

Dynamic Population of Gut Microbiota as an Indicator of Inflammatory Bowel Disease

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ABSTRACT

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Background: Inflammatory bowel disease is a chronic inflammatory disease of the gastrointestinal tract. The gut microbiota is an important factor in the pathogenesis of IBD. Due to a link between the gut microbiota and IBD, studying microbiota changes using an accurate, sensitive and rapid method for detection of the disease seems necessary. This study aimed to compare the composition of gut microbiota in three groups of people, including IBD patients, CIBD, and healthy groups.

Methods: For this study, 45 stool samples (15 from each group) were collected. Using real-time PCR, the abundance of 11 bacterial 16S rRNA gene sequences was examined.

Results: In the IBD group, the number of three bacterial phyla, including Firmicutes, Actinobacteria, and Bacteroidetes, decreased ($p < 0.01$, $p < 0.01$, and $p < 0.001$, respectively), while the population of γ -Proteobacteria increased significantly ($p < 0.0001$). In the CIBD group, the number of Actinobacteria enhanced ($p < 0.01$), but that of Bacteroidetes and Firmicutes decreased ($p < 0.01$, and $p < 0.05$, respectively).

Conclusion: Findings of this study indicate that decrease in Firmicutes and increase in γ -Proteobacteria could be used as an indicator of IBD instead of employing invasive and costly detection methods such as colonoscopy and other tests. **DOI: 10.52547/ibj.3772**

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INTRODUCTION

Inflammatory bowel disease is a chronic inflammatory disease of the gastrointestinal tract, that results from impaired interaction between the gut immune system and the gut microbiota^[1,2]. CD and UC are two main types of IBD that affect the large and small intestines and have the unique microbiota composition pattern^[1]. In CD, inflammation occurs in any part of the gastrointestinal tract, whereas in UC, inflammation happens in the mucosal layer of the colon. The clinical features of IBD vary depending on

the site and severity of inflammation, as well as the status of the disease in different individuals^[2].

While the exact cause of IBD remains unknown, several factors, including host's genetics, immune system function, environmental factors, and gut microbiota have been shown to play important roles in development of the disease. In addition, multiple epidemiological factors, such as birth status (cesarean section), breastfeeding, smoking, health conditions, infections, antibiotics, diet, and sleep patterns are thought to cause IBD and also microbial changes in the body, indicating the important role of the gut

List of Abbreviations:

CD, Crohn's disease; **CIBD**, cured Inflammatory bowel disease; **IBD**, inflammatory bowel disease; **UC**, ulcerative colitis

microbiota in the pathogenesis of IBD^[3-6].

The intestinal microbiota is a large collection of microbes in the body, accounting for 10^{12} cells/g of the luminal contents of the intestine. In the gastrointestinal tract of healthy people, there are generally five bacterial phyla, including two main phyla (Firmicutes and Bacteroidetes) along with three other phyla (γ -Proteobacteria, Actinobacteria, and Verrucomicrobia)^[7]. The gut microbiota has many significant functions in the host by inducing symbiosis. These functions include metabolism and synthesis of nutrients, especially vitamins K and B, the tropism of mucous membranes, metabolism of drugs and toxins, and protection against pathogens. In fact, the gut microbiota forms a complex and extremely important structure that acts as a link between the host and the environment. This intestinal barrier regulates the interaction between bacteria and host cells and modulates the uptake of nutrients^[8].

In IBD patients, the composition and function of the gut microbiota change^[9,10]. The microbial taxonomic profile may differ from patient to patient, making it difficult to determine whether specific microbial species or strains are involved in disease development and progression^[11]. The abundance of γ -Proteobacteria, such as *Enterobacteriaceae*, is increasing in IBD patients, whereas the proportion of Firmicutes such as *Lactobacillus* and *Faecalibacterium*, which have a protective effect on the gastrointestinal tract, is decreasing^[12-14]. Evidence has shown that diversity of the gut microbiota, as well as the known beneficial bacteria such as *Faecalibacterium prausnitzii*, *Roseburia intestinalis*, and other butyrate producers decrease in IBD patients^[15].

Detection of IBD is challenging in terms of cost and side effects of methods. As mentioned earlier, changes in the gut microbiota could serve as an indicator of the progression of IBD. On the other hand, real-time PCR is an inexpensive and non-invasive method, compared to previously used approaches such as colonoscopy, for detecting IBD. Given these reasons, in this study, real-time PCR was used for 11 bacterial groups to identify alterations in the intestinal microbiota of IBD and CIBD patients compared to the healthy ones.

MATERIALS AND METHODS

Sample collection

In this study, 45 stool samples were collected from three groups, including IBD patients, CIBD, and healthy individuals with a mean age of 33.5 years, ranging from 18 to 42 years. The first group (n = 15) consisted of patients with IBD who had been diagnosed with either UC (n = 8) or CD (n = 7). A specialized gastroenterologist diagnosed the cases

based on clinical symptoms, as well as accepted radiological and paraclinical findings. The patients of this group suffered from painful complications such as diarrhea, bloody stools, abdominal pain, heartburn, and weakness. The second group (n = 15) were CIBD patients who were in remission, and whose disease was controlled by medication, i.e. mesalazine for all patients and thiopurine for some cases, depending on the severity of the disease. The last group (control group) included healthy individuals (n = 15), with inclusion criteria including normal body mass index, no history of gastrointestinal disease, no use of antibiotics in four weeks before sampling, no special diet, and no pregnancy.

DNA extraction

DNA was extracted from the stool samples using the FavorPrep Stool DNA Isolation Mini Kit (Taiwan) in accordance with the manufacturer's instructions. The stool samples (200 mg) were mixed with 20 μ l of proteinase K and 300 μ l of lysis buffer in a bead tube, and the steps were continued according to the protocol of the extraction kit. The concentration and purity of DNA were measured using a NanoDrop 1000 UV-Vis spectrophotometer (BioTek, USA) and stored at -20 °C until real-time PCR analysis.

Amplification efficiency of real-time PCR

Real-time PCR amplification efficiency was determined using a standard curve. At first, the extracted DNA of 10 stool samples was mixed in a microtube. Then serial dilutions (10^{-1} - 10^{-5}) of this DNA were prepared and used to generate the standard curve for determination of slope, y-intercept, and correlation coefficient values.

Determining the gut microbiota composition

Investigation of the bacterial 16S rRNA genes in the stool sample was carried out based on the primers listed in Table 1 by using an ABI Step One Plus detection system (Applied Biosystems, USA). The real-time PCR amplifications were performed in 20 μ l of reaction volume using 12 μ l of 2 \times SYBR Green Master Mix (Amplicon, Denmark), 0.5 μ mol/l of each primer, 3 μ l of template DNA, and nuclease-free water to a final volume of 20 μ l. Amplification included one cycle at 95 °C for 15 minutes for initial denaturation, followed by 40 cycles of denaturation at 95 °C for 15 seconds and primer annealing at 60 °C for 60 seconds. Data were analyzed using $RQ = 2^{-\Delta\Delta C_t}$ equation, in which the readings were normalized with all bacterial genes^[16]. In this method, the C_t values of the target bacterium were normalized with all bacterial genes, and their comparison was evaluated using the comparative fold change.

Table 1. Sequences of oligonucleotide primers used in this study

Target bacterial	Sequence (5'-3')	Amplicon size (bp)	References
All bacteria	F: TCCTACGGGAGGCAGCAGT R: GGACTACCAGGGTATCTATCCTGTT	466	26
Actinobacteria	F: TACGGCCGCAAGGCTA R: TCATCCCCACCTTCCTCCG	300	30
γ -Proteobacteria	F: TCGTCAGCTCGTGTAGTGA R: CGTAAGGGCCATGATG	154	30
Firmicutes	F: TGAAACTAAAAGGAATTGACG R: ACCATGCACCACCTGTC	155	30
Bacteroidetes	F: CRAACAGGATTAGATACCCT R: GGTAAGGTTCCCTCGCGTAT	204	30
<i>Lactobacillus</i>	F: TGGATGCCTTGGCACTAGGA R: AAATCTCCGATCAAAGCTTACTTAT	92	27
<i>Bifidobacterium</i>	F: GGGTGGTAATGCCGGATG R: TAAGCCATGGACTTTCACACC	278	26
<i>Enterobacteriaceae</i>	F: CATTGACGTTACCCGCAGAAGAAGC R: CTCTACGAGACTCAAGCTTGC	195	26
<i>Enterococcus faecalis</i>	F: AACCTACCCATCAGAGGG R: GACGTTTCAGTTACTAACG	360	26
<i>Clostridium clostridioforme</i>	F: AATCTTGATTGACTGAGTGGCGGAC R: CCATCTCACACTACCGGAGTTTTTC	148	26
<i>Roseburia</i>	F: TACTGCATTGGAACTGTCTG R: CGGCACCGAAGAGCAAT	230	28
<i>Faecalibacterium prausnitzii</i>	F: AGAGTTTGATCATGGCTCAG R: GGTTACCTTGTTACGACTT	191	29

Statistical analysis

All data were expressed as mean \pm standard deviation. Differences in gut microbiome composition between the groups were determined using a one-way analysis of variance (ANOVA). All comparisons were analyzed by the $2^{-\Delta\Delta C_t}$ method. GraphPad Prism 8.0.2 was used for statistical analysis of the data. Differences were considered statistically significant at a value of $p < 0.05$.

RESULTS

Comparison of gut microbiota composition in the study groups

Results of real-time PCR showed that the bacterial composition of the intestine was different in all groups of individuals. Using the relative method, changes in the intestinal microbiota of the three groups were observed. The number and diversity of the intestinal microbiota significantly reduced in IBD patients compared to the healthy group. The number and bacterial variations were also lower in the CIBD

compared to the healthy group. The abundance of the three bacterial phyla, i.e. Firmicutes, Actinobacteria, and Bacteroidetes, decreased in the IBD group compared to the healthy group, while that of γ -Proteobacteria increased (Fig. 1). In contrast, in the CIBD group, the abundance of Actinobacteria increased, and the composition of Bacteroidetes and Firmicutes decreased. In both the IBD and CIBD groups, population of *Clostridium clostridioforme* did not significantly changed compared to the healthy group (Fig. 2).

Comparison of gut microbiota composition of CD and UC patient subgroups

According to the results of real-time PCR, the total amount of bacteria in the CD group was lower than that of the UC group. Comparison of CD and UC groups with the healthy group showed different results in some bacterial groups, including *Lactobacillus*, *Enterococcus faecalis*, *Clostridium*, and *Enterobacteriaceae* (Fig. 3). Comparing the CD-cured and UC-cured groups with the healthy group indicated

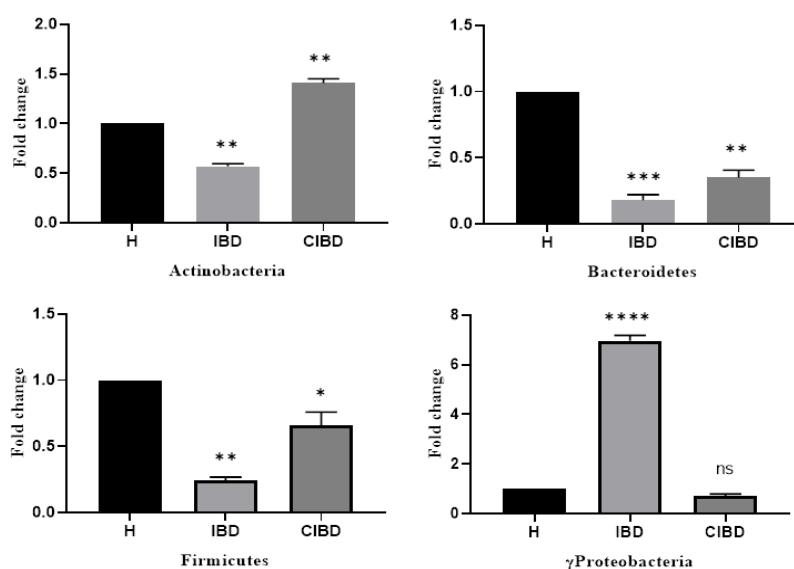


Fig. 1. Differences in the abundance of bacterial phyla in IBD patients and CIBD compared to the control group (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, and **** $p < 0.0001$). H, healthy; ns, not significant;

an increase in the abundance of Actinobacteria ($p < 0.0001$), γ -Proteobacteria ($p < 0.0001$), and Bacteroidetes ($p = 0.02$) in the UC-cured group. Also population of Firmicutes increased in the CD-cured group compared to the healthy group ($p = 0.03$).

DISCUSSION

Alteration in the composition of the gut microbiota may influence the pathogenesis and etiology of

IBD^[17]. In this study, the real-time PCR technique and the relative method were used to compare the composition of the gut microbiota in IBD and CIBD groups with healthy group.

The results of this study showed that the composition of the gut microbiota in IBD patients was significantly different from the healthy group and CIBD. The findings of gene amplification of all bacteria also demonstrated that the total amount of bacteria in the gut of IBD patients reduced compared to the healthy group. In IBD patients, the three major

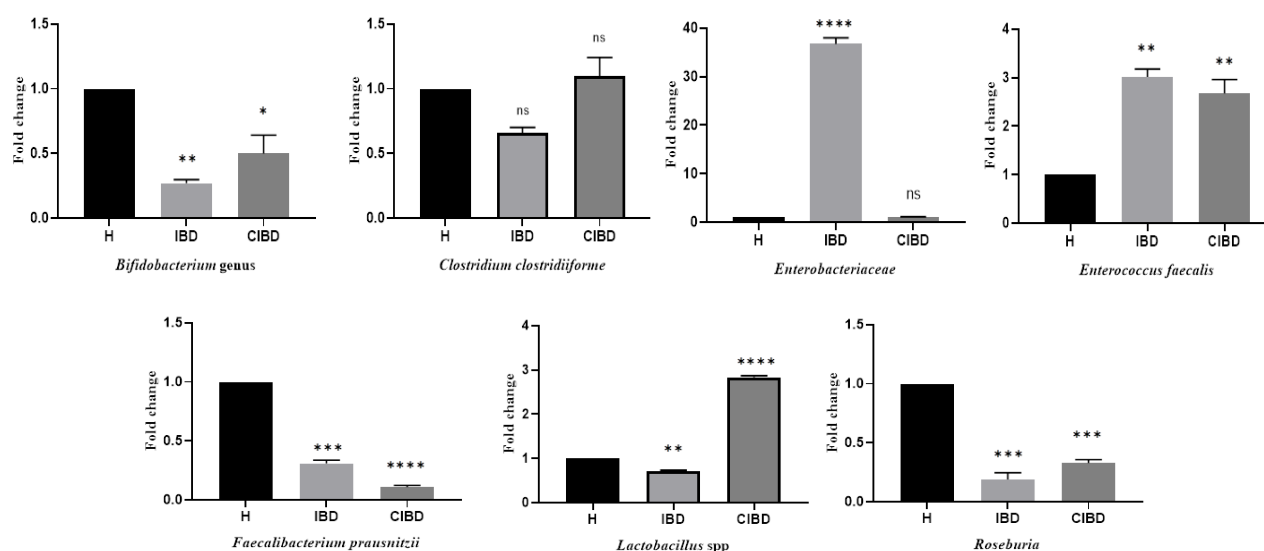


Fig. 2. Differences in bacterial abundance in IBD patients and CIBD compared to control group. Statistical analysis was performed using one-way ANOVA test (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ and **** $p < 0.0001$). ns, not significant; H, healthy

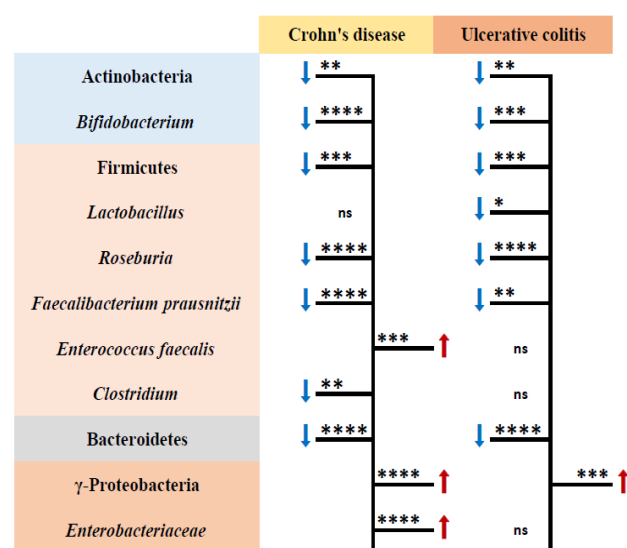


Fig. 3. Gut microbiota associated with CD and UC compared to the control. Statistical analysis was performed with one-way ANOVA test (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, and **** $p < 0.0001$). Increase ↑ and decrease ↓ in abundance of bacterial phyla; ns: not significant.

bacterial phyla of the gut; Bacteroidetes, Firmicutes, and Actinobacteria, reduced. There are conflicting reports on changes in the Bacteroidetes population in the IBD group. A study in the Netherlands reported an increase in the Bacteroidetes group^[18], whereas a decrease was observed in the Bacteroidetes population of IBD, in a study conducted in India^[19]. This discrepancy may be due to differences in environmental and population conditions. Our results of the Bacteroidetes population in both CD and UC groups displayed that decrease in the Bacteroidetes was more evident in CD group than in the UC group. However, in the CIBD group, the population of Bacteroidetes was significantly ($p < 0.01$) lower than in the healthy group, suggesting that it takes longer time for the gut microbiota, including Bacteroidetes, to return to the normal population. Firmicutes phyla examined in this study to compare patients with healthy individuals include *Lactobacillus*, *Faecalibacterium*, *Roseburia*, *Clostridium*, and *Enterococcus*. In our study, all of these bacterial groups were examined in the stool samples of the three study groups. The results showed that the population of *Lactobacillus* decreased in the two groups CD and UC compared to the healthy group. It has also been reported that *lactobacilli*, as one of the most important probiotics, have ability not only to inhibit pro-inflammatory cytokines but also to balance the gut microbiota^[20]. Our study disclosed that the *lactobacilli* load was very low in the UC group, which in turn could set the stage for inflammation. On the other

hand, in the treated group, especially in the cured UC, the amount of *lactobacillus* was higher compared to the healthy group, suggesting that a change in medication and diet could increase the *lactobacillus* population again. The abundance of *Faecalibacterium* and *Roseburia* in the patients with IBD, as well as in the treated patients, was also significantly lower compared to the healthy group. *F. prausnitzii* and its metabolites may have a significant effect on the prevention of IBD by increasing bacterial diversity. *F. prausnitzii* could be influenced by increasing short-chain fatty acid-producing bacteria, decreasing level of TNF- α , and also the population of γ -Proteobacteria^[21]. In one study, it was found that the reduction of *F. prausnitzii* in the CD subgroup could be the result of oxidative stress caused by intestinal inflammation and the reduction of antioxidant biosynthetic pathways^[22]. *Roseburia* also plays an important role in inhibiting inflammation by enhancing the differentiation of Treg cells and anti-inflammatory cytokines such as TSLP, IL10, and TGF- β ^[23]. Reduction of these beneficial bacteria in the gut of patients with IBD led to inflammation in the gastrointestinal tract, which pathobiont bacteria can exploit and proliferate.

In the current study, with the reduction of Firmicutes and Bacteroidetes in the IBD group, the abundance of γ -Proteobacteria, one of the most important classes of Proteobacteria, enhanced. The increase in γ -Proteobacteria in the CD group was greater than that of the UC group, and a significant difference was found between the two subgroups. A survey has shown that the population of Proteobacteria in IBD has been proposed as a potential diagnostic marker for dysbiosis of the intestinal microbiota^[22]. The abundance of *Enterobacteriaceae* in the IBD group was significantly different from the CIBD and healthy groups and was significantly higher in the CD group than in the UC group. This bacterial group may increase intestinal permeability and inflammation by stimulating the secretion of cytokines IL-8, TNF- α , IL-1 β , and the destruction of mucosal junctions^[24]. The findings of a study similar to our results showed an increase in *Enterobacteriaceae* population alone in the CD group, whereas no change was seen in the UC group^[18].

In general, microbial changes occur more frequently in patients with CD than in patients with UC. The results of this study are in agreement with previous studies that identified intestinal inflammation as one of the main factors responsible for the differences in the microbiome in CD and UC patients^[2,25]. On the other hand, the γ -Proteobacteria and *Enterobacteriaceae* in the treated group were not significantly different from those in the healthy ones. Altogether, each of the subgroups CD and UC has its own microbial

population in both the IBD patient group and CIBD group. Thus, the cured CD and UC subgroups were similar only in terms of the composition of *F. prausnitzii*.

The present study showed that important groups of bacteria, which play an important role in causing or inhibiting inflammation, belong two phyla Firmicutes and Proteobacteria; hence, the changes in population of these two phyla can be used as diagnostic markers. In addition, real-time PCR can be used as an accurate, sensitive, and non-invasive molecular method compared to the conventional IBD diagnostic methods to identify this disease.

DECLARATIONS

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Ethical statement

The study protocol was approved by the Ethics Committee of the Pasteur Institute of Iran, Tehran (ethical code: IR.PII.REC.1398.060). Signed informed consent was obtained from all participants.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' Contributions

AS: designed the research, carried out sampling, lab work, statistical analysis, and data collection, and wrote the final manuscript; AS: contributed to lab works and data analysis; HA: developed the original idea, provided materials, and supervised the work; SA: contributed to lab works and data analysis; MT: developed the original idea, provided materials, and supervised the work; MR: developed the original idea, provided materials, and supervised the work; MRP: developed the original idea, provided materials, and supervised the work.

Conflict of interest

None declared.

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REFERENCES

1. Franzosa EA, Sirota-Madi A, Avila-Pacheco J, Fornelos N, Haider HJ, Reinker S, Vatanen T, Hall B, Mallick H, McIver LJ, Sauk JS, Wilson RG, Stevens BW, Scott JM, Pierce K, Deik AA, Bullock K, Imhann F, Porter JA, Zhernakova A, Fu J, Weersma RK, Wijmenga C, Clish CB, Vlamakis H, Huttenhower C, Xavier RJ. Gut microbiome structure and metabolic activity in inflammatory bowel disease. *Nature microbiology* 2019; **4**: 293-305.
2. Imhann F, Vich Vila A, Bonder MJ, Fu J, Gevers D, Visschedijk MC, Spekhorst LM, Alberts R, Franke L, van Dulleman MH, Ter Steege RWF, Huttenhower C, Dijkstra G, Xavier RJ, Festen EAM, Wijmenga C, Zhernakova A, Weersma RK. Interplay of host genetics and gut microbiota underlying the onset and clinical presentation of inflammatory bowel disease. *Gut* 2018; **67**(1): 108-119.
3. Ananthakrishnan AN. Epidemiology and risk factors for IBD. *Nature reviews. Gastroenterology and hepatology* 2015; **12**(4): 205-217.
4. Jost T, Lacroix C, Braegger CP, Rochat F, Chassard C. Vertical mother-neonate transfer of maternal gut bacteria via breastfeeding. *Environmental microbiology* 2014; **16**(9): 2891-2904.
5. Thaïss CA, Zeevi D, Levy M, Zilberman-Schapira G, Suez J, Tengeler AC, Abramson L, Katz MN, Korem T, Zmora N, Kuperman Y, Biton I, Gilad S, Harmelin A, Shapiro H, Halpern Z, Segal E, Elinav E. Transkingdom control of microbiota diurnal oscillations promotes metabolic homeostasis. *Cell* 2014; **159**(3): 514-529.
6. David LA, Maurice CF, Carmody RN, Gootenberg DB, Button JE, Wolfe BE, Ling AV, Devlin AS, Varma Y, Fischbach MA, Biddinger SB, Dutton RJ, Turnbaugh PJ. Diet rapidly and reproducibly alters the human gut microbiome. *Nature* 2014; **505**(7484): 559-563.
7. McIlroy J, Ianiro G, Mukhopadhyay I, Hansen R, Hold GL. Review article: the gut microbiome in inflammatory bowel disease—avenues for microbial management. *Alimentary pharmacology and therapeutics* 2018; **47**(1): 26-42.
8. Rizzatti G, Lopetuso LR, Gibiino G, Binda C, Gasbarrini A. Proteobacteria: A Common Factor in Human Diseases. *BioMed research international* 2017; **2017**: 9351507.
9. Nishida A, Inoue R, Inatomi O, Bamba S, Naito Y, Andoh A. Gut microbiota in the pathogenesis of inflammatory bowel disease. *Clinical journal of gastroenterology* 2018; **11**(1): 1-10.
10. Sun Y, Li L, Xia Y, Li W, Wang K, Wang L, Miao Y, and Ma S. The gut microbiota heterogeneity and assembly changes associated with the IBD. *Scientific reports* 2019; **9**(1): 440.
11. Schirmer M, Franzosa EA, Lloyd-Price J, McIver LJ, Schwager R, Poon TW, Ananthakrishnan AN, Andrews E, Barron G, Lake K, Prasad M, Sauk J, Stevens B, Wilson RG, Braun J, Denson LA, Kugathasan S, McGovern DPB, Vlamakis H, Xavier RJ, Huttenhower C. Dynamics of metatranscription in the inflammatory

- bowel disease gut microbiome. *Nature microbiology* 2018; **3**(3): 337-346.
12. Lupp C, Robertson M L, Wickham M E, Sekirov I, Champion O L, Gaynor EC, Finlay BB. Host-mediated inflammation disrupts the intestinal microbiota and promotes the overgrowth of Enterobacteriaceae. *Cell host and microbe* 2007; **2**(2): 119-129.
 13. Frank DN, Robertson CE, Hamm CM, Kpadeh Z, Zhang T, Chen H, Zhu W, Sartor RB, Boedeker EC, Harpaz N, Pace NR, Li E. Disease phenotype and genotype are associated with shifts in intestinal-associated microbiota in inflammatory bowel diseases. *Inflammatory bowel diseases* 2011; **17**(1): 179-184.
 14. Kostic AD, Xavier RJ, Gevers D. The microbiome in inflammatory bowel disease: current status and the future ahead. *Gastroenterology* 2014; **146**: 1489-1499.
 15. Gevers D, Kugathasan S, Denson LA, Vázquez-Baeza Y, Treuren WV, Ren B, Schwager E, Knights D, Jin Song S, Yassour M, Morgan XC, Kostic AD, Luo C, González A, McDonald D, Haberman Y, Walter T, Baker S, Rosh J, Stephens M, Heyman M, Markowitz J, Baldassano R, Griffiths A, Sylvester F, Mack D, Kim S, Crandall W, Hyams J, Huttenhower C, Knight R, Xavier RJ. The treatment-naïve microbiome in new-onset Crohn's disease. *Cell host and microbe* 2014; **15**(3): 382-392.
 16. Livak KJ, Schmittgen TD. Analysis of relative gene expression data using real-time quantitative PCR and the 2(-Delta Delta C(T)) method. *Methods* 2001; **25**(4): 402-408.
 17. Ott SJ, Musfeldt M, Wenderoth DF, Hampe J, Brant O, Folsch UR, Timmis KN, Schreiber S. Reduction in diversity of the colonic mucosa associated bacterial microflora in patients with active inflammatory bowel disease. *Gut* 2004; **53**: 685-693.
 18. Vich Vila A, Imhann F, Collij V, Jankipersadsing SA, Gurry T, Mujagic Z, Kurilshikov A, Bonder MJ, Jiang X, Tigchelaar EF, Dekens J, Peters V, Voskuil MD, Visschedijk MC, van Dullemen HM, Keszthelyi D, Swertz MA, Franke L, Alberts R, Festen EAM, Dijkstra G, Masclee AAM, Hofker MH, Xavier RJ, Alm EJ, Fu J, Wijmenga C, Jonkers DMAE, Zhernakova A, Weersma RK. Gut microbiota composition and functional changes in inflammatory bowel disease and irritable bowel syndrome. *Science translational medicine* 2018; **10**(472): 8914.
 19. Kedia S, Shankar Ghosh T, Jain S, Desigamani A, Kumar A. Gut microbiome diversity in acute severe colitis is distinct from mild to moderate ulcerative colitis. *Journal of gastroenterology and hepatology* 2021; **36**: 731-739.
 20. Chou Y, Ho P, Chen W, Wu Sh, Pan M. *Lactobacillus fermentum* V3 ameliorates colitis-associated tumorigenesis by modulating the gut microbiome. *American journal of cancer research*. 2020; **10**(4): 1170-1181.
 21. Zhou Y, Xu H, Xu J, Guo X, Zhao HF. *prausnitzii* and its supernatant increase SCFAs-producing bacteria to restore gut dysbiosis in TNBS-induced colitis. *AMB express* 2021; **11**(1): 33.
 22. Méndez-Salazar EO, Ortiz-López MG, Granados-Silvestre MA, Palacios-González B, Menjivar M. Altered Gut Microbiota and Compositional Changes in Firmicutes and Proteobacteria in Mexican Undernourished and Obese Children. *Frontiers in microbiology* 2018; **9**: 2494.
 23. Shen Zh, Zhu C, Quan Y, Yang J, Yuan W. Insights into Roseburia intestinalis which alleviates experimental colitis pathology by inducing anti-inflammatory responses. *Journal of gastroenterology and hepatology* 2018; **33**(10): 1751-1760.
 24. Baldelli V, Scaldaferri F, Putignani L, Chierico FD. The Role of Enterobacteriaceae in Gut Microbiota Dysbiosis in Inflammatory Bowel Diseases. *Microorganisms* 2021; **9**: 697.
 25. Halfvarson J, Brislawn CJ, Lamendella R, Vázquez-Baeza Y, Walters WA, Bramer LM, D'Amato M, Bonfiglio F, McDonald D, Gonzalez A, McClure EE, Dunkleberger MF, Knight R, Jansson JK. Dynamics of the human gut microbiome in inflammatory bowel disease. *Nature microbiology* 2017; **2**: 17004.
 26. Bartosch S, Fite A, Macfarlane G, McMurdo ME. Characterization of Bacterial Communities in Feces from Healthy Elderly Volunteers and Hospitalized Elderly Patients by Using Real-Time PCR and Effects of Antibiotic Treatment on the Fecal Microbiota. *Applied and environmental microbiology* 2004; **70**(6): 3575-3581.
 27. Haarman M, Knol J. Quantitative Real-Time PCR Analysis of Fecal *Lactobacillus* Species in Infants Receiving a Prebiotic Infant Formula. *Applied and environmental microbiology* 2006; **72**(4): 2359-2365.
 28. Larsen N, Vogensen FK, van den Berg FWJ, Nielsen DS, Andreassen AS, Pedersen BK, Abu Al-Soud W, Sørensen SJ, Hansen LH, Jakobsen M. Gut Microbiota in Human Adults with Type 2 Diabetes Differs from Non-Diabetic Adults. *PLoS one* 2010; **5**(2): e9085.
 29. Jia W, Whitehead RN, Griffiths L, Dawson C, Waring RH, Ramsden DB, Hunter JO, Cole JA. Is the abundance of *Faecalibacterium prausnitzii* relevant to Crohn's disease? *FEMS microbiology letters* 2010; **310**: 138-144.
 30. De Gregoris TB, Aldred N, Clare AS, Burgess JG. Improvement of phylum- and class-specific primers for real-time PCR quantification of bacterial taxa. *Journal of microbiological methods* 2011; **86**: 351-356.