



## Tight junctions in inflammatory bowel diseases and inflammatory bowel disease associated colorectal cancer

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### Abstract

Inflammatory bowel diseases are characterised by inflammation that compromises the integrity of the epithelial barrier. The intestinal epithelium is not only a static barrier but has evolved complex mechanisms to control and regulate bacterial interactions with the mucosal surface. Apical tight junction proteins are critical in the maintenance of epithelial barrier function and control of paracellular permeability. The characterisation of alterations in tight junction proteins as key players in epithelial barrier function in inflammatory bowel diseases is rapidly enhancing our understanding of critical mechanisms in disease pathogenesis as well as novel therapeutic opportunities. Here we give an overview of recent literature focusing on the role of tight junction proteins, in particular claudins, in inflammatory bowel diseases and inflammatory bowel disease associated colorectal cancer.

**Key words:** Claudin; Tight junction; Ulcerative colitis; Pouchitis; Crohn's disease

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**Core tip:** Epithelial barrier function is compromised in inflammatory bowel diseases (IBD). Apical tight junction proteins, in particular claudins, are key players in epithelial barrier function. However, there is little consensus regarding the expression of most claudin isoforms in these conditions or whether these findings are primary or secondary to disease pathogenesis. Knowledge of tight junction protein expression and function in IBD and IBD associated colorectal cancer will enhance our understanding of critical mechanisms in disease pathogenesis as well as novel therapeutic opportunities.

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## INTRODUCTION

A number of routes exist for passage across the epithelial barrier between the internal and external environment. The intercellular spaces between adjacent cells, linked together by junctional complexes, are critical in regulating the mucosal barrier. Ions and solutes pass transcellularly utilising channels, carriers and transporting ATPases<sup>[1]</sup>. The paracellular pathway also regulates permeability to water, ions and low molecular weight molecules (< 600 kDa). The differences in paracellular permeability between different epithelia such as the proximal or distal nephron, has led to the concept of "leaky" or "tight" epithelia. In disease states, epithelia may become more "tight" or more "leaky" such as is seen in inflammatory bowel diseases<sup>[1]</sup>.

The tight junctions (TJs) form the apical most unit, defining the boundary between the apical and basolateral membranes and are predominantly the rate-limiting factor in paracellular passage<sup>[2]</sup>. The tight junction is built up by both transmembrane proteins such as occludin, tricellulin, different claudins and junctional adhesion molecules (JAMs), as well as peripheral membrane proteins such as zona occludens (ZO)-1,-2,-3 and cingulin. They are linked to the cytoskeleton of the cell by F-actin and myosin II<sup>[3,4]</sup>. These ZO proteins have three PDZ domains that mediate binding to other transmembrane tight junction proteins such as claudins in a dynamic energy dependent manner<sup>[5]</sup>. They are also the direct targets

and effectors of different signalling pathways (such as the myosin light chain kinase) thereby altering the assembly, maintenance, and barrier function of the TJ complex<sup>[6]</sup>.

The expression of different TJs in the gut varies according to localization (*e.g.*, villus vs crypt, small bowel vs colon), cell membrane localization (*e.g.*, apical, lateral or basolateral) and the gut's functional properties at the site<sup>[4,7,8]</sup>. For example, claudin 2 is expressed at the apical pole throughout the crypt-villus axis in the jejunum whilst in the colon expression is restricted to the crypts, whereas claudin 4 expression is throughout the crypt-villus axis in the small and large intestine. The segmental distribution of claudin expression may relate to cell differentiation, carbohydrate metabolism and transcription factors such as HNF1 $\alpha$ , Cdx2 and GATA-4<sup>[9]</sup>.

In health, the apical TJs construct a dynamic intestinal barrier that regulates the paracellular uptake of water, nutrients and electrolytes<sup>[3,5]</sup>. TJs may be size and/or charge selective and prevent contact between the proteins of the two cell poles: the basolateral and apical cell membranes<sup>[10]</sup>. While many tight junction proteins have properties of increased barrier formation, others form size and/or charge selective channels or pores<sup>[1]</sup>. Adherens junctions and desmosomes are mostly involved in communication between neighbouring epithelial cells<sup>[4,10,11]</sup>. TJ dysfunction can lead to the disruption of the intestinal barrier integrity. Changes in pH, osmotic load or cytoskeleton function all affect the barrier function of TJs<sup>[12]</sup>.

There are 27 different claudin isoforms that modulate the paracellular movement of ions based on charge and size<sup>[13]</sup>. Claudin 1 and claudin 2 are able to initiate the formation of TJ strands on fibroblasts lacking TJs, suggesting that they are the major components of TJ strands<sup>[14]</sup>. Claudin 2 controls the movement of monovalent cations such as Na<sup>+</sup> to the interstitium and reduces the paracellular trans-epithelial resistance as well as enhances trans-epithelial water flux<sup>[15,16]</sup> in contrast to other claudins (like 1, 3, 4, 5, 8) that tighten the epithelium<sup>[17-23]</sup>. Claudin 2 also directly decreases the barrier function of Claudin 1 and Claudin 4 strands<sup>[13]</sup>. Therefore the ratio of different claudins in the TJ determines its functional property as either leaky or tight. This review will focus on the role of key TJPs (Table 1) in the pathogenesis of IBD and IBD associated colorectal cancer (CRC).

## EPITHELIAL BARRIER FUNCTION IN INFLAMMATORY BOWEL DISEASES

Inflammatory bowel diseases (IBD) share a multifactorial aetiology of genetic susceptibility, environmental factors and immune dysregulation<sup>[24]</sup>. These diseases are characterized by intestinal inflammation that compromises the integrity of the epithelial barrier leading to increased permeability

**Table 1** Tight junctions of interest in inflammatory bowel diseases

TJ protein	Function	Expression in CD	Expression in UC	Expression in pouchitis
Claudin 1	Tightens the epithelium <sup>[17,23]</sup> able to initiate formation of TJ strands <sup>[14]</sup>	Active: ↑ <sup>[46,65]</sup> ↔ <sup>[50]</sup> Inactive: ↔ <sup>[65]</sup>	Active: ↑ <sup>[65]</sup> , ↔ <sup>[45]</sup> Inactive: ↔ <sup>[65]</sup>	↓ <sup>[40]</sup>
Claudin 2	Important pore-forming TJ protein <sup>[15,16,23]</sup> , able to initiate formation of TJ strands <sup>[14]</sup> , decreases barrier function of CLDN1 and CLDN4 <sup>[13]</sup>	↑ <sup>[44,50,65,101]</sup>	↑↑ <sup>[44,50,65,101]</sup>	↑ <sup>[40]</sup>
Claudin 4	Tightens the epithelium, decreases paracellular conductance through decrease in sodium permeability <sup>[19]</sup>	↓ <sup>[44]</sup> Active inflammation: ↑ <sup>[65]</sup> ↔ <sup>[50]</sup>	Active: ↓ <sup>[44,45]</sup> Active Inflammation: ↑ <sup>[65]</sup>	↔ <sup>[40]</sup>
Claudin 5	Tightens the epithelium <sup>[20]</sup>	↓ <sup>[50]</sup>		↔ <sup>[40]</sup>
Claudin 8	Tightens the epithelium <sup>[21]</sup>	↓ <sup>[50]</sup>		
Claudin 12	Tightens the epithelium	↑ <sup>[48]</sup>		
Claudin 18	Uncertain function		↑ <sup>[47]</sup>	
Occludin	Binds ZO-1, regulates paracellular permeability, function in cellular adhesion <sup>[102]</sup>	↓ <sup>[46,50,52]</sup> ↔ <sup>[65]</sup>	↓ <sup>[52]</sup> ↔ <sup>[65]</sup>	↔ <sup>[40]</sup>
ZO-1	Mediates protein-protein interactions, link to actin cytoskeleton: “anchoring” protein <sup>[4,103]</sup>	↓ <sup>[68]</sup>	↔ <sup>[64]</sup> (Mees <i>et al.</i> : “in patients with a history of UC”)	↓ <sup>[54]</sup> (chronic pouchitis)

TJ: Tight junction; ZO-1: Zona occludens-1; CD: Crohn’s disease; UC: Ulcerative colitis.

and infiltration of pathogens<sup>[25]</sup>. Both Crohn’s disease (CD) and ulcerative colitis (UC) share common features such as epithelial breaks, a reduction in tight junction strands, and glandular atrophy<sup>[11,26,27]</sup>. Patients with clinically active CD have increased intestinal permeability<sup>[28-30]</sup>. Barrier dysfunction is likely to be caused by epithelial damage including apoptosis, erosion and ulceration that are characteristic of gut inflammation. Inflammatory cytokines associated with gut inflammation alter epithelial permeability through their effects on the junctional complexes<sup>[31-33]</sup>.

However, impaired barrier function is also evident in quiescent IBD and even in first degree relatives of patients with CD<sup>[34,35]</sup>. Genetic studies have identified new UC susceptibility loci pertaining to defects of the epithelial barrier<sup>[36,37]</sup>. Barrier properties of ileoanal pouch mucosa in both pouchitis and in ileoanal pouches where backwash ileitis was present prior to restorative proctocolectomy for UC are reduced<sup>[38-40]</sup> and increased bacterial translocation has been reported in pouches functioning for longer than 12 mo<sup>[41]</sup>. Dysregulation of the epithelial barrier with changes in paracellular permeability due to altered cell to cell junctions is likely to be significantly more selective and may be a critical primary factor in the pathogenesis of IBD.

## ULCERATIVE COLITIS

Gitter *et al.*<sup>[42]</sup> identified that in the sigmoid colon of patients with early UC where the epithelium looks intact, there are in fact already leaks from apoptotic foci. Furthermore, the higher the degree of inflammation observed, the higher the conductance of the epithelium measured<sup>[42]</sup>. A study using epithelial resistance as a measure of barrier function in samples from UC patients with inflamed sigmoid colon<sup>[43]</sup>

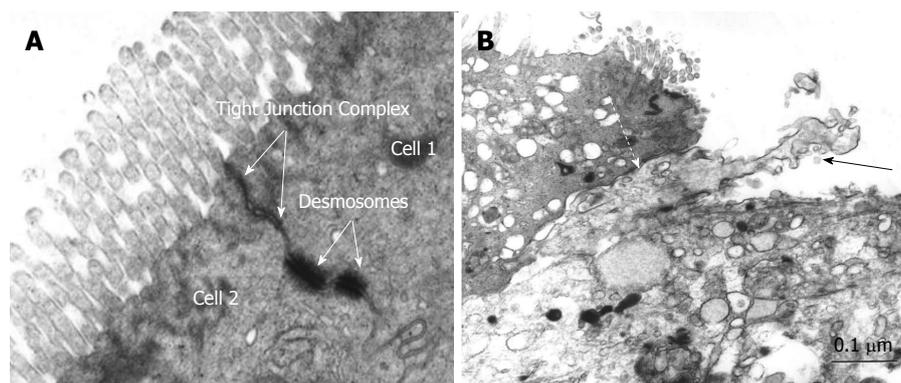
demonstrated an 80% reduction in epithelial resistance and a decrease in epithelial (not crypt) TJ depth in inflamed samples.

Several studies have focused on expression of claudins in UC patients<sup>[43-45]</sup>, demonstrating higher expression of claudin 2 in colonic samples from patients with UC. Additionally, the increases in “pore-forming” claudin 2 correlate with disease severity on both protein and transcriptional levels. Reductions in other “tightening” tight junctions also occur concomitantly. Reduced staining intensity for claudin 3, 4 and 7 have been shown both on the surface epithelium as well as mislocation of claudin 4 extra-junctionally in UC patients<sup>[44,45]</sup>.

In contrast, Poritz *et al.*<sup>[46]</sup> found an increase in claudin 1:occludin ratios in colonic samples from UC patients compared with healthy controls and CD samples by Western blot analysis. This change in ratio was the result of both an increase in claudin 1 and a decrease in occludin. Disease severity, measured by the degree of inflammation, was directly proportional to the alterations seen in TJ structure in UC. In another study, claudin 1 was demonstrated to be upregulated in the colon of UC patients compared to healthy controls, but did not correlate to disease severity<sup>[47]</sup>. In sigmoid samples of active UC patients, a trend toward upregulation of claudin 12 (another “tightening” claudin) was observed<sup>[48]</sup>. Claudin 18 expression was found to be elevated in UC patients compared with controls, but did not correlate with severity of inflammation postulating a primary defect in barrier function<sup>[47]</sup>.

## CROHN’S DISEASE

In CD, intestinal permeability is considered a predictive



**Figure 1** Electron microscopy of pouch epithelium tight junction complex in non-inflamed pouch (A) and electron micrograph demonstrating dendritic cell penetrating between two epithelial cells in pouchitis (B). Bar = 0.1  $\mu\text{m}$ . Solid arrow: Dendritic cell; Dashed arrow: Tight junction complex between epithelial cell and dendritic cell.

factor for disease susceptibility and relapse<sup>[34,49]</sup>. Changes in tight junctions and epithelial apoptosis might dominate in causing barrier dysfunction<sup>[50]</sup>. Marin *et al*<sup>[51]</sup> studied 10 patients with CD. The epithelial cells of the terminal ileum from these patients demonstrated tight junction disorganisation which was present in minimally inflamed areas although more pronounced in cobblestone areas.

In samples from the sigmoid colon in active CD, the expression of claudins 5, 8 and 3 were decreased, whereas claudin 2 expression was moderately increased<sup>[50]</sup>. Kucharzik *et al*<sup>[52]</sup> demonstrated similar changes in tight junction expression in both UC and CD with global down-regulation of occludin. This finding was present both in active and quiescent UC whilst only in active CD. Das *et al*<sup>[53]</sup> showed claudin 2 to be strongly expressed in the ileum of approximately 50% of quiescent as well as active CD. Moreover, the distribution of claudin 2 expression was altered in colonic biopsies from CD patients and associated with disrupted tight junctions. Others have found no change in ileal expression of claudin 2 in CD, whilst in the sigmoid colon of CD patients, claudin 2 was found to be significantly down regulated compared to controls. However, claudin 12 was found to be increased in the ileum of CD patients<sup>[48]</sup>.

## POUCHITIS

Barrier properties of ileoanal pouch mucosa in pouchitis and in non-inflamed pouches are reduced<sup>[38]</sup> with increased bacterial translocation in long lasting pouches<sup>[41]</sup>. Merrett *et al*<sup>[39]</sup> showed an increase in pouch permeability in patients with pouchitis compared with those with a normally functioning pouch. Electron micrography of mucosal epithelium from non-inflamed UC pouch (Figure 1A) and pouchitis suggests membranes between cells are more loosely arranged with increased intercellular distance and perijunctional cytoskeleton condensation<sup>[54]</sup>. In addition, dendritic cells appear to penetrate the epithelial cell layer more frequently (personal communication) (Figure

1B). Analysis of claudin expression from pouch biopsies before ileal pouch anal anastomosis (IPAA), during pouchitis and at a time point over a year after ileostomy closure demonstrated an elevation in claudin 2 levels in acute pouchitis<sup>[40]</sup>. We also recently demonstrated altered expression of TJP in the ileal pouch of patients with UC. In particular increased expression of claudin 2 occurred early following ileostomy closure, prior to the development of histological inflammation. Claudin 2 was also elevated in UC patients without pouchitis compared with FAP patients and in acute, but not chronic pouchitis samples whilst epithelial expression of ZO-1 and claudin 1 were reduced in patients with chronic pouchitis. These findings suggest that increased claudin 2 expression may be an early event in the development of inflammation<sup>[54]</sup>.

## TIGHT JUNCTIONS AND IBD

### ASSOCIATED COLORECTAL CANCER

Passage of luminal antigens or metabolites through diminished epithelial barrier is known to promote chronic inflammation and CRC<sup>[55-57]</sup>. In general, claudins are associated with different types of neoplasms, including breast, prostate, ovarian, pancreatic, gastric and colorectal carcinoma<sup>[58,59]</sup>. They may also be involved in the progression to metastasis, and provide unfavourable signalling pathways between the extra- and intracellular milieu<sup>[60-63]</sup>.

Mees *et al*<sup>[64]</sup> investigated the expression of both adherens, and TJ proteins in patients with CRC with a history of UC. Claudins 1, 3, 4 and  $\beta$ -catenin were upregulated in CRC tissue compared with normal controls or intraepithelial neoplasia, whilst the expression of claudin 2, ZO-1 and occludin did not vary significantly between samples. Other studies have demonstrated elevated claudin 1 and claudin 2 levels in IBD-associated carcinoma<sup>[59,65,66]</sup>. Kinugasa *et al*<sup>[66]</sup> demonstrated increased staining for claudin 1 in both high-grade dysplasia and UC-associated CRC when

compared with normal or UC colonic samples.

In the study of Weber *et al.*<sup>[65]</sup>, the expression of claudin 1, 2, 4 and occludin were evaluated in IBD patients, IBD-associated dysplasia, acute self-limited colitis (ASLC) and sporadic adenomas. During active inflammation, claudin 1 expression was upregulated in both UC and CD patients and localization of claudin 1 was not limited to the TJ, but was expressed on the lateral membrane. Claudin 2 expression was the richest in the TJ region and the apical cytoplasm. In an identical manner to claudin 1, the expression of claudin 2 correlated with the degree of inflammation in both UC and CD, but not in ASLC<sup>[65]</sup>. Claudin 1 and claudin 2 levels were also increased in IBD-associated dysplasia and sporadic adenomas in comparison to non-dysplastic IBD. However, occludin expression and localization in both active and inactive IBD and in adenomas or carcinomas was no different compared with controls. The changes in TJ expression in IBD associated dysplasia may represent the severity and longevity of histological inflammation, a known risk factor for neoplastic progression in IBD<sup>[67]</sup>.

## CHICKEN OR EGG?

It is not clear whether the changes observed in tight junctions in IBD are causal, leading to abnormal epithelial barrier integrity and the aberrant immune responses, or whether the inflammation itself causes the alterations in tight junction expression and distribution.

### Inflammatory cytokines and tight junction regulation

Heller *et al.*<sup>[31]</sup> demonstrated a significant upregulation of IL-13 in patients with UC compared to CD patients and non-inflammatory controls. Following the upregulation of IL-13, there was a decrease in trans-epithelial resistance and an increase in epithelial cell apoptosis and conductance. Furthermore, IL-13 caused an upregulation of the claudin 2 gene, thus elevating claudin 2 protein production threefold. IL-13 did not have a significant effect on the expression of occludin, claudin 1 and claudin 4.

In CD, interferon gamma (IFN- $\gamma$ ) contributes to impairment of epithelial barrier function through disrupting tight junction complexes by causing decreased expression and increased internalization of occludin and ZO-1<sup>[68]</sup>. The effects of IFN- $\gamma$  on barrier function may be mediated through 5' adenosine monophosphate-activated protein kinase (AMPK). AMPK is key in sensing the cell's energy levels, which decrease during inflammation and subsequently increase the demand for AMPK. Scharl *et al.*<sup>[68]</sup> showed that inhibiting AMPK not only reverses its effect on TJs but also its negative effect on trans epithelial resistance. Watson *et al.*<sup>[69]</sup> also showed in T84 cells (model intestinal epithelial cell line) that IFN- $\gamma$  increased intestinal permeability to large molecules such as *E. coli*-derived lipopolysaccharide. Effects

were exerted presumably by decreasing expression of occludin and increasing the expression of claudin 1 but expression of claudin 2 or 3 were not affected<sup>[69]</sup>.

TNF- $\alpha$  can also affect tight junctions and decrease epithelial barrier function by increasing Myosin Light Chain Kinase (MLCK) phosphorylation. Inhibition of MLCK in TNF- $\alpha$  treated epithelial monolayers can acutely restore barrier function<sup>[32]</sup>. Furthermore, MLCK-activation promotes IL-13 expression and claudin 2 synthesis<sup>[70]</sup>. TNF- $\alpha$  induced MLCK expression may therefore be a critical mechanism for barrier dysfunction in UC and CD. Ileal MLCK expression is increased in ileal biopsies from patients with CD compared with controls and increased MLCK correlates with disease activity<sup>[71]</sup>.

### Animal models of epithelial permeability and inflammation

A recent study of transgenic mice expressing activated MLCK showed increased paracellular permeability without histological inflammation. Further analysis however, found an increase in the absolute numbers of lamina propria CD4<sup>+</sup> lymphocytes and a significant redistribution of CD11c<sup>+</sup> dendritic cells to the superficial lamina propria as well as polarisation to a Th1 cytokine profile<sup>[72]</sup>. Despite increased epithelial permeability these mice did not develop intestinal inflammation. However, when crossed with mice that develop spontaneous inflammation an accelerated and exaggerated inflammatory response was seen. This mouse model therefore suggests that barrier loss may not initiate inflammation but accelerate inflammatory responses.

Other studies suggest that tight junction abnormalities and epithelial permeability may precede the increase of inflammatory cytokines. Interleukin-10 (IL-10) blocks IFN- $\gamma$  induced epithelial permeability and IL-10 knockout mice have increased permeability and spontaneously develop chronic intestinal inflammation<sup>[33]</sup>. Inhibition of the zonulin receptor (a key receptor in tight junction binding regulation) in IL-10 knockout mice reduced intestinal permeability and attenuated the spontaneous development of colitis<sup>[33]</sup>. However, increased intestinal permeability in IL-10 knockout mice not only preceded the onset of inflammation but also occurred significantly earlier than any differences in IFN- $\gamma$  or TNF- $\alpha$ .

A recent study of intestine-specific claudin 7 knockout mice<sup>[73]</sup> demonstrated increased neutrophil infiltration into the lamina propria and increased mRNA expression of inflammatory cytokines without altered epithelial integrity. Further investigation showed increased epithelial permeability and paracellular absorption of small molecules and increased absorption of a bacterial derived neutrophil chemoattractant in the claudin 7 knockouts. Treatment with antibiotics or exogenous administration of the soluble bacterial derived chemoattractant, abolished and initiated the onset of inflammation respectively. This model

suggests that the loss of claudin 7 enabled increased absorption of soluble bacterial products leading to the development of colonic inflammation.

### ***Ileoanal pouch as a human model for inflammatory bowel disease***

Unlike UC and CD, the ileal pouch offers a unique opportunity to study the development of inflammation before disease onset. In patients with UC, increased epithelial expression of the "pore-forming" tight junction claudin 2 was an early event after ileostomy closure and preceded increased IL-6 levels, as well as increased TLR4 and CD40 activation marker expression in patients with mucosal inflammation of the pouch at twelve months following ileostomy closure<sup>[54]</sup>.

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## **THERAPEUTIC OPPORTUNITY IN INFLAMMATORY BOWEL DISEASES**

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Strategies to manipulate tight junctions and intestinal permeability are likely to have an important role in the future treatment of inflammatory bowel diseases.

### ***Anti-TNF therapy and tight junctions***

Anti-TNF therapy is effective in the treatment of Crohn's disease, ulcerative colitis and chronic pouchitis<sup>[74-76]</sup>. Barrier function is significantly restored following anti-TNF therapy for CD<sup>[77,78]</sup>. In the study by Zeissig *et al.*<sup>[78]</sup>, this was associated with a reduction in epithelial apoptosis but no significant changes in occludin, claudin 1 or claudin 4. However, other claudins including claudin 2 were not assessed. In a study of experimental colitis in mice, both etanercept and infliximab attenuated inflammation induced reductions in ZO-1 and occludin as well as reducing the upregulation of claudin 2<sup>[79]</sup>. More recently, in epithelial cell lines adalimumab prevented increased phosphorylation of myosin light chain and reversed the TNF induced down regulation of claudins 1 and 4<sup>[80]</sup>.

### ***Short chain fatty acids***

In the colon, anaerobic bacterial fermentation of undigested polysaccharides leads to the production of short chain fatty acids, particularly acetic, propionic and butyric acids. Short chain fatty acids, in particular butyrate are thought to be the principal source of energy for colonocytes and in UC patients colonocytes have demonstrated diminished oxidation of butyrate<sup>[81,82]</sup>. *In vitro* culture demonstrated butyrate enhanced claudin 1 transcription and enhanced barrier function<sup>[83,84]</sup>. In colonic epithelial cells treated with butyrate claudin 2 was down regulated<sup>[85]</sup>. Butyrate might be postulated to have a role in maintaining barrier function *via* tight junction regulation.

### ***Novel compounds and probiotics***

Novel compounds that alter epithelial barrier function may be available from nutritional sources. Several

plant extracts have been observed to regulate TJ expression. Quercetin, a common flavanoid increase epithelial resistance in Caco-2 cell monolayers by upregulating claudin 4 expression<sup>[86]</sup>. Berberine, an isoquinolone alkaloid, prevented TNF- $\alpha$  induced claudin 1 disassembly and upregulation of claudin 2 in a cell culture model<sup>[87]</sup>. Polyunsaturated fatty acids can also have beneficial effects on the assembly and morphology of TJs<sup>[88]</sup>. Omega-3 and omega 6 polyunsaturated fatty acids up-regulate expression of occludin, reduce permeability and strengthen the epithelial barrier<sup>[89]</sup>. Polyunsaturated fatty acids also reverse the disruptions in TJs caused by proinflammatory cytokines in Caco 2 epithelial cells<sup>[90,91]</sup> and might play a role in preventing the alteration in the epithelial barrier caused by inflammation or proinflammatory cytokines that could be exploited as a therapeutic target in the treatment of gut inflammation.

Much attention has focused on the effects probiotic bacteria and their products may have on tight junction expression and epithelial barrier function<sup>[92]</sup>. *In vitro* and animal models have shown Lactobacilli to attenuate epithelial permeability in experimental colitis and to upregulate tight junction expression of ZO-1, occludin and claudin-3<sup>[93-95]</sup>. VSL#3 (a mixture of eight probiotic strains) prevented the reduction and redistribution of ZO-1 and claudins -1,-3,-4 and -5 in a murine model of colitis. Furthermore, bacterial products may be a source of novel therapies affecting epithelial barrier function. Uncharacterized extracellular proteins secreted by *B. longum* subsp. *infantis*, increased the production of ZO-1 and occludin in epithelial cells<sup>[96]</sup>. Extracellular proteins derived from *Lactobacillus rhamnosus* GG attenuated reduction in epithelial resistance in an *in vitro* model, preventing the redistribution of tight junction proteins including ZO-1 and occludin in a dose dependent manner<sup>[97]</sup>. Moreover, *Salmonella* infection increased claudin-2 expression in epithelial cell lines facilitating its invasion. Therefore, blocking claudin-2 as a potential therapeutic target to prevent bacterial invasion has been suggested<sup>[98]</sup>.

Zonulin has been shown to be a key regulator of intestinal permeability through modulation of epithelial tight junctions<sup>[99]</sup>. A synthetic peptide inhibitor of zonulin known as AT 1001 or Larazotide has undergone clinical studies in the treatment of coeliac disease<sup>[100]</sup>. In the IL-10 knockout mouse, AT 1001 reduced intestinal permeability and attenuated the development of spontaneous colitis<sup>[33]</sup>. Future studies are necessary to determine the role these proteins may have in modulating tight junctions and epithelial barrier function in inflammatory bowel diseases.

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## **CONCLUSION**

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Dysregulation of TJ proteins is involved and may precede the development of IBD. It is probable that they also contribute to the development of IBD-

associated CRC. Recent evidence suggests that a dysregulated expression of TJ proteins may precede the development of intestinal inflammation. However, a number of questions remain unanswered regarding the role of TJs in the aetiology of inflammatory bowel diseases. Significant differences may exist between animal models and human studies regarding TJ expression profiles and further human studies are necessary to elucidate the role of TJs in IBD aetiology or acceleration of aberrant inflammatory responses.

Claudin 2 appears to be upregulated in UC, CD and pouchitis and some studies also suggest elevated claudin 2 to be present in quiescent disease. However, there is little consensus regarding the up- or down regulation of the other claudin isoforms in these conditions. This may be explained to some extent by methodological differences and heterogeneity of patients and sampling with regard to disease activity and history. Further evaluation of the patterns of expression of claudins in active and inactive IBD patients should help to elucidate their contribution to disease, but longitudinal studies are also necessary. Future studies should evaluate therapeutic approaches that manipulate TJs, restoring epithelial barrier integrity, for the treatment of active inflammatory bowel diseases, maintenance of remission and prevention of onset of inflammation in the gut.

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