrition in IBD.

Accepted Manuscript

Manuscript Doi: 10.1093/ecco-jcc/jjx109

Introduction

The current dogma of inflammatory bowel disease (IBD) pathogenesis involves a complex, yet elusive, interaction between environmental factors and the gut microbiota in people who are genetically predisposed. However, the rapid rise in global prevalence of both ulcerative colitis (UC) and Crohn's disease (CD) cannot be attributed to human genetics alone [1]. Evidence now proposes that while human genetics are important, they explain only a small fraction of the risk of developing the disease, with microbial determinants and other environmental exposures thought to be more important than genetic susceptibility [2]. Among environmental factors, dietary influences have attracted the most interest, and are likely to significantly contribute to the rapid rise in disease epidemiology [3]. There are several lines of evidence to suggest that diet is a key player in the onset, perpetuation and management of the disease: Epidemiological evidence associates certain dietary nutrients and components to increased risk of IBD, exclusive enteral nutrition (EEN) is the primary induction treatment of active paediatric CD and there is emerging evidence that exclusion diets could treat or prevent subsequent disease flare. As malnutrition is a frequent presenting symptom of IBD that fluctuates erratically during the course of the disease, assessment of malnutrition and supportive nutritional therapy are important aspects of the multidisciplinary management of patients with IBD [4].

In contrast to the efforts thus far to understand the genetic and microbial origins of IBD or the development of effective and side-effect free pharmacological treatments in IBD, there is currently very little research on the role of nutrition or diet in these areas. As the current doctrine of IBD pathogenesis proposes a complex interplay between dietary influences, genetics and environment in the aetiology of IBD, there is now a pressing need to review past and current research and identify gaps for future research. The aim of this topical review was to extensively review the literature on the role of diet and nutrition in the aetiology and management of IBD and set the agenda for future research.

Accepted Manuscript

Manuscript Doi: 10.1093/ecco-jcc/jjx109

Methodology

A contributors' group was assembled involving all members of the D-ECCO Working Group (https://www.ecco-ibd.eu/index.php/about-ecco/ecco-operational-board/d-ecco-wg.htmland) and competitive application for membership of a Topical Review Group launched by ECCO. Selection of contributors was based on their curriculum vitae, a personal supporting statement and ensuring equal representation of professions and countries, as dictated by ECCO instructions for topical reviews and advised by its Governing Board. Three main thematic areas were selected *a priori* and working groups and thematic leaders were assigned for each.

A thorough literature search was conducted using Medline and a combination of appropriate keywords and Boolean operators. Search was limited to articles published in English and focus was given to recent evidence published over the past 15 years and until January 2016. Draft reports produced by each contributor were reviewed by the thematic leaders and project coordinators. The main research gaps were identified and agreed by consensus in a face-to-face meeting involving all contributing authors in Amsterdam in March 2016. Consensus was defined as agreement of >80% following blind electronic voting and discussion between contributors where required. The final manuscript for publication was reviewed by all members of the Topical Review Group and approved by the Governing Board of ECCO.

Accepted Manuscript

Manuscript Doi: 10.1093/ecco-jcc/jjx109

1. Role of diet as an environmental factor in IBD aetiology

1.1 Diet, Microbiota and Pathogenesis of IBD

Diet can contribute to gastrointestinal health, either via direct effects on gut homeostasis and barrier function or indirectly via the intestinal microbiome (Supplementary Figure 1). This densely populated microbial community is shaped by host genetics and environmental factors, and comprises a limited number of phyla, dominated by Bacteroidetes and Firmicutes [5]. It involves complex microbe-microbe and host-microbe interactions that vary along the gastrointestinal tract, with indispensable effects on host functions with regard to the immune system, epithelial and barrier function and its large metabolic capacity [6]. Segregation into three robust clusters (i.e. 'enterotypes') driven by Bacteroides, Prevotella and Ruminococcus [7], is associated with long-term dietary preferences, (*i.e.* high protein and fat consumption with the Bacteroides and carbohydrate-rich diets with the Prevotella enterotype) [8]. Others reported on a bimodal distribution in microbial gene richness, in which a lower richness was associated with impaired metabolic factors and inflammation [9] and being less responsive to dietary interventions [10].

The global increasing incidence in IBD seems to be associated with western lifestyle [11,12]. Diet can shape the microbiota composition and activity and impact host-microbe interactions. Dietary intake of a high protein diet and/or red meat can result in increased production of bacterial metabolites, such as ammonia, indoles, phenols and sulphide, that may be harmful to the gut [13]. On the other hand, bacterial fermentation of non-digestible carbohydrates, results in short-chain fatty acids (SCFAs), which are an energy source for host epithelial cells and act as signaling molecules with anti-inflammatory, immunomodulatory, anti-oxidative and improved mucosal barrier effects [14]. Fat can have effects on the microbiome by release and conversion of bile salts [15] and altering the microbiota composition [16].

However, it is critical to appreciate the limitations of this rapidly expanding research area [17]. Common to all microbiome studies is the inherent variability (intra- and inter-individual) and the fact that even minor variations in research and laboratory methodology dramatically impact findings; this includes sampling, storage, DNA extraction, amplification, sequencing protocols, and data analysis [18,19]. Disease factors (location, activity, medication, and faecal consistency) also impact the microbiome [20,21] and are often not taken into account. Most importantly, even

Accepted Manuscript

clear associations between microbes and IBD do not establish cause and effect [20,22]. Therefore, interpretation of findings requires caution and findings may not always be reproducible. Nevertheless, there are several emerging specificities regarding the microbiome in IBD:

Diversity: The single most reproducible finding of studies on microbes in IBD is a reduction in α-diversity. Diversity is generally thought to represent community health; reduced diversity results in less flexibility and adaptation and is likely to impact negatively on the microbial functional capacity. Reduced diversity can be the result of taxa elimination and/or bloom of taxa that displace others. Both are likely to occur in IBD [23]. Reduced diversity as a marker of IBD could indicate pathogenic mechanisms; however, it also has prognostic value since reduced richness (representing number of species) predicts failure to respond to corticosteroids in children with severe UC [24]. Recently, a reduction in the diversity of mucosa-associated bacteria was found in paediatric UC at non-inflamed sites, suggesting that the microbial changes may be an inherent defect in IBD and not just the result of inflammation [25].

Compositional changes: For the reasons stated above, it is difficult to commit to specific reproducible alterations in microbiota in IBD. Frequent phylum-level observations include reduction in Firmicutes and Bacteroidetes and an increase in Proteobacteria [26]. Enterobacteriaceae are frequently increased in IBD, and are especially relevant since they include *Escherichia coli* (such as adherent-invasive strains) [27]. Rodent models of colitis have demonstrated that colonisation with adherent-invasive *E. coli* (AIEC) may be affected by diet [28]. Other taxonomic groups are depleted in IBD, such as Clostridia, Ruminococcaceae, and Bifidobacteria, and at species level, many have reported losses of *Faecalibacterium prausnitzii*, which may also have functional roles [22,29]. Beyond the identity of bacteria, one must also consider their spatial organization, which is altered in IBD [30]. Some of the observed changes are mediated by access to nutrients and oxygen gradients [31].

Functional changes: Current focus is shifting towards the functional capacity of the microbiome, as ‘what are they doing’ might be more important than ‘who is there’. The European MetaHIT Project identified a functional microbial dysbiosis in patients with IBD [32], supported also by others [33]. Metabolomic analyses of breath or faeces revealed differences in IBD *versus* controls, (e.g. reduced butyrate, acetate, and (tri)methylamine and elevated amino acid levels) [34-36]. Interestingly, individuals with UC appear to have defective or deficient production of SCFA [37,38].

Accepted Manuscript

Furthermore, analysis of microbiota-derived small molecules, considered important mediators in microbe-microbe and microbe-host interactions, reveal a variety of biological actions, including antibiosis and immune modulation [39]. Further studies integrating the metagenome with proteome and/or metabolome data in IBD, and taking into account disease phenotypes, activity and medication use, are needed.

The observed microbial perturbations can result from the disease itself, but may also contribute to inflammation as shown by transfer of microbiota from colitis models to wildtype donors [40,41] and improvement of disease activity after decontamination of the gut lumen [42,43]. So far, microbial modulation of disease activity by administration of probiotics or prebiotics showed limited efficacy [44]. However, findings, mainly resulting from metabolic and animal studies, clearly demonstrate that diet can impact gut homeostasis and immune function via the microbiome.

Research gaps:

- ***Establishing causality between diet, microbiome and IBD is an important research gap. Priority should be given to a systems biology approach.***
- ***Longitudinal studies investigating early life exposure including diet, microbiome, and other environmental factors on IBD onset are needed.***
- ***Stratification of patients by disease phenotype, specific microbial perturbations and dietary intake will be necessary to develop successful therapeutic and/or preventive strategies.***
- ***Studies evaluating the ability to modify the microbiota by dietary interventions, and the effect on disease in affected individuals should be a priority.***

1.2 Effect of Diet on Rodent Models and Cell Lines

Multiple dietary components have been shown to cause or aggravate inflammation in animal models of IBD [20,28,45-47]. Due to the concise nature of this review, we will confine ourselves to landmark studies that demonstrate an association between dietary components and inflammation in IBD models, or those studies that best highlight research gaps.

Key dietary components thought to be possibly associated with CD in animal models and cell lines include high fat (HF), high animal or milk fat, or high fat/high sugar (HF/HS) diets [20,28,45,46], as well as gluten [47], maltodextrin [48], emulsifiers [49-51] titanium dioxide nanoparticles [52], luminal iron [53] and aluminum a food chain contaminant [54].

Accepted Manuscript

All of these are common components of diets in economically-developed countries, so-called 'Western diets'. Martinez-Medina et al [28] used a transgenic CEABAC10 mouse that uniquely expresses CEACAM6, the ligand for CD-associated bacteria AIEC, to compare the effect of standard chow to HF/HS 'Western diet' and AIEC infection. Both wild type and transgenic mice fed a HF/HS diet were more likely to develop dysbiosis, increased intestinal permeability, decreased expression of mucins and mucus thickening. In addition, CEABAC10 mice fed HF/HS were rapidly colonized by AIEC and presented higher degree of crypt abscesses when compared to the standard chow group. Another study highlighting the role of specific fats, namely isocaloric low fat (LF), polyunsaturated fatty acids (PUFA) and milk-derived fat (MF), in IL-10$^{-/-}$ mice was conducted by Devkota and colleagues [20]. They reported an increase in colitis severity in the MF group compared to PUFA- and LF-fed IL-10$^{-/-}$ mice. Colitis was also associated with the bloom of colitogenic *Bilophila wadsworthia* in the MF group, and was dependent of exposure to MF-induced taurine conjugated bile acids. Sodium caprate in MF has been shown to increase intestinal permeability independent of the taurine dependent mechanism previously described [20]. High fat was also shown to accelerate ileitis in a TNF$^{\Delta ARE/WT}$ mouse model [45]. The same group subsequently demonstrated that gluten induced ileitis in these mice through the gluten-dependent increased intestinal permeability [47].

Adherence of AIEC via CEACAM6 appears to be critical for the pathogenic effect of this strain in human CD. Maltodextrin, a key polysaccharide used in sweeteners (Sucralose) and as a thickening agent was shown to enable AIEC adherence and biofilm formation independently of the presence of CEACAM6. In a viewpoint article, Roberts and colleagues hypothesised that the increased incidence of CD could be attributed to a higher consumption of emulsifiers in processed foods [55]. In support of this hypothesis, Chassaing and colleagues [48] showed that TLR5$^{-/-}$ and IL-10$^{-/-}$ mice exposed to two common emulsifiers, carboxymethylcellulose and polysorbate-80, develop obesity/metabolic syndrome in TLR5$^{-/-}$ and severe colitis in IL-10$^{-/-}$. Both mice strains fed the emulsifiers showed increased gut permeability, reduced mucus thickness, higher penetration of intestinal bacteria and dysbiosis. These changes resulted in an accelerated metabolic syndrome in TLR5$^{-/-}$ mice and in an increased incidence and extent of colitis and enrichment in *Bilophila* spp. in IL-10$^{-/-}$ mice with both CMC and polysorbate-80. In line with these results, translocation of *E. coli* across M-cells was increased in the presence of polysorbate-80 [50].

Accepted Manuscript

The studies outlined above accentuate the aggravating effect of HF diets in models of CD, however, the results to date on the effect of HF on disease in animal models of UC are inconclusive [56-59]. The reason being differences in diet composition (e.g. fat/sugar ratio, n-3/n-6 ratio), duration of diet consumption and type of model used. For example, HF or n-6 PUFA feeding to mice exposed to Dextran Sodium Sulphate (DSS)-induced colitis resulted in either worsening or amelioration of disease [56,57,59]. In contrast, HF feeding to Mdr1$^{-/-}$, a spontaneous model of UC, led to worsening of colitis, although no colitis was observed in WT mice [58].

An exciting new concept involves "humanised mice" which may contain human genes or microbiome. Studies involving diet with such models could shed more light on the interaction between diet, microbiome and IBD in humans. An important research gap is the development of a model in which different food ingredients could be tested with relevance to the human condition.

In conclusion, the collected data points towards diet-induced effects on microbiota composition, epithelial responses and inflammation primarily in genetic susceptible animals but less in wild type animals. The translational relevance of these findings to the human conditions is yet to be addressed.

Research gaps:

- ***Studies should evaluate if improvement of intestinal inflammation can be achieved with dietary interventions in animal models***
- ***Development of experimental models as a platform for testing multiple dietary ingredients potential to cause or inhibit inflammation should be a priority.***

1.3 Epidemiology Linking Diet with risk of IBD

Epidemiological evidence shows that individuals migrating from regions of low IBD prevalence to higher-prevalent regions are at increased risk of developing IBD [60]. Numerous studies have evaluated the association between pre-illness intake of specific nutrients such as fats, carbohydrates and protein and food groups such as fruits, vegetables and meats for UC. All were case–control studies and analysed dietary intake retrospectively. The most frequently reported food components associated with IBD were cereals, fibre-containing food, bread, sugar and

Accepted Manuscript

sugar-containing foods, fruits and vegetables, fat, sucrose, starch or total carbohydrate and protein intake or energy drinks [14,61-64].

Despite methodological limitations, several prospective studies have consistently identified animal protein to be associated with increased risk of UC [61,64,65]. In the study by Jantchou *et al*, the highest tertile for consumption of animal protein had a hazard ratio of 3.29 for developing UC (p=0.005). Jowett *et al*. studied 191 UC patients, and they demonstrated a significant association between high meat intake and risk of relapse of UC [65].

Although several studies suggested significant associations of particular dietary habits in UC [14], an equal or even higher number of studies could not confirm these findings. Since many of the current methodologies are based on historical food frequency questionnaires (FFQ) the current evidence is not sufficient to draw firm conclusions on the role of specific nutrients in the aetiology of UC. Dietary ingredients in western diet are not limited to the "natural components" listed above. There is an increased consumption of food additives, such as sweeteners, emulsifiers, thickeners, preservatives and food colorings. These products, some of which have been linked to IBD [49,62,66], should be further investigated in large well-designed epidemiological studies that provide data regarding exposure to these products.

The Nurses' Health Study examined the association between fibre intake and incident IBD. Subjects consuming large amounts of fibre, particularly fruits, were less likely to be subsequently diagnosed with CD, although no association was observed for UC [67]. There is evidence for a gene–diet interaction, in which variants in genes for fatty acid metabolism affect the relationship between IBD risk and PUFA consumption [68]. Together, these findings support the hypothesis that consumption of fruits and possibly vegetables, rather than meats and fats, can lower the risk of IBD. The study using the European Prospective Investigation into Cancer and Nutrition (EPIC) database prospectively investigated the impact of nutrition on IBD development [69]. The EPIC-IBD study is a sub-cohort involving a total of 401,326 initially healthy men between 1991-1998. In this large multicenter prospective study using dietary data from a validated FFQ, they did not find any associations between total dietary carbohydrate, sugars (monosaccharides and disaccharides), or starch intakes and the odds of developing CD and UC. D'Souza *et al* assessed Canadian children for dietary patterns, and idenified a diet rich in fruit and vegetables (prudent diet) as protective for CD while a partial 'Western diet' increased risk for CD [70].

Accepted Manuscript

Manuscript Doi: 10.1093/ecco-jcc/jjx109

Research gaps:

- ***Risk associated with consumption of commercially processed food, including, but not limited to nutrients, additives and processing should be assessed in longitudinal studies***
- ***Future studies should address dietary patterns rather than individual dietary components***

Accepted Manuscript

2. Diet as induction and maintenance therapy in IBD

2.1 Exclusive Enteral Nutrition in Management of IBD

Exclusive enteral nutrition is the most extensively researched dietary intervention for induction of remission in mild to moderate CD both in children and adults. Case series and clinical trials have demonstrated the ability of EEN to induce clinical remission in approximately 80% of patients. Treatment response rates varied depending upon type of study design (retrospective or prospective), type of analysis (per protocol or intention to treat) [71-73], but seem to be independent of type of formula and its constituent nutrients.

In paediatrics, a meta-analysis of studies comparing EEN to standard treatment has demonstrated an overall combined remission rate for EEN of 73% [74,] whereas two large, single-center studies have confirmed a treatment efficacy of approximately 80% [71,73]. Similar remission rates were reported in studies conducted in adults, particularly one randomised controlled study demonstrated that 21/30 adults refractory to steroids entered remission with EEN [75,76]. However, the most recent meta-analysis demonstrated that steroids were more effective than EEN [77]. Studies on EN in adults are sparse, of poor quality and therefore it is difficult to draw clear conclusions. Interestingly, and in contrast to steroids effect, EEN also has the potential to induce mucosal healing. In a prospective Australian study, 58% of patients had early endoscopic response, and one third had complete transmural healing on small bowel imaging [78].

Disease severity and luminal disease seem to be the only significant predictors of response to EEN [69,70]. According to the ECCO/ESPGHAN consensus, EEN should be the first line therapy to induce remission in children with active mild-to-moderate luminal CD [79]. There are no data supporting the use of EEN for extra-intestinal manifestations or penetrating disease.

It has traditionally been speculated that use of EEN should be limited to patients with small bowel involvement, however results from further meta-analyses have shown no difference in the efficacy of EEN when considering disease location [73,74,80]. Likewise, there are no confirmatory data on the effectiveness of such treatment in severe isolated Crohn's pancolitis, and no data for isolated oral or perianal disease.

The efficacy of EEN has been attributed to different mechanisms including bowel rest, anti-inflammatory effects, restoration of the epithelial barrier and favorable changes in the intestinal microbiota [81]. As both polymeric and elemental formulas show similar efficiency [76,82],

Accepted Manuscript

gut rest is unlikely to be the primary mechanism. More recently, the effect of EEN has also been related to the exclusion of specific components from the diet [83].

A few studies have demonstrated a decrease in pro-inflammatory [84] and an increase in anti-inflammatory molecules (TGF-β) [85] in response to EEN. Incubation of CD-biopsies with elemental formula led to an increased ratio of IL-1Ra to IL-1 β compared to control samples [86]. Other authors confirmed the direct effect of a polymeric formula on colonic epithelial cell chemokine responses to the pro-inflammatory cytokine TNF-α [87]. At the mesenteric fat level, EEN treatment decreased pro-inflammatory adipokines (TNF-α and leptin) and increased adiponectin levels [88].

The effects of EEN on the intestinal barrier have mostly been clarified by *in vitro* or animal studies. In human colonic epithelial cells, EEN has been found to prevent epithelial barrier dysfunction in the presence of TNF-α [89]. In IL-10$^{-/-}$ mouse model of colitis, EEN treatment maintained normal gut barrier function and integrity and reversed inflammatory changes [90].

Profound changes in the composition of mucosal microbiome induced by EEN have been suggested by pioneer investigations [91] and recently confirmed by several studies. Reduced diversity of the microbiota, occurring after a few days or weeks of EEN, has been frequently reported [92-95]. The microbiome effect induced by EEN differs from the one induced by anti-TNF medications and most importantly from partial EN (PEN) [96]. In contrast, one study demonstrated an increase in species diversity after elemental diet [97]. Species specific effects induced by EEN were reported by different authors, particularly a significant decrease in Bacteroides [92-94,98]. A reduction of *F. prausnitzii* was observed both in adults [99] and children [92], challenging the previous paradigm of a protective role in CD. Reports describing changes in the intestinal metabolic profile are unequivocal [92,100]. A single study reported the metagenomic changes induced by EEN, particularly an increase in relative abundance of genes involved in cell growth and renewal and possibly in tissue healing [95].

The efficacy of EEN related to the exclusion of some dietary components is indirectly supported by studies indicating that PEN associated with a normal diet did not induce remission [72], while 70% of children and 69% of adults on a PEN combined with a specific CD exclusion diet achieved remission [83]. Furthermore, specific dietary restriction seems to be therapeutic in CD [101,102].

Accepted Manuscript

Manuscript Doi: 10.1093/ecco-jcc/jjx109

There are not enough studies to determine the optimal duration of EEN; the reported duration of an induction therapy varied from 2 to 12 weeks in studies, however it is most frequently used for 6 to 8 weeks. If the clinical response is not achieved within 3 weeks an alternative treatment should be considered. There is a paucity of evidence to guide the reintroduction of normal food after the end of EEN. There are few studies that have evaluated reintroduction of foods. Faiman *et al* demonstrated that rapid food reintroduction (3 days) after EEN is as equally effective as delayed food reintroduction (5 weeks) after follow up of 1 year [103].

Research gaps

- ***Mechanisms of action of EEN need to be explored, including the interaction of epigenetic, immunological and microbiological changes.***
- ***Studies evaluating the reintroduction of specific foods following EEN need to be performed***
- ***EEN should be evaluated in a variety of conditions, including adults with CD, in UC, complicated CD, and pre- and post-operative setting.***

Accepted Manuscript

Manuscript Doi: 10.1093/ecco-jcc/jjx109

2.2 Partial Enteral Nutrition in Management of IBD

Partial enteral nutrition (PEN) is the use of liquid enteral formula in addition to consuming food for maintenance of remission or treatment of active CD; using <100% of total energy requirements from liquid nutrition. There is increasing interest in the use of PEN (Supplementary Table 1). In part, as a result of the limitations of EEN, with food abstinence and the monotony of drinking enteral formula being common reasons for poor compliance to and subsequent success of EEN [104]. The mechanisms via which PEN might impact on CD activity, if at all, are poorly understood. Unlike EEN, the complete removal of dietary antigen as a hypothetical mechanism is no longer the case, therefore if studies indicate that PEN is at least as effective as EEN then this might also exclude this as a mechanism for the effectiveness of EEN.

Type of supplementation varies widely between studies and clinical practice [72,83,105-110]. The volume investigated has ranged from 35-90% of total energy requirements and the food consumed can either be a free diet or a defined restrictive diet. A small number of studies have investigated PEN compared to normal diet for maintenance of remission [105,106,109-112]. One RCT evaluated PEN with normal diet for the maintenance of adults with recently-induced remission of CD [106]. The study was halted early due to an interim analysis showing improved outcome in those following PEN. The relapse rates in the PEN arm (35%) were lower compared with normal diet (64%), with a multivariate adjusted hazard ratio for relapse of 0.40 [106].

Another RCT compared PEN (≥900 kcal/day) with 6-mercaptopurine (6-MP) and to no drug therapy (normal diet, no placebo) [105]. At 2 years, PEN resulted in 56% relapse, 6-MP in 43% (no difference) but both were lower than control normal diet (79%).

Several non-randomised trials have investigated the effect of PEN on maintenance of remission; a selection of key studies is presented here (Supplementary Table 1). In another study, patients in medically-induced remission were selected to continue to have PEN plus low fat diet (if they had previously been compliant to EEN) or to follow normal diet (if they had previously been non-compliant to EEN) [109]. At 12-months, PEN resulted in lower relapse rates, lower disease activity and lower endoscopic inflammation compared with normal diet. In an identical study published by the same group but in those with surgically-induced remission, PEN was confirmed to lower relapse rates and endoscopic recurrence compared with normal diet at 12 months [110], whereas in those with infliximab-induced remission it was not shown to impact relapse rates [113]. Finally a retrospective, non-randomised trial in children with EEN-induced

Accepted Manuscript

remission, compared relapse rates in those who chose to continue nocturnal PEN compared with those who did not [112]. PEN reduced relapse rate at both 6 months and 12 months.

There is only one RCT of PEN in the treatment of active CD in comparison with normal diet. This was a randomised, cross-over trial in adults with on average very mildly active CD and malnutrition [114]. Although some nutritional markers were improved, PEN did not impact on disease activity (Harvey Bradshaw Index) [114]. One RCT has compared elemental PEN and EEN for induction of remission in children with moderate to severely active disease over a six-week period. However, PEN resulted in fewer patients entering remission and a smaller reduction in PCDAI compared with EEN [72].

A recent, non-randomised trial compared PEN with EEN or anti-TNF treatment for the treatment of active CD in children/adolescents, with patients allocated to the intervention based upon the unit in which they were recruited [115]. Following 8-weeks, fewer patients receiving PEN had a clinical response compared with either EEN or with anti-TNF treatment and fewer were in clinical remission. However, the limitation of non-randomised treatment allocation and clinically important differences in baseline characteristics makes interpretation of these findings difficult [115]. One uncontrolled trial has investigated PEN in conjunction with a CD exclusion diet in children/young adults, reporting a clinical response in 78.7% and with 70.2% entering full disease remission [83].

Research gaps

- ***Investigation of the effectiveness of PEN as a monotherapy or in combination with medical therapy for preventing relapse in IBD is a research gap***
- ***The optimal regimen of PEN for maintenance of CD, including the dose, composition, duration, method of delivery of feeding, and nature of the accompanying oral diet should be identified.***

Accepted Manuscript

Manuscript Doi: 10.1093/ecco-jcc/jjx109

2.3 Elimination Diets in Management of IBD

EEN is an effective therapy for induction of remission in CD [74]; however there are drawbacks. EEN is difficult to adhere to, particularly in adults [104], and there is limited evidence for post-EEN strategy. Understanding the mechanism of response could lead to diets that are easier to comply and follow that could be implemented for longer duration.

Several elimination diets have been developed and evaluated for induction of remission, maintenance of remission or improvement of functional symptoms (Supplementary Table 2). This field still lacks adequately powered high quality studies. Most of the published data have severe methodological limitations or did not report standardised clinical outcomes such as remission, decline in inflammation or mucosal healing.

Diets reviewed included the Specific Carbohydrate Diet (SCD) [116], the Crohn's Disease Exclusion Diet (CDED) [83], the Anti-inflammatory diet (IBD-AID) [117], Allergen elimination diet (IgG) [118], the Semi-vegetarian diet (SVD) [119], the low Fermentable Oligo-saccharides, Di-saccharides, Mono-saccharides And Polyols diet (FODMAP) [120,121], and the Mediterranean Diet [122]. Only one study for UC met requirements for outcomes [123]. A summary of these diets is presented in Supplementary Table 2. However, only two diets (SCD and CDED) reported significant improvement in clinical remission and data demonstrating a significant reduction in inflammation and therefore are discussed here.

The theoretical assumption underlying the SCD is that CD is caused by malabsorption of disaccharides and complex carbohydrates resulting in bacterial overgrowth and intestinal injury [124]. Cohen et al [116] conducted a prospective pediatric study in 9 children with active CD using the SCD. Patients were evaluated using the PCDAI, Harvey-Bradshaw Index (HBI), and Lewis score at baseline, week 12 and week 52. At week 12, 6/10 entered remission (PCDAI<10) and 8/10 showed significant mucosal improvement (P=0.012) compared with baseline. The Lewis score declined significantly from 2153±732 to 960±433 (P=0.012). Three patients had scores consistent with mucosal healing. Seven patients continued the diet up to 52 weeks, by which

Accepted Manuscript

point the HBI (0.1 ± 0.4) and PCDAI (5.4 ±_5.5) remained low (P = 0.016 and 0.027 compared to baseline), with 2 patients showed sustained mucosal healing. Obih et al [101] conducted a retrospective study with the SCD in 26 patients (20 CD, 6 UC). They demonstrated an improvement in the abbreviated PCDAI during 12 months, however several patients received additional induction medication while others started the diet while being in remission. Walters et al [125] evaluated the composition and complexity of the gut microbiota and resolution of IBD symptoms between the SCD and a Low Residue Diet. They demonstrated a general increase in the microbial diversity of faecal samples under the SCD and decrease in diversity among the Low Residue Diet.

The Crohn's Disease Exclusion Diet (CDED) is based on exclusion of dietary components that in rodent models have been demonstrated to impair innate immunity, increase intestinal permeability, cause microbial dysbiosis or allow bacteria to adhere and translocate through the intestine epithelium. The diet is rich in fibre and natural sources of resistant starch. Sigall Boneh et al [83] conducted a retrospective study to demonstrate their experience in 47 children and young adults with active CD treated for 12 weeks. Patients were reviewed at baseline, week 6 and week 12 and were evaluated with PCDAI, HBI, CRP, ESR, and albumin at each point. The diet was coupled with Partial Enteral Nutrition up to 50% of the energy requirements in most cases. After 6 weeks, clinical remission was achieved in 33/47 patients (70%). Six out of seven (85.7%) patients who used the diet without supplemental formula, entered remission. Normalization of CRP was obtained in 21/30 (70%) patients with previously elevated CRP. At last follow-up, 11/15 patients evaluated had complete mucosal healing. This diet is currently being evaluated in two prospective randomised controlled trials.

Chiba et al conducted a prospective two year trial to evaluate the effect of a semi-vegetarian diet in maintenance of remission in 22 adult patients in medical remission, with the control group comprising only 6 patients on regular diet. After 2 years of follow up, 16/22 patients continued the semi-vegetarian diet and 15/16 maintained remission compared to 2/6 in the control group (p=0.0003) [119].

The original rationale for the low FODMAP diet in IBD was that several dietary FODMAPs may undergo fermentation that may cause tissue injury as a result of increased intestinal permeability [126]. The use of FODMAP diet to manage functional symptoms in patients with IBD will be discussed later in this topical review.

Accepted Manuscript

In conclusion, dietary manipulation offers promise for IBD, however there is an urgent need for RCTs to evaluate the efficacy of those diets together with their effect on the microbiota.

Research gaps

- ***Clinical trials to develop and evaluate efficacy of elimination diets for induction and maintenance of remission in IBD are required***
- ***Dietary ingredients added or eliminated that are responsible for the clinical effects, and definition of mechanisms underlying response need to be identified.***

3. Assessment of nutritional status and supportive nutritional therapy in IBD

Malnutrition is an extra-intestinal manifestation of IBD comprising undernutrition and overnutrition. It presents with different forms via a range of mechanisms and its severity varies during the natural course of IBD (Supplementary Figure 2). The origin and manifestations of undernutrition in IBD are multifactorial including suboptimal nutritional intake, alterations in energy/nutrient requirements and metabolism, malabsorption, excessive gastrointestinal losses and medication [4]. While literature is still inconclusive, a higher basal metabolic rate:FFM ratio has regularly been reported in IBD patients compared with healthy controls [127-129] and children with CD fail to adapt their resting energy expenditure (REE) per kg lean mass to the same extent that patients with anorexia do [127]. In adult CD patients, malabsorption is a major contributor to being underweight when in remission [130] and impaired gastric acid and pancreatic enzyme secretion were observed in undernourished patients [131]. The effect of proinflammatory cytokines on energy/nutrient requirements, bone and development can also interact independently in the

Accepted Manuscript

aetiology of undernutrition [132]. Physical activity as contributor of total energy expenditure has barely been studied [133]. Hence, assessment of nutritional status, prevention and correction of deficits is imperative and the cornerstone to multidisciplinary management of IBD patients.

3.1 Assessment of Nutritional Status

Involuntary weight loss and being underweight are common features of the newly diagnosed IBD patient and frequently accompany episodes of disease relapse. Whilst more common in CD than UC, presenting in approximately 60% and 35% of new cases respectively [4], recent evidence suggests that fewer patients currently present underweight, reflecting either the obesity epidemic or earlier disease recognition [134,135]. There are limited data on the progression of undernutrition following diagnosis and whether this is predictive of disease outcomes. In a paediatric study, a similar proportion of children with CD had short stature two years post-diagnosis but being underweight decreased dramatically from 35% to 2% [134].

IBD-specific alterations in body composition, with depletion of lean mass and normal or increased fat mass have been consistently reported [136]. Hence, a high degree of adiposity and less lean mass should be expected for a given BMI. Interestingly, normalisation of BMI at two years follow-up has not been associated with an increment in fat-free mass (FFM) in CD [137], which suggests that BMI changes may not be good proxies for body composition changes in IBD. Such features of sarcopenia might be clinically relevant as people with IBD may have an increased risk of cardiovascular events [138] and recently intra-abdominal body composition has been associated with adverse clinical outcomes but both of these findings need to be replicated in prospective studies [139,140].

Osteopenia and osteoporosis are often seen in CD. Adult patients have a 60–70% higher risk for vertebral and hip fracture incidence compared with healthy controls [59,141]. In children, data are not suggestive of increased fracture risk during childhood but it might be that a higher risk of fracture occurs early in adulthood. Up to 25% of CD patients will present with growth deficits, and a proportion will not attain their height predicted by genetic potential [142].

While clinical presentation of frank micronutrient deficiencies in IBD is rare and largely limited to case reports, low circulating levels are reported for most of micronutrients [4,143]. However, caution should be paid in the interpretation of plasma micronutrient measurements in

Accepted Manuscript

the presence of systemic inflammatory response (e.g. high CRP). Plasma concentrations of various micronutrients (e.g. iron, zinc, selenium, copper, vitamins A, C and E) are substantially affected by nutrient carrier protein concentration changes [144-146] so are unlikely to reflect total body reserves and inappropriate clinical interpretation may trigger unnecessary interventions [147]. Development of novel biomarkers of micronutrient body stores are required and dietary intake assessment should complement biochemical indices.

In contrast to the wealth of data on clinical diagnostics and pharmacological management of IBD, limited data have explored the frequency of routine nutritional assessment and management of IBD, particularly in elderly patients where data are scarce. Data from a United Kingdom survey identified adult service resource gaps/shortages and absence of uniform practice standards on nutritional assessment and management [104]. Assessment of nutritional status requires at least measurement and interpretation of anthropometry and dietary intake, making dietitians integral members of the multi-disciplinary team caring for patients with IBD [148]. Assessment of body composition using sophisticated techniques is appealing, but the implications of this for clinical practice improvement and patient benefit need to be explored and justify the resources used.

Research gaps

- ***There are limited data on the evolution of malnutrition following diagnosis and whether this is predictive of disease outcomes.***
- ***New biomarkers of micronutrient status are needed to overcome limitations of plasma measurements in the presence of systemic inflammatory response.***
- ***More research is needed on nutritional status and management of IBD patients, particularly in pregnancy, the elderly and pre-operative state.***

Accepted Manuscript

3.2 Supportive therapy in Short Bowel Syndrome in IBD

Short bowel syndrome (SBS) is a rare but devastating complication of IBD characterised by malabsorption, typically following extensive or repeated intestinal resection. It is a form of (temporary) intestinal failure or intestinal insufficiency compromising fluid, electrolyte, and nutrient malabsorption leading to dependency of intravenous supplementation required for

growth and health maintenance (e.g. in high-output (ileal) stoma or enterocutaneous fistula) [149-151]. Retrospective case-control studies report that early onset, family history of IBD, stricturing disease, younger age at first surgery, surgical complications and delay in diagnosis predispose towards SBS and intestinal failure in IBD [152-156].

Since SBS is accompanied by reduced intestinal surface, a biomarker is needed to diagnose clinically significant reduced intestinal mass/ intestinal function and monitor adaptation and mucosal healing. Potential biomarkers are serum citrulline (generation test) and intestinal fatty acid binding protein (I-FABP) [157-159]. Studies on biomarkers that can predict or diagnose the presence of intestinal failure/intestinal insufficiency are required.

Glucagon-like peptide-2 (GLP-2; Teduglutide) enhances structural adaptation of the small intestinal mucosa in patients with SBS [160-162]. Studies are lacking on the reparative (adaptation, mucosal healing) and immunomodulatory effects of GLP-2 in IBD patients with SBS.

Intestinal transplantation may be considered in intestinal failure as a high-risk, last option treatment. A prospective study in 20 CD patients with chronic intestinal failure who were dependent on parenteral nutrition (PN) suggested that a scoring system enables the physician to identify which patients may benefit from intestinal transplantation before PN-associated secondary organ failure develops [163]. Further work assessing which CD patients with intestinal failure receiving PN will benefit from intestinal transplantation are necessary to improve clinical and patient outcomes.

Enterocutaneous fistula can often be a serious complication of CD. Aggressive nutritional support to treat sepsis and reverse catabolic state can improve outcome [164]. Enteral nutrition for three months is an effective therapeutic strategy [165] and can prevent enterocutaneous fistula post-operatively in CD [166]. PN can also have a supportive role where enteral nutrition is compromised, but evidence is lacking on the efficacy to heal enterocutaneous fistula and other complicated fistulas in CD patients [167]. Whether EN or PN is a more effective nutritional strategy in patients with fistulizing CD needs to be further elucidated.

Accepted Manuscript

High-output stomas in CD are common within three weeks of ileostomy and resolve spontaneously in almost half of patients, while the remaining need ongoing treatment due to a short small-intestinal remnant. Successful treatments include hypotonic fluid restriction, oral rehydration solution, salt rich diets, exclusive enteral nutrition and/or short-term parenteral electrolytes [168-171]. Prospective research on optimal nutritional strategies to manage high-output stomas in IBD preventing dehydration and avoiding acute hospital admission (e.g. hypotonic fluid restrictions, and/or oral rehydration solutions, iv-glucose-sodium) should be compared with 'free diet'. Patient reported outcomes (e.g. quality of life) should also be considered.

Multiple factors relating to clinical, social, and economic issues contribute to lower quality of life (QOL) in patients dependent upon home PN[172]. Living with CD and intestinal failure reduces QOL and hugely impacts day-to-day living and inhibits autonomy [173], however there is limited research on QOL in CD patients with SBS.

Multidisciplinary team working is crucial for optimising the management of SBS/intestinal failure in IBD [174]. The value of the dietitian is important where available, however when not available, it is unknown whether there are failings in clinical and patient outcomes.

Research gaps

- ***New biomarkers that can predict, diagnose, monitor intestinal failure or intestinal insufficiency are needed in IBD***
- ***Nutritional treatment strategies for the management of high output stoma and intestinal failure/insufficiency in IBD need to be developed***

3.3 Supportive nutritonal therapy for functional bowel symptoms in IBD

Functional bowel symptoms include abdominal pain, bloating, increased flatulence, diarrhoea and/or constipation and affect 35% of patients with inactive IBD [175]; however, these symptoms can be mistaken for active IBD. Patients with IBD and coexisting functional bowel symptoms

Accepted Manuscript

also exhibit increased anxiety/depression and reduced QOL compared with patients without [176]. Clinical (symptoms) and objective (histological and inflammatory markers (e.g. faecal calprotectin, CRP)) assessment helps to distinguish between functional bowel symptoms and active IBD, although often the diagnostic validity is poor [177,178]. Identification of functional bowel symptoms in inactive IBD is of utmost importance to ensure unnecessary and potentially harmful treatment strategies are avoided, conversely presence of active IBD lesions should be excluded before determining that symptoms are functional in nature.

Similar treatment strategies as those used in irritable bowel syndrome (IBS) such as antispasmodics, antidiarrhoeals and low dose antidepressants can be used for functional bowel symptoms in IBD, however there is limited research on their safety and effectiveness in IBD. From a dietary perspective, identification of dietary triggers can be helpful [179] but is difficult to determine the culprits due to the complexity of the diet and delay of symptom generation following consumption of the food or ingredient. In IBS, alteration of dietary fibre intake can be beneficial [180,181]; however, there is limited research for functional bowel symptoms in IBD. A low (FODMAP) diet is recognized as a successful management strategy for functional bowel disorders like IBS [180,182]. FODMAPs are poorly absorbed carbohydrates that can increase small intestinal luminal water and colonic fermentation by the gastrointestinal microbiota [183-185] which, in susceptible individuals, induces functional bowel symptoms [182]. Some FODMAPs are prebiotic (e.g. fructo-oligosaccharides and galacto-oligosaccharides presumably having a beneficial effect on the gastrointestinal microbiota. In IBS, short-term FODMAP reduction correlates with reduced luminal Bifidobacterium spp. and *F. prausnitzii* [186,187] which may negatively impact the gastrointestinal microbiome. For this reason, the low FODMAP diet incorporates short-term FODMAP restriction (4-8 weeks) to induce symptom control, followed by FODMAP reintroduction using food challenges to personal tolerance. Thus, in the long-term, only high FODMAP foods that trigger symptoms are avoided maintaining long-term nutritionally adequacy [188]. Whether the gastrointestinal microbial changes seen following FODMAP restriction return to normal in the long term is unknown.

In active Crohn's disease, a RCT of FOS supplementation significantly increased the incidence and severity of abdominal symptoms compared to placebo, although it was not known if any of these patients had concomitant IBS [189]. A double-blind crossover, re-challenge RCT in

Accepted Manuscript

patients with inactive IBD and functional bowel symptoms who had responded to a low FODMAP diet showed that FOS, but not GOS or the polyol sorbitol, induced symptoms [190].

In a retrospective case-note review of 72 IBD patients (CD=52) who had previously received low FODMAP dietary advice, 56% reported overall symptom improvement [121]. A prospective study of the low FODMAP diet in 88 IBD patients (CD=39) showed significantly more patients reported satisfactory relief from their functional bowel symptoms at follow-up (78%) compared to baseline (16%; $p<0.001$) [191]. Abdominal pain, bloating, flatulence, belching, incomplete evacuation, nausea and heartburn also improved. Similar findings were reported when Crohn's and ulcerative colitis were sub-analysed. In a non-blinded RCT in patients with inactive IBD and functional bowel symptoms greater symptom ($p=0.02$) and QOL ($p<0.001$) improvements were reported for the low FODMAP diet (n=44) versus habitual diet (n=45) [192].

Research gaps

- ***Mechanisms of food-related functional symptoms in IBD need to be identified***
- ***Functional symptoms should be assessed after excluding inflammation, food intolerance, coeliac disease etc.***
- ***Studies are needed to demonstrate whether dietary interventions are effective and safe for the management of functional symptoms in patients with inactive IBD.***

Accepted Manuscript

Manuscript Doi: 10.1093/ecco-jcc/jjx109

Conclusions

Hereby, we provide a summary of our current knowledge and emerging evidence on the broad role of diet and nutrition in the aetiology and management of IBD. The subject is topical and findings of current and future multidisciplinary research are expected to have major impact on understanding the dietary influences of CD onset and improving dietary therapies in all aspects of IBD management. We propose a list of research gaps that we anticipate to set the future research agenda in the topic of nutrition and diet in IBD.

DISCLAIMER TEXT

The ECCO Topical Review Projects are based on an international consensus process. Any treatment decisions are a matter for the individual clinician and should not be based exclusively on the content of the ECCO Topical Reviews. The European Crohn's and Colitis Organisation and/or any of its staff members and/or any consensus contributor may not be held liable for any information published in good faith in an ECCO Topical Review.

CONFLICT OF INTEREST

ECCO has diligently maintained a disclosure policy of potential conflicts of interests (CoI). The conflict of interest declaration is based on a form used by the International Committee of Medical Journal Editors (ICMJE). The CoI statement is not only stored at the ECCO Office and the editorial office of JCC but also open to public scrutiny on the ECCO website (https://www.ecco-ibd.eu/about-ecco/ecco-disclosures.html) providing a comprehensive overview of potential conflicts of interest of authors.

Participant list with full affiliations

Philip Allan, Department of Translational Gastroenterology, John Radcliffe Hospital, Headley Way, Headington, OX3 9DU Oxford, UNITED KINGDOM

Gionata Fiorino, Department of Gastroenterology, IBD Center, Humanitas Research Hospital, Via Manzoni 56, Building 4, Stanza 28, 20089 Rozzano, ITALY

Accepted Manuscript

Manuscript Doi: 10.1093/ecco-jcc/jjx109

Simona Gatti, Department of Paediatrics, Polytechnic University of Marche Via Corridoni 11, 60123 Ancona, ITALY

Konstantinos Gerasimidis, Human Nutrition, School of Medicine, Dentistry and Nursing, University of Glasgow, New Lister Building Glasgow, Royal Infirmary, G31 2ER Glasgow, UNITED KINGDOM

Daisy Jonkers, Division Gastroenterology-Hepatology, Department of Internal Medicine, NUTRIM School for Nutrition and Translational Research in Metabolism, Maastricht University Medical Center+ (MUMC+), P.O. Box 5800, 6202 AZ Maastricht, THE NETHERLANDS

Konstantinos H. Katsanos, Department of Gastroenterology and Hepatology, University and Medical School of Ioannina, Leoforos Stavrou Niarhou, P.O. Box 1186, 45110 Ioannina, GREECE

Jarosław Kierkuś, Department of Gastroenterology, Hepatology, Feeding Disorders and Pediatrics, Children's Memorial Health Institute, Al. Dzieci Polskich 20, Warsaw, POLAND

Arie Levine, Paediatric Gastroenterology & Nutrition Unit, Wolfson Medical Center, Tel Aviv University, 62 Halohamim Str, 58100 Holon, Tel Aviv, ISRAEL

Miranda Lomer, Department of Nutrition and Dietetics, Guy's and St Thomas' NHS Foundation Trust and King's College London, London, Se1 7EH, UNITED KINGDOM

Silvia Melgar, APC Microbiome Institute, University College Cork, Cork, IRELAND

Elif Saritas Yuksel, Department of Gastroenterology, Izmir Katip Celebi University Ataturk Teaching and Research Hospital, Basin sitesi, 35350 Izmir, TURKEY

Rotem Sigall-Boneh, PIBD Research Center, Pediatric Gastroenterology and Nutrition Unit, Edith Wolfson Medical Center, 62 Halohamim Street, 58100 Holon, ISRAEL

Kevin Whelan, King's College London, Division of Diabetes and Nutritional Sciences, 150 Stamford Street, SE1 9NH London, UNITED KINGDOM

Nicolette Wierdsma, Department of Nutrition and Dietetics, VU University Medical Centre, De Boelelaan 1117, 1081 HV, Amsterdam, THE NETHERLANDS

Eytan Wine, Division of Paediatric Gastroenterology and Nutrition, Departments of Paediatrics and Physiology, University of Alberta, 11405 87th Avenue, T6G 1C9 Edmonton, AB, CANADA

Accepted Manuscript

Manuscript Doi: 10.1093/ecco-jcc/jjx109

References

1. Henderson P, Hansen R, Cameron FL*, et al.* Rising incidence of pediatric inflammatory bowel disease in scotland. *Inflammatory bowel diseases* 2012;**18**:999-1005.
2. Jostins L, Ripke S, Weersma RK*, et al.* Host-microbe interactions have shaped the genetic architecture of inflammatory bowel disease. *Nature* 2012;**491**:119-24.
3. Lee D, Albenberg L, Compher C*, et al.* Diet in the pathogenesis and treatment of inflammatory bowel diseases. *Gastroenterology* 2015;**148**:1087-106.
4. Gerasimidis K, McGrogan P, Edwards CA. The aetiology and impact of malnutrition in paediatric inflammatory bowel disease. *Journal of human nutrition and dietetics : the official journal of the British Dietetic Association* 2011;**24**:313-26.
5. Wu GD, Bushmanc FD, Lewis JD. Diet, the human gut microbiota, and ibd. *Anaerobe* 2013;**24**:117-20.
6. Wlodarska M, Kostic AD, Xavier RJ. An integrative view of microbiome-host interactions in inflammatory bowel diseases. *Cell host & microbe* 2015;**17**:577-91.
7. Arumugam M, Raes J, Pelletier E*, et al.* Enterotypes of the human gut microbiome. *Nature* 2011;**473**:174-80.
8. Wu GD, Chen J, Hoffmann C*, et al.* Linking long-term dietary patterns with gut microbial enterotypes. *Science (New York, NY)* 2011;**334**:105-8.
9. Le Chatelier E, Nielsen T, Qin J*, et al.* Richness of human gut microbiome correlates with metabolic markers. *Nature* 2013;**500**:541-6.
10. Cotillard A, Kennedy SP, Kong LC*, et al.* Dietary intervention impact on gut microbial gene richness. *Nature* 2013;**500**:585-8.
11. Spooren CE, Pierik MJ, Zeegers MP*, et al.* Review article: The association of diet with onset and relapse in patients with inflammatory bowel disease. *Alimentary pharmacology & therapeutics* 2013;**38**:1172-87.
12. Wu GD. Diet, the gut microbiome and the metabolome in ibd. *Nestle Nutrition Institute workshop series* 2014;**79**:73-82.
13. Yao CK, Muir JG, Gibson PR. Review article: Insights into colonic protein fermentation, its modulation and potential health implications. *Alimentary pharmacology & therapeutics* 2016;**43**:181-96.
14. Tilg H, Moschen AR. Food, immunity, and the microbiome. *Gastroenterology* 2015;**148**:1107-19.
15. Zoetendal EG, de Vos WM. Effect of diet on the intestinal microbiota and its activity. *Current opinion in gastroenterology* 2014;**30**:189-95.
16. Cani PD, Everard A. Talking microbes: When gut bacteria interact with diet and host organs. *Molecular nutrition & food research* 2016;**60**:58-66.
17. Dubilier N, McFall-Ngai M, Zhao L. Microbiology: Create a global microbiome effort. *Nature* 2015;**526**:631-4.

Accepted Manuscript

18. Mirsepasi H, Persson S, Struve C*, et al.* Microbial diversity in fecal samples depends on DNA extraction method: Easymag DNA extraction compared to qiaamp DNA stool mini kit extraction. *BMC research notes* 2014;**7**:50.
19. Sankar SA, Lagier JC, Pontarotti P, Raoult D, Fournier PE. The human gut microbiome, a taxonomic conundrum. *Systematic and applied microbiology* 2015;**38**:276-86.
20. Devkota S, Wang Y, Musch MW*, et al.* Dietary-fat-induced taurocholic acid promotes pathobiont expansion and colitis in il10-/- mice. *Nature* 2012;**487**:104-8.
21. Ding T, Schloss PD. Dynamics and associations of microbial community types across the human body. *Nature* 2014;**509**:357-60.
22. Kostic AD, Xavier RJ, Gevers D. The microbiome in inflammatory bowel disease: Current status and the future ahead. *Gastroenterology* 2014;**146**:1489-99.
23. Wine E. Should we be treating the bugs instead of cytokines and t cells? *Digestive diseases* 2014;**32**:403-9.
24. Michail S, Durbin M, Turner D*, et al.* Alterations in the gut microbiome of children with severe ulcerative colitis. *Inflammatory bowel diseases* 2012;**18**:1799-808.
25. Alipour M, Zaidi D, Valcheva R*, et al.* Mucosal barrier depletion and loss of bacterial diversity are primary abnormalities in paediatric ulcerative colitis. *Journal of Crohn's & colitis* 2016;**10**:462-71.
26. Gevers D, Kugathasan S, Denson LA*, et al.* The treatment-naive microbiome in new-onset crohn's disease. *Cell host & microbe* 2014;**15**:382-92.
27. Chassaing B, Darfeuille-Michaud A. The commensal microbiota and enteropathogens in the pathogenesis of inflammatory bowel diseases. *Gastroenterology* 2011;**140**:1720-28.
28. Martinez-Medina M, Denizot J, Dreux N*, et al.* Western diet induces dysbiosis with increased e coli in ceabac10 mice, alters host barrier function favouring aiec colonisation. *Gut* 2014;**63**:116-24.
29. Sokol H, Pigneur B, Watterlot L*, et al.* Faecalibacterium prausnitzii is an anti-inflammatory commensal bacterium identified by gut microbiota analysis of crohn disease patients. *Proceedings of the National Academy of Sciences of the United States of America* 2008;**105**:16731-6.
30. Lavelle A, Lennon G, O'Sullivan O*, et al.* Spatial variation of the colonic microbiota in patients with ulcerative colitis and control volunteers. *Gut* 2015;**64**:1553-61.
31. Albenberg L, Esipova TV, Judge CP*, et al.* Correlation between intraluminal oxygen gradient and radial partitioning of intestinal microbiota. *Gastroenterology* 2014;**147**:1055-63.e8.
32. Qin J, Li R, Raes J*, et al.* A human gut microbial gene catalogue established by metagenomic sequencing. *Nature* 2010;**464**:59-65.
33. Erickson AR, Cantarel BL, Lamendella R*, et al.* Integrated metagenomics/metaproteomics reveals human host-microbiota signatures of crohn's disease. *PloS one* 2012;**7**:e49138.
34. Bodelier AG, Smolinska A, Baranska A*, et al.* Volatile organic compounds in exhaled air as novel marker for disease activity in crohn's disease: A metabolomic approach. *Inflammatory bowel diseases* 2015;**21**:1776-85.
35. Le Gall G, Noor SO, Ridgway K*, et al.* Metabolomics of fecal extracts detects altered metabolic activity of gut microbiota in ulcerative colitis and irritable bowel syndrome. *Journal of proteome research* 2011;**10**:4208-18.
36. Marchesi JR, Holmes E, Khan F*, et al.* Rapid and noninvasive metabonomic characterization of inflammatory bowel disease. *Journal of proteome research* 2007;**6**:546-51.
37. James SL, Christophersen CT, Bird AR*, et al.* Abnormal fibre usage in uc in remission. *Gut* 2015;**64**:562-70.
38. Khalil NA, Walton GE, Gibson GR, Tuohy KM, Andrews SC. In vitro batch cultures of gut microbiota from healthy and ulcerative colitis (uc) subjects suggest that sulphate-reducing

Accepted Manuscript

bacteria levels are raised in uc and by a protein-rich diet. *International journal of food sciences and nutrition* 2014;**65**:79-88.
39. Donia MS, Fischbach MA. Human microbiota. Small molecules from the human microbiota. *Science (New York, NY)* 2015;**349**:1254766.
40. Elinav E, Strowig T, Kau AL*, et al.* Nlrp6 inflammasome regulates colonic microbial ecology and risk for colitis. *Cell* 2011;**145**:745-57.
41. Garrett WS, Lord GM, Punit S*, et al.* Communicable ulcerative colitis induced by t-bet deficiency in the innate immune system. *Cell* 2007;**131**:33-45.
42. Rutgeerts P, Goboes K, Peeters M*, et al.* Effect of faecal stream diversion on recurrence of crohn's disease in the neoterminal ileum. *Lancet (London, England)* 1991;**338**:771-4.
43. Wellmann W, Fink PC, Benner F, Schmidt FW. Endotoxaemia in active crohn's disease. Treatment with whole gut irrigation and 5-aminosalicylic acid. *Gut* 1986;**27**:814-20.
44. Jonkers D, Penders J, Masclee A, Pierik M. Probiotics in the management of inflammatory bowel disease: A systematic review of intervention studies in adult patients. *Drugs* 2012;**72**:803-23.
45. Gruber L, Kisling S, Lichti P*, et al.* High fat diet accelerates pathogenesis of murine crohn's disease-like ileitis independently of obesity. *PloS one* 2013;**8**:e71661.
46. Suzuki T, Hara H. Dietary fat and bile juice, but not obesity, are responsible for the increase in small intestinal permeability induced through the suppression of tight junction protein expression in leto and oletf rats. *Nutrition & metabolism* 2010;**7**:19.
47. Wagner SJ, Schmidt A, Effenberger MJ*, et al.* Semisynthetic diet ameliorates crohn's disease-like ileitis in tnfdeltaare/wt mice through antigen-independent mechanisms of gluten. *Inflammatory bowel diseases* 2013;**19**:1285-94.
48. Nickerson KP, McDonald C. Crohn's disease-associated adherent-invasive escherichia coli adhesion is enhanced by exposure to the ubiquitous dietary polysaccharide maltodextrin. *PloS one* 2012;**7**:e52132.
49. Chassaing B, Koren O, Goodrich JK*, et al.* Dietary emulsifiers impact the mouse gut microbiota promoting colitis and metabolic syndrome. *Nature* 2015;**519**:92-6.
50. Roberts CL, Keita AV, Duncan SH*, et al.* Translocation of crohn's disease escherichia coli across m-cells: Contrasting effects of soluble plant fibres and emulsifiers. *Gut* 2010;**59**:1331-9.
51. Swidsinski A, Ung V, Sydora BC*, et al.* Bacterial overgrowth and inflammation of small intestine after carboxymethylcellulose ingestion in genetically susceptible mice. *Inflammatory bowel diseases* 2009;**15**:359-64.
52. Nogueira CM, de Azevedo WM, Dagli ML*, et al.* Titanium dioxide induced inflammation in the small intestine. *World journal of gastroenterology* 2012;**18**:4729-35.
53. Werner T, Wagner SJ, Martinez I*, et al.* Depletion of luminal iron alters the gut microbiota and prevents crohn's disease-like ileitis. *Gut* 2011;**60**:325-33.
54. Pineton de Chambrun G, Body-Malapel M, Frey-Wagner I*, et al.* Aluminum enhances inflammation and decreases mucosal healing in experimental colitis in mice. *Mucosal immunology* 2014;**7**:589-601.
55. Roberts CL, Rushworth SL, Richman E, Rhodes JM. Hypothesis: Increased consumption of emulsifiers as an explanation for the rising incidence of crohn's disease. *Journal of Crohn's & colitis* 2013;**7**:338-41.
56. Ma X, Torbenson M, Hamad AR, Soloski MJ, Li Z. High-fat diet modulates non-cd1d-restricted natural killer t cells and regulatory t cells in mouse colon and exacerbates experimental colitis. *Clinical and experimental immunology* 2008;**151**:130-8.
57. Nagy-Szakal D, Mir SA, Harris RA*, et al.* Loss of n-6 fatty acid induced pediatric obesity protects against acute murine colitis. *FASEB journal : official publication of the Federation of American Societies for Experimental Biology* 2015;**29**:3151-9.

Accepted Manuscript

58. Paik J, Fierce Y, Treuting PM, Brabb T, Maggio-Price L. High-fat diet-induced obesity exacerbates inflammatory bowel disease in genetically susceptible mdr1a-/- male mice. *The Journal of nutrition* 2013;**143**:1240-7.
59. van Staa TP, Cooper C, Brusse LS*, et al.* Inflammatory bowel disease and the risk of fracture. *Gastroenterology* 2003;**125**:1591-7.
60. Bernstein CN, Shanahan F. Disorders of a modern lifestyle: Reconciling the epidemiology of inflammatory bowel diseases. *Gut* 2008;**57**:1185-91.
61. Jantchou P, Morois S, Clavel-Chapelon F, Boutron-Ruault MC, Carbonnel F. Animal protein intake and risk of inflammatory bowel disease: The e3n prospective study. *The American journal of gastroenterology* 2010;**105**:2195-201.
62. Merga Y, Campbell BJ, Rhodes JM. Mucosal barrier, bacteria and inflammatory bowel disease: Possibilities for therapy. *Digestive diseases* 2014;**32**:475-83.
63. Racine A, Carbonnel F, Chan SS*, et al.* Dietary patterns and risk of inflammatory bowel disease in europe: Results from the epic study. *Inflammatory bowel diseases* 2016;**22**:345-54.
64. Shoda R, Matsueda K, Yamato S, Umeda N. Epidemiologic analysis of crohn disease in japan: Increased dietary intake of n-6 polyunsaturated fatty acids and animal protein relates to the increased incidence of crohn disease in japan. *The American journal of clinical nutrition* 1996;**63**:741-5.
65. Jowett SL, Seal CJ, Pearce MS*, et al.* Influence of dietary factors on the clinical course of ulcerative colitis: A prospective cohort study. *Gut* 2004;**53**:1479-84.
66. Swidsinski A, Loening-Baucke V, Herber A. Mucosal flora in crohn's disease and ulcerative colitis - an overview. *Journal of physiology and pharmacology : an official journal of the Polish Physiological Society* 2009;**60 Suppl 6**:61-71.
67. Ananthakrishnan AN, Khalili H, Konijeti GG*, et al.* A prospective study of long-term intake of dietary fiber and risk of crohn's disease and ulcerative colitis. *Gastroenterology* 2013;**145**:970-7.
68. Costea I, Mack DR, Lemaitre RN*, et al.* Interactions between the dietary polyunsaturated fatty acid ratio and genetic factors determine susceptibility to pediatric crohn's disease. *Gastroenterology* 2014;**146**:929-31.
69. Chan SS, Luben R, van Schaik F*, et al.* Carbohydrate intake in the etiology of crohn's disease and ulcerative colitis. *Inflammatory bowel diseases* 2014;**20**:2013-21.
70. D'Souza S, Levy E, Mack D*, et al.* Dietary patterns and risk for crohn's disease in children. *Inflammatory bowel diseases* 2008;**14**:367-73.
71. Buchanan E, Gaunt WW, Cardigan T*, et al.* The use of exclusive enteral nutrition for induction of remission in children with crohn's disease demonstrates that disease phenotype does not influence clinical remission. *Alimentary pharmacology & therapeutics* 2009;**30**:501-7.
72. Johnson T, Macdonald S, Hill SM, Thomas A, Murphy MS. Treatment of active crohn's disease in children using partial enteral nutrition with liquid formula: A randomised controlled trial. *Gut* 2006;**55**:356-61.
73. Rubio A, Pigneur B, Garnier-Lengline H*, et al.* The efficacy of exclusive nutritional therapy in paediatric crohn's disease, comparing fractionated oral vs. Continuous enteral feeding. *Alimentary pharmacology & therapeutics* 2011;**33**:1332-9.
74. Dziechciarz P, Horvath A, Shamir R, Szajewska H. Meta-analysis: Enteral nutrition in active crohn's disease in children. *Alimentary pharmacology & therapeutics* 2007;**26**:795-806.
75. Rigaud D, Cosnes J, Le Quintrec Y*, et al.* Controlled trial comparing two types of enteral nutrition in treatment of active crohn's disease: Elemental versus polymeric diet. *Gut* 1991;**32**:1492-7.
76. Royall D, Jeejeebhoy KN, Baker JP*, et al.* Comparison of amino acid v peptide based enteral diets in active crohn's disease: Clinical and nutritional outcome. *Gut* 1994;**35**:783-7.

Accepted Manuscript

77. Zachos M, Tondeur M, Griffiths AM. Enteral nutritional therapy for induction of remission in crohn's disease. *The Cochrane database of systematic reviews* 2007:Cd000542.
78. Grover Z, Muir R, Lewindon P. Exclusive enteral nutrition induces early clinical, mucosal and transmural remission in paediatric crohn's disease. *Journal of gastroenterology* 2014;**49**:638-45.
79. Ruemmele FM, Veres G, Kolho KL*, et al.* Consensus guidelines of ecco/espghan on the medical management of pediatric crohn's disease. *Journal of Crohn's & colitis* 2014;**8**:1179-207.
80. Day AS, Whitten KE, Sidler M, Lemberg DA. Systematic review: Nutritional therapy in paediatric crohn's disease. *Alimentary pharmacology & therapeutics* 2008;**27**:293-307.
81. Levine A, Wine E. Effects of enteral nutrition on crohn's disease: Clues to the impact of diet on disease pathogenesis. *Inflammatory bowel diseases* 2013;**19**:1322-9.
82. Verma S, Brown S, Kirkwood B, Giaffer MH. Polymeric versus elemental diet as primary treatment in active crohn's disease: A randomized, double-blind trial. *The American journal of gastroenterology* 2000;**95**:735-9.
83. Sigall-Boneh R, Pfeffer-Gik T, Segal I*, et al.* Partial enteral nutrition with a crohn's disease exclusion diet is effective for induction of remission in children and young adults with crohn's disease. *Inflammatory bowel diseases* 2014;**20**:1353-60.
84. Breese EJ, Michie CA, Nicholls SW*, et al.* The effect of treatment on lymphokine-secreting cells in the intestinal mucosa of children with crohn's disease. *Alimentary pharmacology & therapeutics* 1995;**9**:547-52.
85. Fell JM, Paintin M, Arnaud-Battandier F*, et al.* Mucosal healing and a fall in mucosal pro-inflammatory cytokine mrna induced by a specific oral polymeric diet in paediatric crohn's disease. *Alimentary pharmacology & therapeutics* 2000;**14**:281-9.
86. Meister D, Bode J, Shand A, Ghosh S. Anti-inflammatory effects of enteral diet components on crohn's disease-affected tissues in vitro. *Digestive and liver disease : official journal of the Italian Society of Gastroenterology and the Italian Association for the Study of the Liver* 2002;**34**:430-8.
87. de Jong NS, Leach ST, Day AS. Polymeric formula has direct anti-inflammatory effects on enterocytes in an in vitro model of intestinal inflammation. *Digestive diseases and sciences* 2007;**52**:2029-36.
88. Feng Y, Li Y, Mei S*, et al.* Exclusive enteral nutrition ameliorates mesenteric adipose tissue alterations in patients with active crohn's disease. *Clinical nutrition (Edinburgh, Scotland)* 2014;**33**:850-8.
89. Nahidi L, Day AS, Lemberg DA, Leach ST. Differential effects of nutritional and non-nutritional therapies on intestinal barrier function in an in vitro model. *Journal of gastroenterology* 2012;**47**:107-17.
90. Nahidi L, Leach ST, Mitchell HM*, et al.* Inflammatory bowel disease therapies and gut function in a colitis mouse model. *BioMed research international* 2013;**2013**:909613.
91. Lionetti P, Callegari ML, Ferrari S*, et al.* Enteral nutrition and microflora in pediatric crohn's disease. *JPEN Journal of parenteral and enteral nutrition* 2005;**29**:S173-5; discussion S5-8, S84-8.
92. Gerasimidis K, Bertz M, Hanske L*, et al.* Decline in presumptively protective gut bacterial species and metabolites are paradoxically associated with disease improvement in pediatric crohn's disease during enteral nutrition. *Inflammatory bowel diseases* 2014;**20**:861-71.
93. Kaakoush NO, Day AS, Leach ST*, et al.* Effect of exclusive enteral nutrition on the microbiota of children with newly diagnosed crohn's disease. *Clinical and translational gastroenterology* 2015;**6**:e71.
94. Leach ST, Mitchell HM, Eng WR, Zhang L, Day AS. Sustained modulation of intestinal bacteria by exclusive enteral nutrition used to treat children with crohn's disease. *Alimentary pharmacology & therapeutics* 2008;**28**:724-33.

Accepted Manuscript

95. Quince C, Ijaz UZ, Loman N*, et al.* Extensive modulation of the fecal metagenome in children with crohn's disease during exclusive enteral nutrition. *The American journal of gastroenterology* 2015;**110**:1718-29; quiz 30.
96. Lewis JD, Chen EZ, Baldassano RN*, et al.* Inflammation, antibiotics, and diet as environmental stressors of the gut microbiome in pediatric crohn's disease. *Cell host & microbe* 2015;**18**:489-500.
97. Shiga H, Kajiura T, Shinozaki J*, et al.* Changes of faecal microbiota in patients with crohn's disease treated with an elemental diet and total parenteral nutrition. *Digestive and liver disease : official journal of the Italian Society of Gastroenterology and the Italian Association for the Study of the Liver* 2012;**44**:736-42.
98. D'Argenio V, Precone V, Casaburi G*, et al.* An altered gut microbiome profile in a child affected by crohn's disease normalized after nutritional therapy. *The American journal of gastroenterology* 2013;**108**:851-2.
99. Jia W, Whitehead RN, Griffiths L*, et al.* Is the abundance of faecalibacterium prausnitzii relevant to crohn's disease? *FEMS microbiology letters* 2010;**310**:138-44.
100. Tjellstrom B, Hogberg L, Stenhammar L*, et al.* Effect of exclusive enteral nutrition on gut microflora function in children with crohn's disease. *Scandinavian journal of gastroenterology* 2012;**47**:1454-9.
101. Obih C, Wahbeh G, Lee D*, et al.* Specific carbohydrate diet for pediatric inflammatory bowel disease in clinical practice within an academic ibd center. *Nutrition (Burbank, Los Angeles County, Calif)* 2016;**32**:418-25.
102. Suskind DL, Wahbeh G, Gregory N, Vendettuoli H, Christie D. Nutritional therapy in pediatric crohn disease: The specific carbohydrate diet. *Journal of pediatric gastroenterology and nutrition* 2014;**58**:87-91.
103. Faiman A, Mutalib M, Moylan A*, et al.* Standard versus rapid food reintroduction after exclusive enteral nutritional therapy in paediatric crohn's disease. *European journal of gastroenterology & hepatology* 2014;**26**:276-81.
104. Lomer MC, Gourgey R, Whelan K. Current practice in relation to nutritional assessment and dietary management of enteral nutrition in adults with crohn's disease. *Journal of human nutrition and dietetics : the official journal of the British Dietetic Association* 2014;**27 Suppl 2**:28-35.
105. Hanai H, Iida T, Takeuchi K*, et al.* Nutritional therapy versus 6-mercaptopurine as maintenance therapy in patients with crohn's disease. *Digestive and liver disease : official journal of the Italian Society of Gastroenterology and the Italian Association for the Study of the Liver* 2012;**44**:649-54.
106. Takagi S, Utsunomiya K, Kuriyama S*, et al.* Effectiveness of an 'half elemental diet' as maintenance therapy for crohn's disease: A randomized-controlled trial. *Alimentary pharmacology & therapeutics* 2006;**24**:1333-40.
107. Triantafillidis JKS, A. Karagianni,V. Gikas, A. Malgarinos, G. Maintenance treatment of crohn's disease with a polymeric feed rich in tgf-β. *Annals of Gastroenterology* 2010;**23**:113-8.
108. Verma S, Holdsworth CD, Giaffer MH. Does adjuvant nutritional support diminish steroid dependency in crohn disease? *Scandinavian journal of gastroenterology* 2001;**36**:383-8.
109. Yamamoto T, Nakahigashi M, Saniabadi AR*, et al.* Impacts of long-term enteral nutrition on clinical and endoscopic disease activities and mucosal cytokines during remission in patients with crohn's disease: A prospective study. *Inflammatory bowel diseases* 2007;**13**:1493-501.
110. Yamamoto T, Nakahigashi M, Umegae S, Kitagawa T, Matsumoto K. Impact of long-term enteral nutrition on clinical and endoscopic recurrence after resection for crohn's disease: A

Accepted Manuscript

prospective, non-randomized, parallel, controlled study. *Alimentary pharmacology & therapeutics* 2007;**25**:67-72.
111. Verma S, Kirkwood B, Brown S, Giaffer MH. Oral nutritional supplementation is effective in the maintenance of remission in crohn's disease. *Digestive and liver disease : official journal of the Italian Society of Gastroenterology and the Italian Association for the Study of the Liver* 2000;**32**:769-74.
112. Wilschanski M, Sherman P, Pencharz P*, et al.* Supplementary enteral nutrition maintains remission in paediatric crohn's disease. *Gut* 1996;**38**:543-8.
113. Yamamoto T, Nakahigashi M, Umegae S, Matsumoto K. Prospective clinical trial: Enteral nutrition during maintenance infliximab in crohn's disease. *Journal of gastroenterology* 2010;**45**:24-9.
114. Harries AD, Jones LA, Danis V*, et al.* Controlled trial of supplemented oral nutrition in crohn's disease. *Lancet (London, England)* 1983;**1**:887-90.
115. Lee D, Baldassano RN, Otley AR*, et al.* Comparative effectiveness of nutritional and biological therapy in north american children with active crohn's disease. *Inflammatory bowel diseases* 2015;**21**:1786-93.
116. Cohen SA, Gold BD, Oliva S*, et al.* Clinical and mucosal improvement with specific carbohydrate diet in pediatric crohn disease. *Journal of pediatric gastroenterology and nutrition* 2014;**59**:516-21.
117. Olendzki BC, Silverstein TD, Persuitte GM*, et al.* An anti-inflammatory diet as treatment for inflammatory bowel disease: A case series report. *Nutrition journal* 2014;**13**:5.
118. Bentz S, Hausmann M, Piberger H*, et al.* Clinical relevance of igg antibodies against food antigens in crohn's disease: A double-blind cross-over diet intervention study. *Digestion* 2010;**81**:252-64.
119. Chiba M, Abe T, Tsuda H*, et al.* Lifestyle-related disease in crohn's disease: Relapse prevention by a semi-vegetarian diet. *World journal of gastroenterology* 2010;**16**:2484-95.
120. Croagh C, Shepherd SJ, Berryman M, Muir JG, Gibson PR. Pilot study on the effect of reducing dietary fodmap intake on bowel function in patients without a colon. *Inflammatory bowel diseases* 2007;**13**:1522-8.
121. Gearry RB, Irving PM, Barrett JS*, et al.* Reduction of dietary poorly absorbed short-chain carbohydrates (fodmaps) improves abdominal symptoms in patients with inflammatory bowel disease-a pilot study. *Journal of Crohn's & colitis* 2009;**3**:8-14.
122. Marlow G, Ellett S, Ferguson IR*, et al.* Transcriptomics to study the effect of a mediterranean-inspired diet on inflammation in crohn's disease patients. *Human genomics* 2013;**7**:24.
123. Candy S, Borok G, Wright JP, Boniface V, Goodman R. The value of an elimination diet in the management of patients with ulcerative colitis. *South African medical journal = Suid-Afrikaanse tydskrif vir geneeskunde* 1995;**85**:1176-9.
124. Hou JK, Lee D, Lewis J. Diet and inflammatory bowel disease: Review of patient-targeted recommendations. *Clinical gastroenterology and hepatology : the official clinical practice journal of the American Gastroenterological Association* 2014;**12**:1592-600.
125. Walters SSQ, A. Rolston, M. Grishina, I. Li, J. Fenton, A. DeSantis, T.Z. Thai, A. Andersen, G.L. Papathakis, P. Nieves, R. Prindiville, T. Dandekar, S. Analysis of gut microbiome and diet modification in patients with crohn's disease. *SOJ Microbiology and Infectious Diseases* 2014;**2**:1-13.
126. Gibson PR, Shepherd SJ. Personal view: Food for thought--western lifestyle and susceptibility to crohn's disease. The fodmap hypothesis. *Alimentary pharmacology & therapeutics* 2005;**21**:1399-409.

Accepted Manuscript

127. Azcue M, Rashid M, Griffiths A, Pencharz PB. Energy expenditure and body composition in children with crohn's disease: Effect of enteral nutrition and treatment with prednisolone. *Gut* 1997;**41**:203-8.
128. Capristo E, Mingrone G, Addolorato G, Greco AV, Gasbarrini G. Metabolic features of inflammatory bowel disease in a remission phase of the disease activity. *Journal of internal medicine* 1998;**243**:339-47.
129. Wiskin AE, Wootton SA, Cornelius VR*, et al.* No relation between disease activity measured by multiple methods and ree in childhood crohn disease. *Journal of pediatric gastroenterology and nutrition* 2012;**54**:271-6.
130. Vaisman N, Dotan I, Halack A, Niv E. Malabsorption is a major contributor to underweight in crohn's disease patients in remission. *Nutrition (Burbank, Los Angeles County, Calif)* 2006;**22**:855-9.
131. Winter TA, O'Keefe S J, Callanan M, Marks T. Impaired gastric acid and pancreatic enzyme secretion in patients with crohn's disease may be a consequenece of a poor nutritional state. *Inflammatory bowel diseases* 2004;**10**:618-25.
132. Wong SC, Macrae VE, McGrogan P, Ahmed SF. The role of pro-inflammatory cytokines in inflammatory bowel disease growth retardation. *Journal of pediatric gastroenterology and nutrition* 2006;**43**:144-55.
133. Werkstetter KJ, Ullrich J, Schatz SB*, et al.* Lean body mass, physical activity and quality of life in paediatric patients with inflammatory bowel disease and in healthy controls. *Journal of Crohn's & colitis* 2012;**6**:665-73.
134. Cameron FL, Gerasimidis K, Papangelou A*, et al.* Clinical progress in the two years following a course of exclusive enteral nutrition in 109 paediatric patients with crohn's disease. *Alimentary pharmacology & therapeutics* 2013;**37**:622-9.
135. Vasseur F, Gower-Rousseau C, Vernier-Massouille G*, et al.* Nutritional status and growth in pediatric crohn's disease: A population-based study. *The American journal of gastroenterology* 2010;**105**:1893-900.
136. Bryant RV, Trott MJ, Bartholomeusz FD, Andrews JM. Systematic review: Body composition in adults with inflammatory bowel disease. *Alimentary pharmacology & therapeutics* 2013;**38**:213-25.
137. Sylvester FA, Leopold S, Lincoln M*, et al.* A two-year longitudinal study of persistent lean tissue deficits in children with crohn's disease. *Clinical gastroenterology and hepatology : the official clinical practice journal of the American Gastroenterological Association* 2009;**7**:452-5.
138. Barclay AR, Keightley JM, Horrocks I*, et al.* Cerebral thromboembolic events in pediatric patients with inflammatory bowel disease. *Inflammatory bowel diseases* 2010;**16**:677-83.
139. Erhayiem B, Dhingsa R, Hawkey CJ, Subramanian V. Ratio of visceral to subcutaneous fat area is a biomarker of complicated crohn's disease. *Clinical gastroenterology and hepatology : the official clinical practice journal of the American Gastroenterological Association* 2011;**9**:684-7 e1.
140. Stidham RW, Waljee AK, Day NM*, et al.* Body fat composition assessment using analytic morphomics predicts infectious complications after bowel resection in crohn's disease. *Inflammatory bowel diseases* 2015;**21**:1306-13.
141. Card T, West J, Hubbard R, Logan RF. Hip fractures in patients with inflammatory bowel disease and their relationship to corticosteroid use: A population based cohort study. *Gut* 2004;**53**:251-5.
142. Lee JJ, Escher JC, Shuman MJ*, et al.* Final adult height of children with inflammatory bowel disease is predicted by parental height and patient minimum height z-score. *Inflammatory bowel diseases* 2010;**16**:1669-77.

Accepted Manuscript

143. Gerasimidis K, Talwar D, Duncan A*, et al.* Impact of exclusive enteral nutrition on body composition and circulating micronutrients in plasma and erythrocytes of children with active crohn's disease. *Inflammatory bowel diseases* 2012;**18**:1672-81.
144. Duncan A, Talwar D, McMillan DC, Stefanowicz F, O'Reilly DS. Quantitative data on the magnitude of the systemic inflammatory response and its effect on micronutrient status based on plasma measurements. *The American journal of clinical nutrition* 2012;**95**:64-71.
145. Ghashut RA, McMillan DC, Kinsella J*, et al.* The effect of the systemic inflammatory response on plasma zinc and selenium adjusted for albumin. *Clinical nutrition (Edinburgh, Scotland)* 2015.
146. Oakes EJ, Lyon TD, Duncan A*, et al.* Acute inflammatory response does not affect erythrocyte concentrations of copper, zinc and selenium. *Clinical nutrition (Edinburgh, Scotland)* 2008;**27**:115-20.
147. Gerasimidis K, Edwards C, Stefanowicz F*, et al.* Micronutrient status in children with ibd: True deficiencies or epiphenomenon of the systemic inflammatory response. *Journal of pediatric gastroenterology and nutrition* 2013;**56**:e50-1.
148. Excellence NIfHaC. Nice quality standard [qs81]; inflammatory bowel disease; . February 2015.
149. Jeppesen PB. Spectrum of short bowel syndrome in adults: Intestinal insufficiency to intestinal failure. *JPEN Journal of parenteral and enteral nutrition* 2014;**38**:8s-13s.
150. Limketkai BN, Parian AM, Shah ND, Colombel JF. Short bowel syndrome and intestinal failure in crohn's disease. *Inflammatory bowel diseases* 2016;**22**:1209-18.
151. Pironi L, Arends J, Bozzetti F*, et al.* Espen guidelines on chronic intestinal failure in adults. *Clinical nutrition (Edinburgh, Scotland)* 2016;**35**:247-307.
152. Agwunobi AO, Carlson GL, Anderson ID, Irving MH, Scott NA. Mechanisms of intestinal failure in crohn's disease. *Diseases of the colon and rectum* 2001;**44**:1834-7.
153. Calvert CR, Lal S. Approaches to intestinal failure in crohn's disease. *The Proceedings of the Nutrition Society* 2011;**70**:336-41.
154. Gearry RB, Kamm MA, Hart AL*, et al.* Predictors for developing intestinal failure in patients with crohn's disease. *Journal of gastroenterology and hepatology* 2013;**28**:801-7.
155. Thompson JS, Iyer KR, DiBaise JK*, et al.* Short bowel syndrome and crohn's disease. *Journal of gastrointestinal surgery : official journal of the Society for Surgery of the Alimentary Tract* 2003;**7**:1069-72.
156. Uchino M, Ikeuchi H, Bando T*, et al.* Risk factors for short bowel syndrome in patients with crohn's disease. *Surgery today* 2012;**42**:447-52.
157. Luo M, Fernandez-Estivariz C, Manatunga AK*, et al.* Are plasma citrulline and glutamine biomarkers of intestinal absorptive function in patients with short bowel syndrome? *JPEN Journal of parenteral and enteral nutrition* 2007;**31**:1-7.
158. Peters JH, Wierdsma NJ, Teerlink T*, et al.* The citrulline generation test: Proposal for a new enterocyte function test. *Alimentary pharmacology & therapeutics* 2008;**27**:1300-10.
159. Stephens AN, Pereira-Fantini PM, Wilson G*, et al.* Proteomic analysis of the intestinal adaptation response reveals altered expression of fatty acid binding proteins following massive small bowel resection. *Journal of proteome research* 2010;**9**:1437-49.
160. Jeppesen PB. Gut hormones in the treatment of short-bowel syndrome and intestinal failure. *Current opinion in endocrinology, diabetes, and obesity* 2015;**22**:14-20.
161. Tappenden KA, Edelman J, Joelsson B. Teduglutide enhances structural adaptation of the small intestinal mucosa in patients with short bowel syndrome. *Journal of clinical gastroenterology* 2013;**47**:602-7.
162. Tee CT, Wallis K, Gabe SM. Emerging treatment options for short bowel syndrome: Potential role of teduglutide. *Clinical and experimental gastroenterology* 2011;**4**:189-96.

Accepted Manuscript

163. Gerlach UA, Vrakas G, Reddy S*, et al.* Chronic intestinal failure after crohn disease: When to perform transplantation. *JAMA surgery* 2014;**149**:1060-6.
164. Polk TM, Schwab CW. Metabolic and nutritional support of the enterocutaneous fistula patient: A three-phase approach. *World journal of surgery* 2012;**36**:524-33.
165. Yan D, Ren J, Wang G, Liu S, Li J. Predictors of response to enteral nutrition in abdominal enterocutaneous fistula patients with crohn's disease. *European journal of clinical nutrition* 2014;**68**:959-63.
166. Li G, Ren J, Wang G*, et al.* Preoperative exclusive enteral nutrition reduces the postoperative septic complications of fistulizing crohn's disease. *European journal of clinical nutrition* 2014;**68**:441-6.
167. Triantafillidis JK, Papalois AE. The role of total parenteral nutrition in inflammatory bowel disease: Current aspects. *Scandinavian journal of gastroenterology* 2014;**49**:3-14.
168. Baker ML, Williams RN, Nightingale JM. Causes and management of a high-output stoma. *Colorectal disease : the official journal of the Association of Coloproctology of Great Britain and Ireland* 2011;**13**:191-7.
169. Grischkan D, Steiger E, Fazio V. Maintenance of home hyperalimentation in patients with high-output jejunostomies. *Archives of surgery (Chicago, Ill : 1960)* 1979;**114**:838-41.
170. Nightingale JM, Lennard-Jones JE, Walker ER, Farthing MJ. Oral salt supplements to compensate for jejunostomy losses: Comparison of sodium chloride capsules, glucose electrolyte solution, and glucose polymer electrolyte solution. *Gut* 1992;**33**:759-61.
171. Pironi L, Guidetti C, Incasa E*, et al.* Oral rehydration solution containing rice maltodextrins in patients with total colectomy and high intestinal output. *International journal of clinical pharmacology research* 2000;**20**:55-60.
172. Winkler MF, Smith CE. Clinical, social, and economic impacts of home parenteral nutrition dependence in short bowel syndrome. *JPEN Journal of parenteral and enteral nutrition* 2014;**38**:32s-7s.
173. Carlsson E, Persson E. Living with intestinal failure caused by crohn disease: Not letting the disease conquer life. *Gastroenterology nursing : the official journal of the Society of Gastroenterology Nurses and Associates* 2015;**38**:12-20.
174. Matarese LE, Jeppesen PB, O'Keefe SJ. Short bowel syndrome in adults: The need for an interdisciplinary approach and coordinated care. *JPEN Journal of parenteral and enteral nutrition* 2014;**38**:60s-4s.
175. Halpin SJ, Ford AC. Prevalence of symptoms meeting criteria for irritable bowel syndrome in inflammatory bowel disease: Systematic review and meta-analysis. *The American journal of gastroenterology* 2012;**107**:1474-82.
176. Mikocka-Walus AA, Turnbull DA, Andrews JM, Moulding NT, Holtmann GJ. The effect of functional gastrointestinal disorders on psychological comorbidity and quality of life in patients with inflammatory bowel disease. *Alimentary pharmacology & therapeutics* 2008;**28**:475-83.
177. Berrill JW, Green JT, Hood K, Campbell AK. Symptoms of irritable bowel syndrome in patients with inflammatory bowel disease: Examining the role of sub-clinical inflammation and the impact on clinical assessment of disease activity. *Alimentary pharmacology & therapeutics* 2013;**38**:44-51.
178. Keohane J, O'Mahony C, O'Mahony L*, et al.* Irritable bowel syndrome-type symptoms in patients with inflammatory bowel disease: A real association or reflection of occult inflammation? *The American journal of gastroenterology* 2010;**105**:1788, 9-94; quiz 95.
179. MacDermott RP. Treatment of irritable bowel syndrome in outpatients with inflammatory bowel disease using a food and beverage intolerance, food and beverage avoidance diet. *Inflammatory bowel diseases* 2007;**13**:91-6.

Accepted Manuscript

180. McKenzie YA, Bowyer RK, Leach H*, et al.* British dietetic association systematic review and evidence-based practice guidelines for the dietary management of irritable bowel syndrome in adults (2016 update). *Journal of human nutrition and dietetics : the official journal of the British Dietetic Association* 2016;**29**:549-75.
181. Moayyedi P, Quigley EM, Lacy BE*, et al.* The effect of fiber supplementation on irritable bowel syndrome: A systematic review and meta-analysis. *The American journal of gastroenterology* 2014;**109**:1367-74.
182. Staudacher HM, Irving PM, Lomer MC, Whelan K. Mechanisms and efficacy of dietary fodmap restriction in ibs. *Nature reviews Gastroenterology & hepatology* 2014;**11**:256-66.
183. Barrett JS, Gearry RB, Muir JG*, et al.* Dietary poorly absorbed, short-chain carbohydrates increase delivery of water and fermentable substrates to the proximal colon. *Alimentary pharmacology & therapeutics* 2010;**31**:874-82.
184. Murray K, Wilkinson-Smith V, Hoad C*, et al.* Differential effects of fodmaps (fermentable oligo-, di-, mono-saccharides and polyols) on small and large intestinal contents in healthy subjects shown by mri. *The American journal of gastroenterology* 2014;**109**:110-9.
185. Ong DK, Mitchell SB, Barrett JS*, et al.* Manipulation of dietary short chain carbohydrates alters the pattern of gas production and genesis of symptoms in irritable bowel syndrome. *Journal of gastroenterology and hepatology* 2010;**25**:1366-73.
186. Halmos EP, Power VA, Shepherd SJ, Gibson PR, Muir JG. A diet low in fodmaps reduces symptoms of irritable bowel syndrome. *Gastroenterology* 2014;**146**:67-75 e5.
187. Staudacher HM, Lomer MC, Anderson JL*, et al.* Fermentable carbohydrate restriction reduces luminal bifidobacteria and gastrointestinal symptoms in patients with irritable bowel syndrome. *The Journal of nutrition* 2012;**142**:1510-8.
188. Martin L, van-Vuuren C, Seamark L*, et al.* Low fodmap advice for patients with irritable bowel syndrome: Long-term outcomes for symptoms and dietary intake. In: Gut, 2015.
189. Benjamin JL, Hedin CR, Koutsoumpas A*, et al.* Randomised, double-blind, placebo-controlled trial of fructo-oligosaccharides in active crohn's disease. *Gut* 2011;**60**:923-9.
190. Cox SP, A, Myers, C. Irving, P. M. Lindsay, J. O. Lomer, M. C. Whelan, K. Fermentable carbohydrates (fodmaps) as triggers of functional gastrointestinal symptoms in patients with quiescent inflammatory bowel disease: A double-blind, placebo-controlled, randomised, cross-over re-challenge trial. ECCO Metting Amsterdam 2016 Amsterdam, 2016.
191. Prince AC, Myers CE, Joyce T*, et al.* Fermentable carbohydrate restriction (low fodmap diet) in clinical practice improves functional gastrointestinal symptoms in patients with inflammatory bowel disease. *Inflammatory bowel diseases* 2016;**22**:1129-36.
192. Pedersen N. Ehealth: Self-management in inflammatory bowel disease and in irritable bowel syndrome using novel constant-care web applications. Ehealth by constant-care in ibd and ibs. *Danish medical journal* 2015;**62**:B5168.
193. Gerasimidis K. Inflammatory bowel disease nutritional consequences. *Advanced nutrition and dietetics in gastroenterology*: John Wiley & Sons, Ltd.; 2014: 180-90.

Accepted Manuscript