NOD2/CARD15 and the Paneth cell

Citation for published version:
https://doi.org/10.1136/gut.52.11.1533

Digital Object Identifier (DOI):
10.1136/gut.52.11.1533

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Publisher's PDF, also known as Version of record

Published In:
Gut

General rights
Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy
The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.
Inflammatory bowel disease

NOD2/CARD15 and the Paneth cell: another piece in the genetic jigsaw of inflammatory bowel disease

M C Aldhous, E R Nimmo, J Satsangi

Expression of NOD2/CARD15 in the Paneth cell may be critical in the pathogenesis of Crohn’s disease

The emergence and application of novel molecular techniques over the last decade has provided a new catalyst to studies of the pathogenesis of the chronic inflammatory bowel diseases (IBD): Crohn’s disease (CD) and ulcerative colitis (UC). Successful development of genetically engineered models of intestinal inflammation has not only provided insight into the dysregulation of the mucosal flora in establishing and maintaining chronic intestinal inflammation. These advances in understanding pathophysiology in turn have already led to novel therapeutic approaches.

However, it is in studies of human genetics that landmark progress has been made, widely recognised not only within gastroenterology but also by investigators in all complex diseases. Genome wide scanning led initially to the identification of a number of susceptibility loci, the statistical evidence for which satisfy stringent criteria for definitive linkage. The subsequent detection of the NOD2/CARD15 gene within the IBD1 linkage interval and the association of mutations within this gene with susceptibility to CD is widely regarded as the most stringent proof of principle for hypothesis free genome scanning in complex diseases.

In the time that has elapsed since the discovery of NOD2/CARD15, the contribution of this gene in determining susceptibility and disease behaviour in IBD has received detailed examination. It is now clear that NOD2/CARD15 mutations are associated with susceptibility to CD but not UC. However, the contribution is subject to considerable ethnic and even regional variation. Whereas mutations may be carried by up to 50% of central Europeans with CD, these mutations are not present in Japanese or Afro-American patients. Even within Europe, there is considerable regional variation and reported population attributable risks vary from 7.1% to 32%. Furthermore, there is heterogeneity within CD, and genotype-phenotype relationships clearly exist. Independent data suggest that NOD2/CARD15 variants are associated with early onset disease, involvement of the terminal ileum, and fibrostenosing disease, all phenotypic characteristics initially implicated in Crohn’s initial descriptions of regional enteritis.

The most intriguing question that remains to be answered concerns the mechanism whereby mutations in the NOD2/CARD15 gene predispose towards the chronic intestinal inflammation characteristic of CD. Studies with respect to protein structure, expression, and function promise to provide the answers but the critical questions remain unresolved. The NOD2/CARD15 gene, initially described by Ogura and colleagues, encodes a 1040 amino acid protein, a member of the Apaf1/CARD family of cytosolic proteins, involved in apoptosis (programmed cell death). NOD2/CARD15 has sequence homology with other family members, notably NOD1/CARD4, which itself is not associated with CD susceptibility. The gene comprises two N terminal caspase activation and recruitment domains (CARD), a nucleotide binding domain, and a C terminal sequence of leucine rich repeats (LRR). The majority of CD associated mutations directly affect the LRR, which is a motif common to bacterial resistance R proteins in plants and mammals, notably the Toll-like receptor family, enabling recognition of pathogen associated microbial patterns (PAMPs). Following PAMP recognition, the NOD2/CARD15 proteins dimerise and an interaction with the serine-threonine kinase RICK in the cytosol occurs, triggering downstream nuclear factor κB (NFκB) activation. The original expression studies had suggested that NOD2/CARD15 was expressed only in monocytes, and implicated the protein as an intracellular regulator of NFκB activity, sensitive to bacterial lipopolysaccharide (LPS), complementary to NOD1/CARD4.

In recent months strong scientific evidence has emerged to complement initial observations. It is now clear that NOD2/CARD15 expression occurs not only in monocytes but may also be induced in dendritic cells and intestinal epithelial cells. Furthermore, independent data suggest that the minimal bacterial motif recognised by NOD2/CARD15 may not be LPS, as initially suggested, but muramyl dipeptide (MDP), a component of both Gram negative and positive bacterial cell walls. It has been a consistent and unexplained observation, if somewhat counterintuitive, that both common and rare CD associated variants of the NOD2/CARD15 gene result in reduced NFκB activity, although these data are from transfection experiments of NOD2/CARD15 gene constructs in embryonic kidney cells. Conversely, the uncontrolled mucosal inflammation of Crohn’s disease is characterised by upregulation of NFκB activation.

In 2003, Hisamatsu et al provided perhaps the most elegant evidence to date, that CARD15/NOD2 may function as an antibacterial factor in CaCo2 intestinal epithelial cells. Cells stably transfected with a wild-type CARD15/NOD2 gene construct were able to prevent invasion by Salmonella typhimurium. This protective effect was lost in cells transfected with gene constructs of mutant CARD15/NOD2. In the same issue of Gastroenterology, Rosenstiel et al also demonstrated that NOD2/CARD15 expression in intestinal epithelial cells might be upregulated by the proinflammatory cytokine tumour necrosis factor α (TNF-α).

Thus with NOD2/CARD15 identification, the emphasis in studies of IBD pathophysiology has shifted to investigations of the innate immune response.

The story now develops further with data that suggest that NOD2/CARD15 may be expressed in the Paneth cells of the small intestine, published in this issue of Gut [see page 1591]. Ogura et al have used the techniques of immunohistochemistry and reverse transcription-polymerase chain reaction to examine NOD2/CARD15 expression in the ileal or colonic tissue from IBD patients and controls. NOD2/CARD15 expression was found to be localised to Paneth cells, within the ileum, or metaphasic Paneth cells within the colon. Indeed, in a parallel paper in Gastroenterology, the same authors have extended these observations using in situ hybridisation and laser capture microdissection. They demonstrated that NOD2/CARD15 expression was enriched in crypts, compared with villi,
and cells expressing NOD2/CARD15 also strongly expressed the proinflammatory cytokine TNF-α, itself a potent stimulus to NOD2/CARD15 expression. However, NOD2/CARD15 expression was not a feature of tissue macrophages in the intestine. Paneth cells are specialised epithelial cells located mainly in the crypts of the small intestine, in close proximity to epithelial stem cells. Paneth cells secrete antibacterial substances, initially located in granules within the cytosol, in response to prokaryotic rather than eukaryotic pathogens. The main antimicrobial factors secreted by the Paneth cell include lysozyme, phospholipase A2, trypsin, α-defensins, and angiotensins. In the current studies, NOD2/CARD15 expression was noted in close proximity to the secretory granules. Indeed, this close proximity prompts speculation that NOD2/CARD15 may be involved in degranulation and mediator released. It should be borne in mind that Paneth cell degranulation is triggered upon the release of the Paneth cell specific trypsin. MMP7; in humans, Paneth cell trypsin release requires lysis of the Paneth cell, and stored as precursor proteins, and cysteine rich peptides are synthesised and stored as precursor proteins, and cysteine rich peptides are synthesised in the Paneth cells of these animals. NOD2/CARD15 expression was not a finding consistent NOD2/CARD15 expression in colonic CD. In the present study in this issue of Gut, Ogura et al were unable to find a correlation between NOD2/CARD15 genotype, NfκB activity, and Paneth cell secretion. It is worth mentioning in this context that the β-defensin 2 gene contains an NFκB binding site in the promoter region, and although this defensin is not a component of Paneth cell granules, it is overexpressed in colonic CD.

In the present study in this issue of Gut, Ogura et al were unable to find consistent NOD2/CARD15 expression in colonic mucosa. Only one patient with colonic CD and concomitant Paneth cell metaplasia showed NOD2/CARD15 colonic expression. This predominant ileal localisation would explain the association of NOD2/CARD15 mutations with ileal disease. However, conflicting data have recently been published, and the issue remains to be resolved.

The functional role of the Paneth cell, initially identified by Joseph Paneth in Vienna in 1888, has remained unclear for more than 100 years. The recent data ever more strongly implicate the Paneth cell as a contributory factor in the innate immune response to bacteria. It is of course, of great interest to speculate that this expression is critical in the pathogenesis of chronic CD and further data are eagerly awaited. Of particular interest will be the phenotypic and morphological characteristics of transgenic animals lacking the NOD2/CARD15 gene, and subsequent attempts to reintroduce NOD2/CARD15 protein into the Paneth cells of these animals.

References
Aspirin: still learning about the wonder drug

E T Hawk, J L Viner

Aspirin, taken daily over at least one year, may exert chemopreventive effects against the early stages of colorectal carcinogenesis

P reclinical, observational, and clinical data consistently show that non-steroidal anti-inflammatory drugs (NSAIDs) – particularly aspirin – reduce colorectal carcinogenesis. Scores of animal studies show that NSAIDs inhibit the development of colorectal neoplasia across the spectrum of disease, ranging from aberrant crypt foci (ACF) to cancer. Human data confirm these findings with dozens of observational studies reporting 40–50% reductions in colorectal adenoma incidence, cancer incidence, and cancer-associated mortality among aspirin users. The most compelling data were published earlier this year. Two randomized placebo controlled trials conducted in patients at moderate risk for colorectal cancer reported that aspirin administered at doses as low as 81–325 mg/day reduced the development of adenomas by up to 35% after a few years of use. In one trial, greater effects were seen against more advanced lesions.

Colorectal adenomas are established as common non-obligate precursors of colorectal cancer. Within the last decade, ACF have been identified in rodent models of carcinogenesis, and have been proposed as precursors of colorectal adenomas and cancers. With the use of recently developed high resolution/magnifying endoscopes, researchers are now making quantitative (for example, number, size, crypt multiplicity) and qualitative (for example, morphology) real-time in vivo assessments of ACF in humans. ACF – or at least a subset of them – may represent important risk markers for adenoma-carcinoma development in humans. They may also serve as markers of chemopreventive response. Thus although relatively little is known about ACF and their relevance to more advanced stages of colorectal neoplasia in humans, they provide an important and promising focus for additional research.

In this issue of Gut, Shpitz and colleagues weave together these two investigational threads. This group describes an association between aspirin use and reduced ACF prevalence and histopathological distribution in ex vivo specimens obtained from 194 patients with colorectal cancer. Among patients who used aspirin for at least one year, they observed a 47% reduction in specimens harbouring ACF, a 64–82% reduction in ACF per cm² of colorectal mucosa, and a 52% reduction in dysplastic ACF. Although ACF reductions were observed in all anatomical sites, the reductions tended to be more dramatic in the distal colorectum. These findings suggest that aspirin taken at 100 mg/day over at least one year may exert chemopreventive effects against the early stages of colorectal carcinogenesis.

While intriguing, these data must be interpreted cautiously. Firstly, the study groups differed with regard to variables that may influence baseline risks for colorectal neoplasia and/or aspirin use, such as gender (males 84% vs 52% in the aspirin and control groups, respectively) and age (aspirin users were much more homogeneous than controls). The investigators do not address the potential impact of these imbalances on the study results, nor did they adjust for them in the analysis. Because we have scant information about ACF, these variables may have confounded interpretations of the effects of aspirin. In addition, the investigators did not report study participants’ dietary habits and their use of concomitant medications. Preclinical studies suggest that the latter two exposures may modulate ACF and therefore these limitations may be particularly important. Secondly, without power estimates, it is impossible to know whether the lack of statistical significance for certain variables is true or merely reflects the small sample size. Finally, the selection of the study cohort is not described in detail; therefore, the generalisability of these study results is uncertain.

Despite these limitations, the preliminary findings of Shpitz and colleagues are stimulating and should prompt additional investigations into whether ACF reductions correlate with or predict aspirin’s preventive efficacy against more advanced stages of colorectal neoplasia. These data contribute to a growing body of research suggesting that ACF might be used to identify the preventive efficacy of investigational agents against colorectal carcinogenesis. Takayama et al originally reported marked reductions in vivo colorectal ACF following 12 months of treatment with sulindac. Both the Shpitz and Takayama studies show that NSAIDs reduce ACF burden after relatively brief exposures. The data of Shpitz and colleagues add another link to the investigational chain by suggesting that aspirin exerts greater effects against more advanced (that is, dysplastic) ACF. Evidence that aspirin modulates both early and advanced ACF would represent a major advance for the field of chemoprevention research. Needless to say, ultimate validation requires linking NSAID induced reductions in

---

ACF to reductions in colorectal adenomas, cancer, and/or cancer associated mortality.\(^1\) Nevertheless, this study moves us closer to a distant but still plausible goal of firmly establishing ACF as meaningful short term markers for cancer prevention research.

The study provides other important insights as well. For example, the effects of aspirin on early colorectal neoplasia appear to be relative, not absolute. While aspirin may have significantly reduced the burden of ACF, all 59 aspirin responsive patients included in the study still developed colorectal cancer. Were ACF reduced to the same extent—or perhaps to a greater extent—among aspirin using patients who did not develop cancer? Do reductions in ACF predict for reductions in adenoma, cancer, or cancer mortality, as suggested by preclinical and observational data? How might we best use or build upon the data generated by Shpitz et al? This provocative study leaves a trail of important questions, the answers to which may pave the way for future successes in chemoprevention research.

Shpitz’s study also advances chemoprevention research through its novel investigational design, by using pathologic specimens originally obtained to diagnose or treat cancer, allowing for parallel insights into earlier stages of neoplasia. More than 75% of controls had ACF, confirming how common neoplasia. More than 75% of controls parallel insights into earlier stages of carcinogenesis, such as those provided by Shpitz et al, will profoundly alter our expectations for aspirin and its potential to improve the public’s health.

Gut 2003; 52:1535–1536

Authors’ affiliations

E T Hawk, J L Viner, Gastrointestinal and Other Cancers Research Group, National Cancer Institute, Division of Cancer Prevention, Bethesda, Maryland, USA

Correspondence to: Dr E T Hawk, Gastrointestinal and Other Cancers Research Group, National Cancer Institute, Division of Cancer Prevention, EPN, Suite 2141, 6130 Executive Boulevard, Bethesda, MD 20892-7317, USA; eh31p@nih.gov

REFERENCES


