

Different intestinal permeability patterns in relatives and spouses of patients with Crohn's disease: an inherited defect in mucosal defence?

J D Söderholm, G Olaison, E Lindberg, U Hannestad, A Vindels, C Tysk, G Järnerot, R Sjödahl

Abstract

Background—A familial defect in intestinal barrier function has been found in Crohn's disease.

Aim—To investigate possible genetic and environmental influences on this barrier defect by studying intestinal permeability in both relatives and spouses of patients with Crohn's disease.

Subjects—The study included 39 patients with Crohn's disease, 34 healthy first degree relatives, and 22 spouses. Twenty nine healthy volunteers served as controls.

Methods—Intestinal permeability was assessed as the lactulose:mannitol ratio in five hour urinary excretion after oral load, both before (baseline) and after ingestion of acetylsalicylic acid. The permeability response represents the difference between the two tests. A ratio above the 95th percentile for controls was classified as abnormal.

Results—Baseline permeability was higher in patients and spouses than in controls. An abnormal baseline permeability was seen in 36% of the patients, 23% of the spouses, 18% of the relatives, and 3% of the controls. After ingestion of acetylsalicylic acid, permeability increased significantly in all groups. Relatives were similar to patients with regard to permeability after exposure to acetylsalicylic acid, whereas spouses were similar to controls. The proportions with an abnormal permeability response to acetylsalicylic acid were 32% in patients, 14% in spouses, 41% in relatives, and 3% in controls.

Conclusion—The findings suggest that baseline permeability is determined by environmental factors, whereas permeability provoked by acetylsalicylic acid is a function of the genetically determined state of the mucosal barrier, and support the notion that environmental and hereditary factors interact in the pathogenesis of Crohn's disease.

(Gut 1999;44:96-100)

Keywords: acetylsalicylic acid; environment; genetics; inflammatory bowel disease; lactulose; mannitol

Crohn's disease is associated with increased intestinal permeability,^{1,2} but it is unclear whether this is of importance in the induction of intestinal inflammation or if it is a result of the inflammatory process itself.^{3,4} A deranged intestinal barrier is, however, thought to be an early

event in the inflammatory process,⁵ and knock-out mice with a breached intestinal barrier have been found to develop intestinal inflammation resembling that in Crohn's disease.⁶

A genetic predisposition seems to be important in the pathogenesis of Crohn's disease. First degree relatives have a 15- to 30-fold increased risk of contracting the disease,⁷ and studies on twins⁸ have shown a high degree of concordance of disease in monozygotic, as opposed to dizygotic, twin pairs with Crohn's disease. It was recently suggested that Crohn's disease is a polygenic disorder, in which susceptibility genes are present on several chromosomes.⁹ The finding of a disrupted intestinal barrier in relatives of patients with Crohn's disease led to the hypothesis of a genetic permeability disorder of aetiological importance.¹⁰ The exciting initial observations could not be reproduced,^{11,12} and subsequent studies have produced conflicting results.⁴ One reason for the discrepancies could be the use of different marker molecules.^{13,14} Several studies have, however, suggested that a subgroup of the relatives of patients with Crohn's disease have a disturbed intestinal barrier.^{11,15-18} Recent results on familial aggregation of increased intestinal permeability in Crohn's disease have differed somewhat: Hilsden *et al*¹⁹ and Pironi *et al*²⁰ have shown an augmented intestinal permeability response to acetylsalicylic acid (ASA) in first degree relatives, suggesting a possible genetic permeability defect, whereas Peeters *et al*²¹ examined relatives and spouses of Crohn's disease patients and found an increased proportion of subjects with high intestinal permeability in both groups, suggesting a shared environmental factor as the cause.

Our aim was to evaluate the influence of genetic and environmental factors on intestinal barrier function in Crohn's disease by comparing intestinal permeability patterns in patients and their relatives and spouses. We studied urinary excretion of lactulose and mannitol under baseline conditions and after ingestion of ASA in a group of Crohn's disease patients, their first degree relatives, their spouses, and in controls.

Materials and methods

STUDY GROUPS

The study groups comprised 39 Crohn's disease patients with a median (range) disease duration

Abbreviations used in this paper: ASA, acetylsalicylic acid; CDAI, Crohn's disease activity index; L/M ratio, lactulose:mannitol ratio; NSAID, non-steroidal anti-inflammatory drug.

Department of Surgery, University Hospital, Linköping, Sweden

J D Söderholm
G Olaison
A Vindels
R Sjödahl

Department of Clinical Chemistry
U Hannestad

Department of Pediatrics, Örebro Medical Centre Hospital, Örebro, Sweden
E Lindberg

Department of Medicine
C Tysk
G Järnerot

Correspondence to:
Dr J D Söderholm,
Department of Surgery,
University Hospital, SE-581
85 Linköping, Sweden.

Accepted for publication
19 August 1998

Table 1 Demographic characteristics of the study groups

	Patients (n=39)	Relatives (n=34)	Spouses (n=22)	Controls (n=29)
Age (median (range))	44 (20–63)	46 (18–70)	47 (25–61)	38 (22–60)
Sex (M/F)	18/21	16/18	11/11	12/17
Smokers/non-smokers	19/20	8/26	4/18	2/27

of 20 (1–34) years, 34 first degree relatives, 22 spouses, and 29 healthy volunteers (table 1). Five patients, two relatives, and one of the spouses did not participate in the ASA ingestion test. Table 2 gives data on the patients with Crohn's disease. Diagnosis was based on standard radiographic and/or endoscopic findings and the Morson morphological criteria.^{22, 23} Disease activity was assessed by Best's modification of his classical Crohn's disease activity index (CDAI).²⁴ The 39 Crohn's disease patients had a total of 123 first degree relatives above the age of 18. Fifty one of these were available for the study (many relatives lived far away, some patients did not want to burden their relatives with the study, and some had little social contact with their relatives). Eight were excluded because of concurrent disease, three because of pregnancy, and six chose not to participate. The 34 first degree relatives included in the study (18 parents, nine siblings, and seven children from 21 families) had no signs or symptoms of Crohn's disease. Eight of the relatives studied were living with the patient at both the time of diagnosis and the time of the test; 14 were living with the patient at the time of diagnosis but not at the time of the test; 12 were not living with the patient either at the time of diagnosis or at the time of the test. Eleven of the 12 relatives in the latter subgroup participated in both the permeability tests (baseline and response to ASA). They are hereafter called "solely relatives"; the period apart from the related patient ranged from 6 to 25 years. The 22 spouses had been living with the patients for a median (range) of 17 (1–41) years at the time of the test. Ten of the spouses were already living with the patient at the time of diagnosis, nine of which participated in both the permeability tests. These nine are designated "spouses at diagnosis", and had shared their environment with their patient partner for a median (range) of 3 (0.5–30) years at the time of diagnosis. The apparently healthy volunteers showed no signs or symptoms of intestinal disorder, were not on medication, and

Table 2 Characteristics of the patients with Crohn's disease (n=39)

Simplified CDAI	
Median (range)	120 (0–460)
Disease activity*	
Active/inactive disease	17/22
Medication	
Azathioprine ± corticosteroids	5
Corticosteroids ± mesalazine	17
Mesalazine only	6
No anti-inflammatory	11
Bowel resection	
Yes/no	25/14
Location of disease	
Ileocaecal or ileal	30
Ileum + extensive colon	5
Colitis	4

*The disease was considered to be active when the simplified CDAI was above 150.
CDAI, Crohn's disease activity index.

had normal dietary habits and normal renal function; the female subjects were not pregnant.

As a separate group, nine of 14 previously identified monozygotic twin pairs⁸ were studied. Five pairs (aged 44–59; eight men, two women) were concordant for Crohn's disease, and four pairs (aged 43–72; four men, four women) were discordant for the disease. The 14 twins with Crohn's disease had a disease duration of 22 (9–30) years. At the time of the investigation, the median CDAI was 80 (0–200). Three of the twin patients had a CDAI above 150, and the disease was inactive in the other 11.

TEST PROCEDURE

Lactulose and mannitol were given orally as Permagnost (lactulose 10.0 g, mannitol 5.0 g, glucose 9.0 g, NaCl 0.1 g, aqua ad 100 ml, osmolarity 1304 mosm/l; Laevosan, Linz, Austria). The permeability test was performed twice, once under baseline conditions and again 5–10 days later after intake of ASA. The subjects were not allowed to take non-steroidal anti-inflammatory drugs (NSAIDs) less than one week before the test, nor to drink alcohol less than three days before. Permagnost (100 ml) was taken together with two glasses of tap water (300 ml) after an overnight fast, and all urine was then collected for the next five hours. During the first two hours of sampling, no oral intake was allowed, but water, coffee or tea (without milk or sugar) was permitted during the last three hours. The bladder was emptied an extra time at five hours. Five to ten days later, the ASA provocation was carried out: 1.25 g ASA in the form of two and a half tablets of Magnecyl (Pharmacia & Upjohn, Stockholm, Sweden) was given twice orally 8–10 hours and one hour before the oral administration of 100 ml Permagnost together with two glasses of water. Urine collection and oral intake were as above. To avoid bacterial growth, the urine was collected in plastic reservoirs containing 0.5 ml 20% chlorhexidine gluconate solution. Urine volume and creatinine were measured and 10 ml aliquots were stored at –20°C for subsequent analysis.

ANALYTICAL METHODS

Lactulose and mannitol were measured essentially as described by Kynaston *et al*,²⁵ except that cellobiose was used as internal standard instead of melibiose, because a compound that was eluted at the same time as melibiose was present in the urine samples. The amount of urine analysed was adjusted for all samples so that the measured concentrations were within the concentration range of the standard solutions. Typically, 0.25 ml urine and 0.75 ml water were mixed with 1.0 ml internal standard solution (cellobiose 0.75 mmol/l). The samples were desalted by adding 0.5 g of an ion-exchange mixture (Amberlite IR120 H and Amberlite IRA420 Cl in mass proportions 1:1.5). Thereafter, each sample was centrifuged at 1000 g for 10 minutes, and the supernatant was filtered through a 0.45 µm disposable filter. Aliquots (25 µl) were then injected on to a 250 × 40 mm Carpac PA-1 anion exchange column coupled to a quaternary gradient HPLC system

Table 3 Lactulose:mannitol (L/M) ratio in five hour urinary excretion at baseline and after ingestion of acetylsalicylic acid (ASA)

	Patients (n=39)	Relatives (n=34)	Spouses (n=22)	Controls (n=29)	Solely relatives (n=11)	Spouses at diagnosis (n=9)
L/M at baseline ¹	0.016 (0.012–0.024)*	0.011 (0.009–0.017)	0.014 (0.011–0.019)*	0.011 (0.009–0.014)	0.011 (0.009–0.013)	0.015 (0.011–0.020)
Proportion with raised L/M at baseline ²	14/39 (36%)*	6/34 (18%)	5/22 (23%)	1/29 (3%)	1/11 (9%)	3/9 (33%)*
L/M after ASA ³	0.025 (0.021–0.035)*	0.028 (0.018–0.038)*	0.020 (0.016–0.026)	0.017 (0.015–0.021)	0.028 (0.016–0.029)	0.019 (0.018–0.025)
Proportion with abnormal L/M increase by ASA ⁴	11/34 (32%)*	13/32 (41%)*	3/21 (14%)	1/29 (3%)	3/11 (27%)*	0/9 (0%)

Data are presented as median (interquartile range).

¹Kruskal-Wallis: H = 14.3; degrees of freedom (DF) = 3; p = 0.003.

² $\chi^2 = 10.9$; DF = 3; p = 0.012.

³Increased L/M ratio in all groups, p < 0.005 (paired sign test). Kruskal-Wallis: H = 13.5; DF = 3; p = 0.004.

⁴ $\chi^2 = 14.6$; DF = 3; p = 0.002.

*p < 0.05 compared with controls (Mann-Whitney or Fisher's exact test).

with a pulsed amperometric detector (Dionex Corporation, Sunnyvale, California, USA). The carbohydrates were separated isocratically at a flow rate of 1.0 ml/min at 22°C, with an eluent consisting of 90 mmol/l NaOH and 0.375 mmol/l zinc acetate. Like Kynaston *et al*,²⁵ we obtained a clear separation between lactose and lactulose. Five standard solutions containing lactulose (0.025–1.0 mmol/l) and mannitol (0.5–20 mmol/l) were used for quantification by internal standardisation with peak:area ratios. The coefficients of variation were 4.2 and 4.9% for mannitol and lactulose respectively.

CALCULATIONS AND STATISTICS

The lactulose:mannitol (L/M) ratio in the urinary output was calculated and used as a permeability index to minimise the influence of differences in gastrointestinal motility, absorptive capacity, urinary volume, and renal function.^{3,4} The difference in L/M ratio between baseline and after ASA provocation was calculated in each individual as a measure of the permeability response to ASA. The 95th percentile in the controls was defined as the upper limit of normality with regard to baseline permeability and response to ASA. Data showed a skewed

distribution and are presented as median (interquartile range), and scattergrams. The Kruskal-Wallis and Mann-Whitney tests were used for comparison between groups, and the paired sign test for within-group comparisons. The χ^2 and Fisher's exact tests were applied to compare proportions. Analysis of covariance was used to assess the influence of various patient factors on permeability. Differences with p < 0.05 were considered to be significant.

ETHICS

The study protocol was approved by the ethics committee of the Faculty of Health Sciences, Linköping University and was conducted according to the Declaration of Helsinki.

Results

The groups did not differ with regard to sex distribution and age. No relation was seen between permeability and age, gender or smoking habits, either at baseline or after ASA ingestion (analysis of covariance).

BASELINE PERMEABILITY

Table 3 gives the baseline L/M ratios. The 95th percentile for controls (0.0195) was used as the

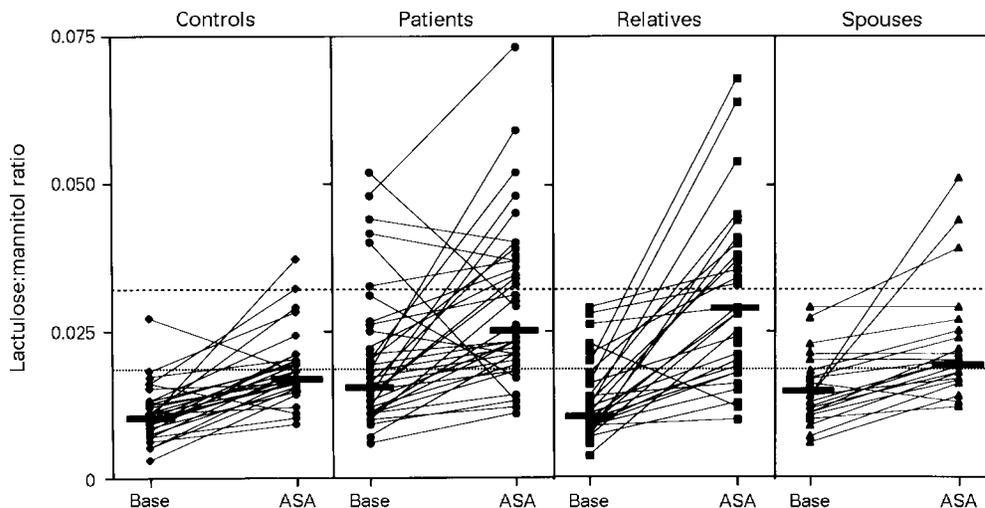


Figure 1 Paired scattergrams of lactulose:mannitol (L/M) ratio in five hour urine samples before (Base) and after oral ingestion of 2 × 1.25 g acetylsalicylic acid (ASA) in the various study groups. The subjects tested were healthy controls (n = 29), Crohn's disease patients (n = 39), first degree relatives (n = 34), and spouses (n = 22). Solid lines indicate the median L/M ratios in the groups. The upper limit of normality (95th percentile in the control group) at baseline (0.0195) is indicated by the dotted line and the upper limit after ASA (0.032) is indicated by the dashed line. At baseline the median L/M ratio was increased in patients and spouses as compared with controls (p < 0.05, Kruskal-Wallis). After intake of ASA the L/M ratio was higher in both patients and relatives than in controls (p < 0.05, Kruskal-Wallis), but not in spouses. Note the marked increase in permeability in a large subgroup of the relatives after ingestion of ASA.

upper limit for normal permeability. Baseline permeability was increased in the patient group as compared with the controls (table 3; fig 1), with a baseline permeability above normal in 14/39 (36%) of the patients. Permeability was not related to the location or activity of the disease (analysis of covariance), but higher permeability was seen in patients on medication than in untreated patients (median 0.017 and 0.012 respectively; $p < 0.05$). The baseline permeability of the relatives was equal to that of the controls (table 3; fig 1), although in a subgroup of the relatives (6/34; 18%) the permeability was increased. The spouses formed an intermediate group with increased permeability compared with controls (table 3; fig 1), and a raised baseline permeability in 5/22 (23%). In the group denoted "solely relatives", a raised baseline permeability was found in 1/11 (9%), whereas the corresponding value for "spouses at diagnosis" was 3/9 (33%; table 3).

PERMEABILITY AFTER INGESTION OF ASA

ASA ingestion increased the L/M ratio significantly in all study groups ($p < 0.005$, paired sign test; table 3), with an increase in the 95th percentile for controls to 0.032. After exposure to ASA, the ratio in the group of relatives was increased to that of the patient group (table 3; fig 1). L/M ratios for spouses did not show a similar rise, and did not differ from the controls after ingestion of ASA (table 3; fig 1).

RESPONSIVENESS TO ASA

The median permeability response to ASA—that is, the increase in L/M ratio from baseline—was 0.009 (0.004–0.011) in the controls, with the 95th percentile being 0.018. There were no differences in the median permeability responses between the various groups, being 0.009, 0.010, and 0.007 in the patients, relatives, and spouses respectively.

An abnormal permeability response to ASA—that is, a rise exceeding that of the 95th percentile for controls—was found in 11/34 (32%) of the patients and 13/32 (41%) of the relatives, whereas the proportion of spouses who were hyperresponders (3/21; 14%) did not differ from that for the controls (table 3). In the group of "solely relatives" the proportion of hyperresponders was 3/11 (27%), whereas no hyperresponders (0/9) were found among "spouses at diagnosis" (table 3).

MONOZYGOTIC TWINS

Baseline L/M ratios in the twin groups were 0.014 (0.010–0.016) and 0.015 (0.009–0.019) for twins with Crohn's disease and healthy twins respectively. After ingestion of ASA the permeability increased to 0.022 (0.019–0.035) and 0.023 (0.018–0.023) respectively. None of the healthy twins (0/4) had an augmented permeability response to ASA, but an abnormal response was seen in four (28%) of the 14 twins with Crohn's disease ($p = 0.03$ compared with controls; Fisher's exact test).

Discussion

This is the first study to compare baseline and ASA-provoked L/M ratios in both relatives and

spouses of patients with Crohn's disease. This approach allowed us to investigate the importance of both hereditary and environmental factors in ASA-provoked intestinal permeability in Crohn's disease. Our most important finding is that relatives and spouses differed with regard to changes in permeability patterns on administration of ASA. The relatives changed from being the most "control-like" group under baseline conditions to being the most "patient-like" group after exposure to ASA. The spouses, on the other hand, who displayed a higher baseline permeability than controls, showed a limited increase in permeability and became more "control-like" after taking ASA. This pattern was more evident when the "solely relatives" (living apart from the patients) were compared with the "spouses at diagnosis" (living with the patients at the time of both diagnosis and the test). Hilsden *et al*¹⁹ and Peeters *et al*²¹ recently examined the possible existence of a genetically determined defect in intestinal permeability, and different conclusions were drawn from the two studies. Our findings seem to confirm both of the reports: we observed a raised baseline permeability in subgroups of patients, relatives, and spouses, which substantiates the data of Peeters and co-workers, and we observed an exaggerated permeability response to ASA in relatives, which was also noted by Hilsden and colleagues. Taken together, our findings suggest that baseline permeability is dependent on environmental factors, whereas the responsiveness to ASA is controlled by hereditary factors. However, only one third of the patients and relatives and none of the healthy twins were hyperresponders, suggesting that hyperresponsiveness is a feature of a subgroup of patients and relatives with a genetic defect in the mucosal defence system. This is well in line with the genetic heterogeneity and polygenic inheritance suggested in recent studies.⁹

Certain early life events have been suggested to be relevant to Crohn's disease,²⁶ and our findings do not rule out a common childhood factor as the cause of a barrier defect. It should also be kept in mind that only a subgroup of the first degree relatives were studied, raising the possibility of a selection bias interfering with the results, and caution is needed when interpreting our data.

Our study confirms that ASA in clinically used doses increases intestinal permeability in man, as opposed to animal studies.^{27, 28} The mechanisms behind the increased L/M ratios obtained after exposure to ASA are, however, unclear. Hilsden and co-workers¹⁹ showed that, in contrast with the L/M ratio (which reflects total small bowel permeability^{3, 4}), the ASA induced increase in sucrose permeability (suggested to reflect gastroduodenal mucosal permeability,²⁹ although disputed³⁰) did not differ between controls and relatives of patients with Crohn's disease. The formulation of ASA used in our study is absorbed mainly in the proximal small bowel,^{31, 32} and the local effect during absorption is thought to be important in NSAID induced damage of the small bowel.³³ Taken together, the cited data imply that an exaggerated increase in the L/M ratio after

ingestion of ASA is probably an indication of a defect in the mucosal defence system in the jejunum. This is in line with previous studies showing that Crohn's disease encompasses a number of defects in jejunal function,^{34,35} including permeability,^{36,37} and suggests that the entire gastrointestinal tract is involved in the disorder. In rat intestine, NSAIDs such as ASA have been found to induce a rapid effect on the mitochondria which includes uncoupling of oxidative phosphorylation.³⁸ That effect should lead to a quick drop in the ATP content in enterocytes, and thereby elicit contraction of the cytoskeleton and increase tight junction permeability.³⁹ In the light of our results, this is a very attractive model for the mechanism of the effects of ASA, as Crohn's disease has been suggested to be a disorder of the tight junctions.^{2,14} Nonetheless, a possible link between ASA and tight junction permeability remains to be proved, and consideration must also be given to other plausible mechanisms, such as effects on mucins and prostaglandins. An aggravating effect of NSAIDs on colitis has been observed, and inhibition of prostaglandin synthesis seems to be the most likely mechanism.³³ If this is also the case in the small bowel, the increase in intestinal permeability in the relatives of patients with Crohn's disease could be a reflection of a subclinical inflammatory or immunological abnormality, rather than a primary disturbance of the epithelial cells.

Our findings support the notion of an interaction of environmental and hereditary factors in the pathogenesis of Crohn's disease, and they are well in line with recent reports indicating polygenic inheritance. Increased knowledge of the mechanisms underlying the effects of ASA on small bowel permeability could provide important clues to the causes of Crohn's disease.

This work was supported by grants from The Swedish Society of Medicine, "Förenade liv" Mutual Group Life Insurance Company, Stockholm, Sweden, The Swedish Society for Medical Research, Örebro County Research Committee, Sweden, and The Swedish Medical Research Council (B94-17X-05983-14C and K98-06X-12618-01A).

- 1 Olaison G, Sjödal R, Tagesson C. Abnormal intestinal permeability in Crohn's disease. A possible pathogenic factor. *Scand J Gastroenterol* 1990;25:321-8.
- 2 Hollander D. The intestinal permeability barrier. A hypothesis to its regulation and involvement in Crohn's disease. *Scand J Gastroenterol* 1992;27:721-6.
- 3 Travis S, Menzies I. Intestinal permeability: functional assessment and significance. *Clin Sci* 1992;82:471-88.
- 4 Bjarnason I, MacPherson A, Hollander D. Intestinal permeability: an overview. *Gastroenterology* 1995;108:1566-81.
- 5 Madara JL, Parkos C, Colgan S, et al. The movement of solutes and cells across tight junctions. *Ann NY Acad Sci* 1992;664:47-60.
- 6 Hermiston ML, Gordon JJ. Inflammatory bowel disease and adenomas in mice expressing a dominant negative N-Cadherin. *Science* 1995;270:1203-7.
- 7 Sachar DB. Crohn's disease: a family affair. *Gastroenterology* 1996;111:813-15.
- 8 Tysk C, Lindberg E, Järnerot G, et al. Ulcerative colitis and Crohn's disease in an unselected population of monozygotic and dizygotic twins. A study of heritability and the influence of smoking. *Gut* 1988;29:990-6.
- 9 Satsangi J, Jewell DP, Bell JI. The genetics of inflammatory bowel disease. *Gut* 1997;40:572-4.
- 10 Hollander D, Vadheim CM, Brettholz E, et al. Increased intestinal permeability in patients with Crohn's disease and their relatives. A possible etiologic factor. *Ann Intern Med* 1986;105:883-5.
- 11 Teahon K, Smethurst P, Levi AJ, et al. Intestinal permeability in patients with Crohn's disease and their first degree relatives. *Gut* 1992;33:320-3.
- 12 Ruttenberg D, Young GO, Wright JP, et al. PEG 400 excretion in patients with Crohn's disease, their first degree relatives, and healthy volunteers. *Dig Dis Sci* 1992;37:705-8.
- 13 Lindberg E, Söderholm JD, Olaison G, et al. Intestinal permeability to polyethylene glycols in monozygotic twins with Crohn's disease. *Scand J Gastroenterol* 1995;30:780-3.
- 14 Hollander D. Permeability in Crohn's disease: altered barrier functions in healthy relatives? *Gastroenterology* 1993;104:1848-51.
- 15 Ainsworth M, Eriksen J, Rasmussen JW, et al. Intestinal permeability of 51Cr-labelled ethylenediaminetetraacetic acid in patients with Crohn's disease and their first degree relatives. *Scand J Gastroenterol* 1989;24:993-8.
- 16 Munkholm P, Langholz E, Hollander D, et al. Intestinal permeability in patients with Crohn's disease and ulcerative colitis and their first degree relatives. *Gut* 1994;35:68-72.
- 17 May G, Sutherland L, Meddings J. Is small intestinal permeability really increased in relatives of patients with Crohn's disease? *Gastroenterology* 1993;104:1627-32.
- 18 Yacyshyn BR, Meddings JB. CD45RO expression on circulating CD19+ B-cells in Crohn's disease correlates with intestinal permeability. *Gastroenterology* 1995;108:132-7.
- 19 Hilsden RJ, Meddings JB, Sutherland LR. Intestinal permeability changes in response to acetylic salicylic acid in relatives of patients with Crohn's disease. *Gastroenterology* 1996;110:1395-403.
- 20 Pironi L, Miglioli M, Ruggeri E, et al. Effect of non-steroidal anti-inflammatory drugs on intestinal permeability in first degree relatives of patients with Crohn's disease. [Abstract] *Gastroenterology* 1992;102:A679.
- 21 Peeters M, Geypens B, Claus D, et al. Clustering of increased small intestinal permeability in families with Crohn's disease. *Gastroenterology* 1997;113:802-7.
- 22 Pera A, Bellando P, Caldera D, et al. Colonoscopy in inflammatory bowel disease. Diagnostic accuracy and proposal of an endoscopic score. *Gastroenterology* 1987;92:181-5.
- 23 Morson BC. Histopathology of Crohn's disease. *Proc R Soc Med* 1968;61:79-81.
- 24 Best WR, Beckett JM. The Crohn's disease activity index as a clinical instrument. In: Pena A, Weterman IT, Booth CC, et al, eds. *Recent advances in Crohn's disease*. The Hague: Martinus Nijhoff, 1981:7-12.
- 25 Kynaston JA, Fleming SC, Laker MF, et al. Simultaneous quantification of mannitol, 3-O-methyl glucose, and lactulose in urine by HPLC with pulsed electrochemical detection, for use in studies of intestinal permeability. *Clin Chem* 1993;39:453-6.
- 26 Russel MGVM, Stockbrügger RW. Epidemiology of inflammatory bowel disease: an update. *Scand J Gastroenterol* 1996;31:417-27.
- 27 Brodie DA, Tatae CL, Hooke KF. Aspirin: intestinal damage in rats. *Science* 1970;170:183-5.
- 28 Davies NM, Corrigan BW, Jamali F. Sucrose urinary excretion in the rat measured using a simple assay: a model for gastroduodenal permeability. *Pharmacol Res* 1995;12:1733-6.
- 29 Meddings JB, Sutherland LR, Byles NI, et al. Sucrose: a novel permeability marker for gastroduodenal disease. *Gastroenterology* 1993;104:1619-26.
- 30 Bjarnason I, Batt R, Catt S, et al. Evaluation of differential disaccharide excretion in urine for non-invasive investigation of altered intestinal disaccharidase activity caused by a-glucosidase inhibition, primary hypolactasia, and coeliac disease. *Gut* 1996;39:374-81.
- 31 Gatti G, Barzaghi N, Attardo Parinello G, et al. Pharmacokinetics of salicylic acid following administration of aspirin tablets and three different forms of soluble aspirin in normal subjects. *International Journal of Pharmacological Research* 1989;9:385-9.
- 32 Muir N, Nichols JD, Clifford JM, et al. The influence of dosage form on aspirin kinetics: implications for acute cardiovascular use. *Curr Med Res Opin* 1997;13:547-53.
- 33 Wallace JL. Nonsteroidal anti-inflammatory drugs and gastroenteropathy: the second hundred years. *Gastroenterology* 1997;112:1000-16.
- 34 Ahrenstedt Ö, Knutson L, Nilsson B, et al. Enhanced local production of mucinolytic components in the small intestines of patients with Crohn's disease. *N Engl J Med* 1990;322:1345-9.
- 35 Marteau P, Colombel JF, Nemeth J, et al. Immunological study of histologically non-involved jejunum in Crohn's disease: evidence for reduced in vivo secretion of secretory IgA. *Clin Exp Immunol* 1990;80:196-201.
- 36 Olaison G, Sjödal R, Tagesson C. Decreased gastrointestinal absorption of peroral polyethylene glycols (PEG 1000) in Crohn's disease. A sign of jejunal abnormality. *Acta Chirurgica Scandinavica* 1987;153:373-7.
- 37 Peeters M, Ghooys Y, Maes B, et al. Increased permeability of macroscopically normal small bowel in Crohn's disease. *Dig Dis Sci* 1994;39:2170-6.
- 38 Somasundaram S, Rafi S, Hayllar J, et al. Mitochondrial damage: a possible mechanism of the "topical" phase of NSAID induced injury to the rat intestine. *Gut* 1997;41:344-53.
- 39 Somasundaram S, Hayllar H, Rafi S, et al. The biochemical basis of non-steroidal anti-inflammatory drug-induced damage to the gastrointestinal tract: a review and a hypothesis. *Scand J Gastroenterol* 1995;30:289-99.