

CHALLENGES IN

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# Inflammatory Bowel Disease

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EDITED BY

Derek P. Jewell

Neil J. Mortensen

A. Hillary Steinhart

John H. Pemberton

Bryan F. Warren

Second edition



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## Preface

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For many years the aetiology and management of inflammatory bowel disease seemed to have reached a steady state where only small but nonetheless important steps were made in our understanding of these potentially devastating diseases. Suddenly, with the molecular biology revolution, there is renewed interest in the mechanisms of inflammation, the genes that may determine them and the development of new powerful designer drugs. As never before, gastroenterologists are having to redefine the place of the established medical and surgical treatments alongside these novel treatments. This has led to unexpected problems in the diagnosis and definitions of disease as histopathologists have struggled with indeterminate colitis, pouchitis and perforating and stenosing varieties of Crohn's disease.

Although exacting and more robust epidemiological tests are available, it is still not clear whether the incidence of either ulcerative colitis or Crohn's disease is changing both within the western world and developing countries. The importance of infective agents within the gut lumen would seem to be intuitively relevant but their role remains undefined. Claims for the importance of specific organisms involved in the pathogenesis of either disease have had their fashionable 'rise and fall' so that no organism has been consistently implicated. Indeed, current evidence would suggest that these diseases represent a genetic susceptibility, mediated by many different genes, to a variety of environmental factors. This hypothesis allows for the very great heterogeneity that is seen by clinicians.

Since the 1950s, aminosalicylates and corticosteroids have provided the only effective treatments,

but the final decade of the last millennium has seen the introduction of many new therapies, principally immunosuppressant and immunomodulatory drugs. It has been encouraging that their effectiveness has been tested in clinical trials and subsequent meta-analyses, continuing the evidence-based approach to these diseases which began with the early trials of corticosteroids and sulphasalazine and which has consistently underpinned the treatment of ulcerative colitis and Crohn's disease. Nevertheless, medical therapy is still imperfect: it may fail to control active disease. Maintenance therapy, especially for Crohn's disease, is very unsatisfactory and drug therapy frequently contributes to long-term morbidity; for example, corticosteroids may contribute to growth failure in children and to reduced bone density in adults. The rapid expansion in drug therapy has been matched with many surgical innovations such as restorative proctocolectomy for ulcerative colitis and the concept of minimal surgery for Crohn's disease. Thus, the number of surgical options now available to us inevitably raise questions concerning the choice of operation to be performed, when and by whom.

The purpose of this book is to address some of the challenges in our understanding of ulcerative colitis and Crohn's disease, the challenges of new diagnostic and therapeutic modalities and the clinical challenges of maintaining good health and hence quality of life for our patients. It is not intended to provide a further text book of inflammatory bowel disease, of which there are many, but rather to consider specific issues. Many readers will want to focus on individual chapters and therefore the editors

make no apology for a degree of repetition which will allow maximum exposure to new knowledge and thought.

The editors are greatly appreciative of the time the authors have given to allow this book to gestate

into a second edition. We are also most grateful to Mrs Toria McNeile for her help in assembling the manuscripts and to Ms Alison Brown and her staff at Blackwell for their patience and expertise.

DJ  
NM  
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# I: Clues to aetiology and pathogenesis

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# 1: Global changes in incidence

Richard F.A. Logan and Emma L. Armitage

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## Introduction

Variation in disease occurrence is the essence of epidemiology. When this variation is between place or person, and standardised measures are available, measurement of such variation can be relatively accurate, albeit often expensive and laborious, as demonstrated by the European collaborative study on inflammatory bowel disease (EC-IBD) [1]. In contrast, measurement of variation over time is usually fraught with difficulty and any trends revealed, unless substantial, are often surrounded by uncertainty. With regard to inflammatory bowel disease (IBD), more sensitive diagnostic techniques, widening case definitions, increasing availability of specialist investigation and greater public and professional awareness of both diseases will all serve to increase the numbers of new diagnoses and have the potential to contribute to an apparent rise in incidence. In this chapter we will review recent data on the incidence of IBD worldwide and, at the risk of over generalising, assess what they imply as to the aetiology of IBD.

The rise in incidences of ulcerative colitis and later Crohn's disease that was seen in many Western countries during the past century, preceded the growth of modern gastroenterology and was evident in both individual studies and routine morbidity and mortality data [2–4]. Over the last few years, however, there have been a number of conflicting reports of the incidence of both diseases either continuing to increase, or being stable or even declining. For example, Bernstein *et al.*, using health insurance data for Manitoba, Canada, reported an overall

incidence of Crohn's disease of 146/million/year, the highest yet reported, whereas a few hundred miles to the south in Olmsted County, Minnesota, Loftus *et al.* found an incidence over a similar period of 69/million/year [5, 6]. An almost two-fold variation has also been reported from the United Kingdom, with Kyle finding the incidence of Crohn's disease continuing to rise in north-east Scotland at 98/million/year in 1985–87, while in the Cardiff area incidence was declining with the figure for 1986–90 being 62/million/year and 56/million/year for 1991–95 [7, 8]. There have been fewer reports of the time trends in incidences of ulcerative colitis, which may reflect the additional challenge for epidemiological studies of distinguishing it from non-recurrent, mainly infective forms of colitis. Even so, in the (EC) IBD study the incidence of ulcerative colitis in parts of Europe as far apart as Iceland and Crete was higher than previously recorded [1].

Are these differences real or can the disparate findings of these studies be explained by differences in study design or imperfections of the methods used? One possible explanation is that the differences reported reflect sampling and study size. For many diseases, cancer in particular, this problem can be overcome by examining mortality or morbidity routinely collected at a national or regional level.

## Evidence from trends in routinely collected morbidity data

For IBD, mortality data are of little value in assessing its incidence over time. Death from IBD is now rare,

with fewer than 400 deaths per year now being certified as due to IBD in the United Kingdom [9]. In addition, over 75% of these deaths occur in those over 70 years, whereas the incidence of IBD is greatest in those under age 40. Although mortality rates do show a broad correlation with incidence figures between countries, the relationship breaks down when comparing mortality and incidence within a country over time [10]. Thus, the rapid rise in incidence of Crohn's disease during the 1950s and 1960s in the United Kingdom and the United States was associated with a less than doubling of mortality rates [11]. At the same time, mortality from ulcerative colitis in these countries declined sharply when other data suggested incidence was unchanged or possibly increasing.

Routinely collected morbidity data has mainly consisted of data on hospital admissions, which has been collected over many years in several countries. Another source of data is that collected by health insurance or health maintenance organisations, typically from North America, which has the advantage of including data on outpatient (ambulatory) care as well as that for inpatient care. Using either source it is necessary to separate first admissions or contacts from repeat contacts. Hospital admission data are also affected by changing patterns of care, with patients being increasingly cared for as outpatients. With these considerations in mind it is notable that in Denmark the annual incidence of Crohn's disease, based on their national registry of inpatients, increased from 46 to 62/million/year in women between 1981–84 and 1989–92, and from 33 to 41/million/year in men over the same period [12]. The figures were similar to the overall crude incidence of 41/million/year reported elsewhere for Copenhagen County in 1979–87. In contrast, the incidence of ulcerative colitis over this period fell from 154 to 123/million/year in women and from 141 to 126/million/year in men.

Hospital admission data (now called hospital episode statistics) are collected in the United Kingdom, but except in the Oxford region and Scotland it is not possible to identify first admissions from repeat admissions [13, 14]. In England, hospital admission rates for Crohn's disease increased by approximately 4% annually during the period from

1970 to 1985, but when admissions in the Oxford region were linked to individuals, first admissions for men declined by 0.5% annually and for women rose by 0.1%, neither being statistically significant [13]. Over the same period hospital admission rates for ulcerative colitis in England showed no change, although first admission rates in the Oxford region showed a 1% average annual increase, which was not statistically significant [13].

Both these studies, like most studies on routinely collected data, relied on accurate coding of the discharge diagnosis. This is a particular problem for inflammatory bowel disease where there is often some uncertainty as to whether the diagnosis is Crohn's disease (CD) or ulcerative colitis (UC). To overcome this problem Bernstein *et al.* in their study using health insurance records for Manitoba, validated the diagnoses according to questionnaire responses obtained from a subset of patients directly approached [5]. They also ignored all cases with a first medical contact within the first 5 years of their study period to try to ensure that only incident cases were included. How successful they were is difficult to judge. Inclusion of a proportion of non-incident cases will disproportionately increase incidence in the older age groups. Their figures for the incidence of Crohn's disease are some of the highest reported at 169/million/year in women and 123/million/year in men. Incidence rates for ulcerative colitis were also high at 144/million/year in women and 143/million/year in men.

Thus, the routinely collected data give a mixed picture. The lack of increase in the figures from the Oxford region could reflect an increased proportion of patients having outpatient care only. The same restriction also applies to the Danish data, although a validation study on a subset showed the diagnostic accuracy to be high, and overall incidence was in keeping with a smaller hospital-based study [12]. The Canadian data are particularly remarkable, as generally the figures for IBD incidence reported from North America have tended to be lower than those from Europe. These three studies reflect some of the important limitations of routinely collected morbidity data – namely that it is usually difficult to make direct comparisons between data sets on account of differences in the health-care systems

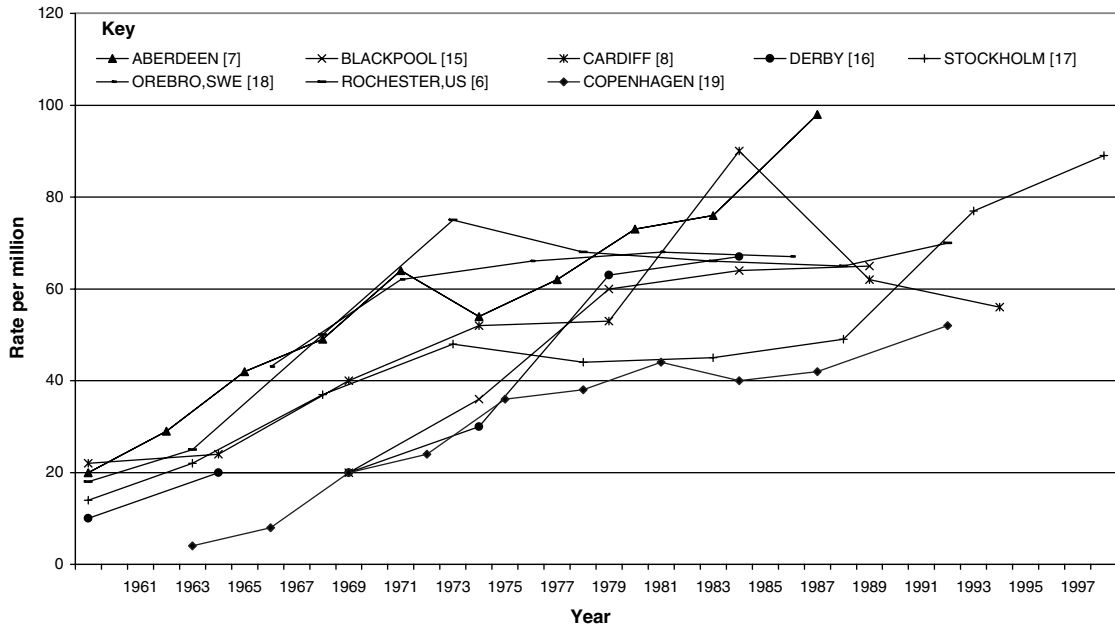


Fig 1.1 Recent time trends in incidence of Crohn's disease.

involved. Secondly, changes in how the data are collected often restrict analyses to time periods of less than 20 years. A third limitation is that it is usually not possible to validate the accuracy of diagnosis, which is of special importance when distinguishing Crohn's disease from ulcerative colitis.

### Time trends in individual studies

The alternative to figures generated from routine data is to use the results of individual *ad hoc* studies. In many European countries with centralised state-funded health care, such studies appear deceptively straightforward. Population catchment areas are often well defined and specialist care is provided by a small number of gastroenterologists, who also usually provide whatever private care is available. However, IBD is relatively uncommon, and prospective studies need to be prolonged to provide reliable figures on time trends. Other issues that have not always been carefully addressed include the criteria for diagnosis, residence criteria and clear definitions for date of onset or diagnosis. In addition, as already mentioned, the effects of increasing

awareness, better case ascertainment, greater use of more sensitive tests such as colonoscopy and evolving case definitions need to be considered.

Fortunately, in a few areas IBD incidence has been monitored either prospectively or by repeated retrospective studies over periods of more than 20 years, and these studies arguably provide the most reliable evidence on incidence trends (Figs 1.1 and 1.2). Rates have been plotted according to the last year of each time period reported and in most areas the rates have been age-standardised to correct for changes in their population age structures over time. Of the eight areas shown in Fig 1.1, only in the Aberdeen area and most recently in Stockholm has the incidence of Crohn's disease shown more than a small increase since 1980 [7, 25]. When the Aberdeen data are age-standardised there is some reduction in the rate of increase, although the final figure remains high at 88/million [26]. It is too soon to know whether this represents a sustained increase; a similar peak in incidence was previously found in Cardiff. Otherwise the remarkable feature is how little variation there is between places as different as Cardiff in the United Kingdom,

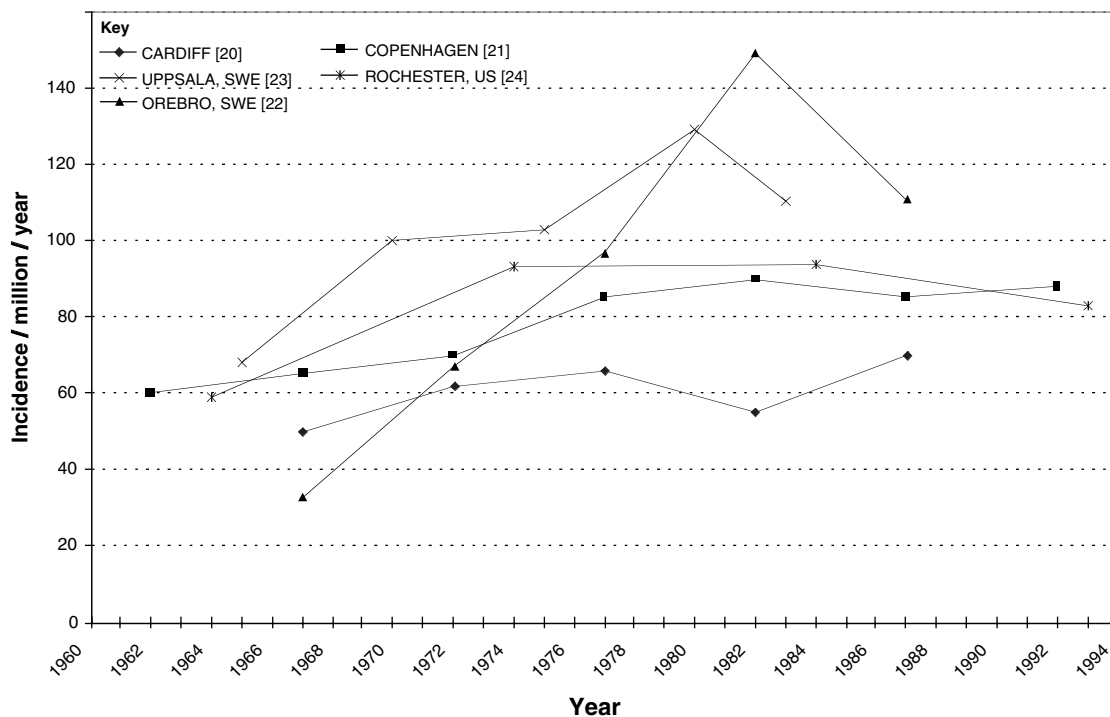


Fig 1.2 Recent time trends in incidence of ulcerative colitis.

Orebro in Sweden and Rochester in the United States.

These studies were all performed in an era when colonoscopy was not regarded as the standard investigation it has now become. For example, in northern France in the 1990s 92% of patients with Crohn's disease and 99% of those with ulcerative colitis had had a colonoscopy at diagnosis [17]. A recent updating of data from Stockholm found that 70% of Crohn's patients had a colonoscopy at diagnosis [25]. Equivalent figures for the 1980s and earlier have not been reported and it is unclear what proportion of IBD would have been labelled as ulcerative colitis in the absence of evidence, either macroscopic or microscopic, obtained at colonoscopy. Nevertheless, greater use of colonoscopy would account for the increasing proportion of patients found to have Crohn's disease affecting the colon, as reported in several recent studies [8, 17, 28].

There have been fewer studies of ulcerative colitis incidence. In the countries where IBD is common

incidence rates for ulcerative colitis have tended to show more variation than those for Crohn's disease. Probably this reflects the additional problems posed by variable ascertainment of mildly symptomatic cases including those with proctitis only, and distinguishing single or transient episodes of colitis induced by infection or drugs. In Nottingham, the prevalence of previously undiagnosed ulcerative colitis in subjects offered faecal occult blood testing for colorectal cancer screening was 700/million [29]. Most were mildly symptomatic but had not sought medical advice. In the recent Norwegian study a diagnosis of ulcerative colitis could not be confirmed in 12% of patients when reinvestigated one year after diagnosis [30].

Given these considerations and the various changes in health care already mentioned, the increases in incidence over time (shown in Fig 1.2) are perhaps less than might have been expected. What does seem to have changed is the age-specific pattern, with an increase in incidence of ulcerative

colitis at older ages in men but not in women. Thus, in the EC-IBD study and in the recent data from northern France the expected peak in incidence in the younger age groups was present for women but not for men [1, 27].

### Geographic trends in incidence

Over the past 30 years a large number of other *ad hoc* studies have been reported from diverse locations worldwide. Table 1.1 shows the incidence rates reported from recent European studies. The incidence of both diseases appears to show around a 10-fold variation across Europe, but in general, the incidence of both is highest in countries in northern latitudes. The north-south gradient in IBD incidence was first described in Europe and was based on observations from these individual studies. However, the conclusions reached by comparison of these

studies are once again hampered by variations in study design, notably case definition, methods of case ascertainment and time period of investigation. In addition, many studies reported only crude rather than age-standardised or age-specific incidence rates for their populations and in others, case ascertainment in children and the elderly was less complete than at other ages. The European collaborative study on IBD incidence was set up to overcome these problems by standardising methods throughout all participating centres. It concluded that the 'magnitude of the observed excess in north is less than expected on the basis of previous studies... this may reflect increases in incidence of IBD in Southern Europe whilst north may have stabilised' [1]. Incidence rates from centres participating in EC-IBD are shown in Table 1.1 in bold.

In North America significant geographic variation also appears to exist, and generally populations

**Table 1.1** European studies of inflammatory bowel disease incidence in the 1990s (Centres from EC-IBD in bold).

First author	Year	Area	Time period	Rates/100,000/year		Design
				UC ( <i>n</i> )	CD ( <i>n</i> )	
Shivananda EC-IBD [1]	1996	8 Northern European cities	1991-93	11.8 (869)	7.0 (477)	Prospective
Shivananda EC-IBD [1]	1996	12 Southern European cities	1991-93	8.7 (510)	3.9 (229)	Prospective
Bjornsson [28]	2000	Iceland	1990-94	16.5 (215)	5.5 (72)	Prospective
Moum [31, 32]	1997	South-east Norway	1990-93	12.8 (496)	6 (232)	Prospective
Salupere [33]	2001	Tartu, Estonia	1993-98	1.7 (16)	1.4 (13)	Prospective
Rubin [34]	2000	North Tees, UK	1990-94	13.9 (94)	8.3 (56)	Retrospective
Yapp [8]	2000	Cardiff, UK	1991-95		5.6 (84)	Retrospective
Russel [35]	1998	Netherlands	1991-95	10 (257)	6.9 (176)	Prospective
Latour [36]	1998	Leige, Belgium	1993-96	3.6 (111)	4.5 (137)	Prospective
Pagenault [37]	1997	Brittany, France	1994-95	2.9 (165)	2.8 (205)	Prospective
Flamenboum [38]	1997	Puy de Dome, France	1993-94	2.4 (29)	6.6 (79)	Prospective
Lakatos [39]	2004	Western Hungary	1977-01	5.8 (560)	2.2 (212)	Retrospective
Ranzi [40]	1996	Cremona, Italy	1990-93	7.0 (82)	3.4 (40)	Prospective
Trallori [41]	1996	Florence	1990-92	9.6	3.4	Retrospective
Tragnone [42]	1996	Italy (8 cities)	1989-92	5.2 (509)	2.3 (222)	Prospective
Manousos [43, 44]	1996	Crete	1990-94	11.3 (116)	3.5 (36)	Prospective
Tsianos [45]	2003	N W Greece	1982-97	6.6 (357)	0.5 (43)	Retrospective
Molinie [27]	2004	Northern France	1988-99	4.0 (2665)	6.0 (4013)	Prospective

UC: ulcerative colitis; CD: Crohn's disease.

with the highest incidence and prevalence rates have been located in northern latitudes [4, 5, 46, 47]. Once again, these findings are based on the results of individual studies and are therefore difficult to compare due to methodological differences. One study that overcomes these problems is a study in the United States of military veterans and Medicare beneficiaries, which shows that the incidence of IBD is higher in the north compared to the south [48, 49].

Further analysis of the large Scottish cohort of juvenile-onset IBD between 1981 and 1995 [50] has also found that northerly region of residence was an independent risk factor for developing CD but not UC [48]. The relative risk of CD in the south compared with the north was 0.73 (95% CI 0.58–0.92,  $p < 0.001$ ), but UC did not show this north/south variation. This pattern has not been examined in other paediatric populations, but does support the hypothesis that CD incidence exhibits a latitudinal gradient with incidence increasing with more northern latitudes.

### Rest of the world

Until the 1980s reports of IBD occurrence from outside Europe and North America consisted essentially of case reports or case series. The exception was South Africa where Wright *et al.* found the incidence of both diseases in the Cape Town area to be greatest in the Whites but with incidence less than half that found in equivalent European populations. Incidence of both diseases in the coloured population was lower again and lowest of all in the Blacks [51]. Recent well-researched studies from Japan and Korea have shown IBD to be much less common than in Europe with UC incidence being 10–20/million/year and CD less than 5/million/year [52–55].

In line with the data from Japan and the Far East, UC has traditionally been regarded as rare in the developing world. However, an impressive pair of population surveys in northern India has revealed an UC incidence of 60/million/year and a prevalence of symptomatic UC of 443/million – figures not much lower than those reported from several European countries [56]. It is unclear whether these figures

reflect an increasing UC incidence, as this is the first formal study of IBD incidence from India.

### Trends in incidence of juvenile-onset Crohn's disease

Incidence patterns for whole populations may conceal changes taking place in smaller subgroups of that population, such as children. Although Crohn's disease incidence may be stable overall, several groups have suggested that incidence in children is particularly increasing. The epidemiology of this subgroup is of particular importance because several current hypotheses as to the causes of CD and UC relate to events happening in infancy or childhood [57–61].

In assessing any increase in incidence in children, one needs to consider some additional factors that could account for a spurious increase (Table 1.2). Firstly, the steep increase in incidence at ages 15 and 16 coincides with the arbitrary division between childhood and adulthood. Thus, any reduction in the time between symptom onset and diagnosis could have a disproportionate effect on incidence in childhood. As Table 1.3 shows, researchers have been divided in choosing age 14, 15 or 16 as the upper limit of childhood. How this might affect the figures is difficult to gauge, but it is notable that in the study from Copenhagen where the low incidence below age 15 is based on only six cases, in a further 17 symptom onset was before age 15 but diagnosis occurred in adulthood. Secondly, time from symptom onset to diagnosis of Crohn's disease in children has shortened; in the United Kingdom this has gone from around 12 months in the early 1980s to around 5 months in the recent data collected [77]. Other factors include the increased intensity of investigation and changing criteria for diagnosis of Crohn's disease.

As noted above, diagnosis for all hospital admissions in Scotland are recorded in a linked fashion for the whole country in the 'Scottish Hospitals discharges linked database' [78]. The linkage of data allows the whole series of that patient's admissions to be identified at any one time, allowing identification of incident cases rather than just hospital admission episodes. Using this database Barton *et al.*

**Table 1.2** Possible factors contributing to an increase in incidence of Crohn's disease in children.

Greater case ascertainment
Quicker diagnosis → diagnosis at age 15, not 16
Diagnostic transfer, atypical UC → CD
Widening case definitions e.g. inclusion of orofacial granulomatosis
Earlier onset in predisposed individuals
Real increase in incidence

UC: ulcerative colitis; CD: Crohn's disease.

looked at incidence rates for juvenile onset IBD from 1968 to 1983 [71]. They found a three-fold rise in incidence for CD, and a marginal fall in UC. The data for CD, after allowing for a short lag, would seem to parallel the increase seen in adults over the preceding few decades. Over the last decade with increasing interest in the aetiological role of perinatal and early childhood factors, other groups have now published comparable epidemiological studies of the juvenile-onset subgroup (Table 1.3).

The figures from the Scandinavian countries seem to show more variation, with the rates from Denmark and Finland being a half to a third of those from Sweden and Norway. In part, this reflects the different age bands used (Table 1.3). Nevertheless, the situation within Sweden is as varied, because the recent data from northern Stockholm (Table 1.4) suggests a doubling in incidence of Crohn's disease, predominantly accounted for by increasing colonic disease, and a decline in ulcerative colitis

**Table 1.3** Recent incidence data for Crohn's disease (CD) and ulcerative colitis (UC) in childhood.

First author	Area	Period	Duration (years)	Age group	CD		UC	
					Rates per 100,000/year	<i>n</i>	Rates per 100,000/year	<i>n</i>
<b>Europe</b>								
Langholz [62]	Copenhagen	1962-87	15	0-14	0.2	6	2.0	63
Olafsdottir [63]	W Norway	1984-85	2	0-15	2.5	10	4.3	17
Bentsen [64]	SE Norway	1990-94	4	0-15	2.0	14	2.2	15
Lindberg [65]	SW Sweden	1984-86	3	0-15	1.9	211 <sup>†</sup>	1.4	287 <sup>†</sup>
		1993-95	3	0-15	2.0	-	3.2	-
Hildebrand [66]	N Stockholm	1990-01	12	0-15	4.9	102	2.4	50
Kolek [67]	Czech republic	1990-01	12	0-15	1.0	19	1.1	22
Van der Zaag-Loonen [68]	Netherlands	1999-01	2	0-17	2.1		1.6	
Tourtelier [69]	NW France	1994-97	4	0-16	1.6	43	0.6	14
<b>UK</b>								
Cosgrove [70]	S Wales	1983-93	11	0-15	2.2	21	0.7	7
Barton [71]	Scotland	1968	1	0-16	0.7	10	1.9*	18
		1983	1	0-16	2.3	28	1.6*	13
Armitage [72]	Scotland	1981-95	15	0-15	2.3	383	3.4	197
Hassan [73]	Wales	1995-97	1	0-16	1.4	20	0.8	11
Sawczenko [74]	UK	1998	1	0-15	3.1		1.4	
<b>USA</b>								
Kugathasan [75]	Wisconsin	2000-01	2	0-17	4.6	129	2.1	60
<b>Australia</b>								
Phavichitr [76]	Melbourne	1996-01	5	0-16	2.0	233	-	-

\*Rate for 6-16 years.

<sup>†</sup>Numbers for both periods.

**Table 1.4** Incidence of Crohn's disease in children – northern Stockholm [65].

	Rate per 100,000/year for ages 0–15 years (95% CI)	
	CD	UC
	N = 102	N = 48
1990–92	1.7 (0.7–3.3)	3.3 (1.9–5.4)
1993–95	3.5 (2.1–5.5)	1.8 (0.8–3.3)
1996–98	5.6 (3.8–8.1)	1.9 (0.9–3.5)
1999–01	8.4 (6.2–11.3)	1.8 (0.9–3.4)
Overall	4.9 (4.0–6.0)	2.2 (1.6–2.9)

UC: ulcerative colitis; CD: Crohn's disease.

in under 16-year-olds during the 1990s, while the larger study covering just over half the childhood population (< 16 years) of Sweden found no increase in Crohn's disease incidence but a two-fold rise in incidence of ulcerative colitis [65, 66].

In the paediatric age group, further research from Scotland has also shown a higher incidence of CD in the more affluent areas of Scotland, as defined by postcode sector [50]. This pattern was independent of temporal, gender or regional trends and was therefore not purely a reflection of the geographical distribution of deprivation. The relationship to affluence was seen in CD, but not in UC, thus it is unlikely that the association was simply due to a higher reporting of symptoms to primary care in affluent areas.

## Conclusions

It would be a serious mistake to assume incidence trends should be similar even in developed countries. With these caveats, there is broad support for the following:

- In Westernised countries, where Crohn's disease is already common, there is no *consistent* evidence of a continuing rise with the most reliable data showing stable incidence since the 1980s.
- In areas reporting an increase in Crohn's disease (northern France and Stockholm) the increase has been predominantly in colorectal Crohn's disease.
- Overall incidence of ulcerative colitis in the same countries is not rising.

- In areas of Europe where historically IBD has been uncommon or rare the incidence of both diseases is rising, although some of the rise may reflect greater access to health care with the general pattern being of an increase in UC followed by Crohn's disease, within a generation or less.
- Both diseases are now appearing in Japan and the rest of Asia.
- The incidence of Crohn's disease in children is increasing but how much of the increase is accounted for by earlier diagnosis, varying definitions of childhood and changes in diagnostic criteria is still not clear.

Overall, this pattern is in keeping with some environmental factors associated with economic development or Westernised lifestyles. Focussing on the emergence of IBD in the developing world is likely to be a fruitful area for research.

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## 2: The role of genetics in inflammatory bowel disease

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### Introduction

In the last 20 years there has been an exponential acceleration in our understanding of human molecular genetics. Important technical advances, such as the discovery of the polymerase chain reaction in the mid-1980s [1], have substantially improved both the precision and rapidity of processing DNA. This, coupled with the recent completion of the human genome project, has heralded a new era for molecular genetics and, in particular, has allowed the study of complex polygenic diseases.

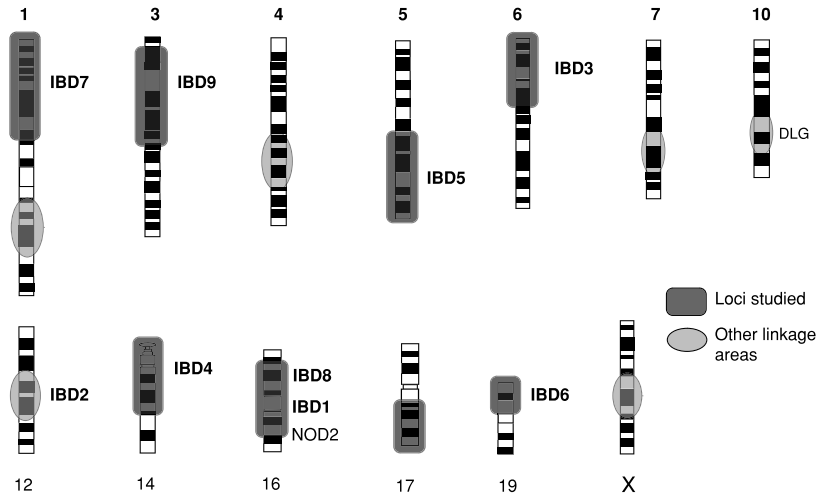
The successful identification of disease-causing genes can follow a number of different pathways, which lead to the isolation of a manageable number of candidate genes. A common strategy, since the advent of micro-satellite marker maps [2], is to perform genome-wide scans of families multiply affected by a particular disease. Loci of interest can be identified by genotyping these individuals for markers distributed evenly across the genome. Linkage is achieved at a particular locus if the extent of allelic sharing between individuals is greater than would be expected by chance. However, these loci are relatively large and fine mapping is required. This can be achieved by using a higher density of markers, usually single nucleotide polymorphisms (SNPs), in the region of interest. Association studies can then be undertaken and candidate genes tested to identify differences in the disease population compared to controls. Functional experiments are then required to confirm a pathological role for the mutant gene identified. New micro-array technology has provided a method of simultaneously analysing

the expression of many hundreds of selected genes or indeed the entire genome. This new field of so-called functional genomics promises to provide a more dynamic picture of gene expression in diseased tissue and sets the stage for inflammatory bowel disease (IBD) genetics in the new millennium.

### Inflammatory bowel disease: a genetically determined condition?

The observation of familial clustering of IBD was first documented by Crohn *et al.* in the early 1930s. This ultimately led to the hypothesis that there might be a genetic component to the pathogenesis of IBD. A large number of epidemiological studies based on both hospital cohorts and unselected populations have supported this finding. Studies of first-degree relatives of patients with Crohn's disease (CD) have shown a relative risk of 10–35 for developing CD and a relative risk of 3–6 for developing ulcerative colitis (UC). The risk is lower in relatives of UC patients with a relative risk of 2–15 for developing UC and 2–3 for developing CD [3]. The risk of IBD is greater if more than one first-degree relative has the condition [3], and is of consistently increased prevalence in the Jewish population [4]. The relative risk of IBD is greatest for siblings [5], especially if the proband has CD [6, 7].

Segregation studies were used in the 1980s to model the mode of inheritance in IBD and were unable to support a simple Mendelian model [8–11]. This was confirmed by more recent genome-wide linkage studies supporting a polygenic model of



**Fig 2.1** Inflammatory bowel disease linkage areas.

genetic susceptibility. Studies of twins have provided further evidence of the involvement of genes in IBD, with monozygotic twins showing greater concordance for IBD than dizygotic twins [12–15].

Disease phenotype is also genetically influenced with associations demonstrated for early disease onset, location and behaviour. It has become apparent that CD and UC are a clinical continuum influenced by an individual's underlying array of disease susceptibility and disease modifying genes. It has been proposed that these modifier genes, with no effect on disease susceptibility themselves, influence disease phenotype by interacting with a limited number of susceptibility genes, acting either alone or in combination [16]. It must be remembered that non-genetic factors also play a role in modifying disease phenotype, illustrated by the preferential CD phenotype in smokers from families susceptible to IBD [17].

These studies provide compelling evidence for the involvement of genes in the pathogenesis of IBD and also provide insight into the influence of genes on phenotype. The overlap of the CD and UC phenotypes within families challenges rigid concepts of distinct diseases and suggests a less polarised inter-play of multiple genes resulting in a given phenotype. This paves the way for a rather more robust molecular classification of IBD.

### The disease susceptibility loci

Genome-wide linkage studies of multiply affected families have been a highly successful strategy in revealing a multitude of potentially relevant disease susceptibility loci, sometimes despite poor replication between studies. Since 1996 twelve genome-wide scans from Europe and North America have been published. These studies have resulted in the identification of a total of nine disease loci designated IBD1–9 (Fig 2.1). Five loci (IBD1, 2, 4–6) have met the stringent 'genome-wide' linkage criteria necessary for definite linkage [18]. IBD3 and IBD7 did not reach genome-wide significance initially, but after more focused studies there was sufficient supportive evidence for these regions to be designated as IBD loci [19, 20]. Interestingly, in a recent meta-analysis of genome-wide scans IBD3 was the only locus that met genome-wide significance whereas IBD1, IBD2 and IBD6 only demonstrated suggestive linkage [21]. There is growing evidence from the stratification of both genome-wide scans and association studies by CARD15 status and also by transmission disequilibrium testing (TDT) to support two further disease loci designated IBD8 (16p 25cMq telomeric to IBD1) [22, 23], and IBD9 (3p) [24], respectively. Two other regions are noteworthy, although they are yet to

be replicated and designated as IBD loci. At the 10q23 locus, variants in the *DLG5* gene that encodes an epithelial scaffolding protein, has been associated with IBD [25]. More recently, strong associations have been found on 7p14.3 between haplotypes (a series of linked alleles at different loci) in the terminal exons of *NOD1* (nucleotide oligomerisation domain 1) and IBD [26]. *NOD1*, which is structurally similar to *NOD2* (nucleotide oligomerisation domain 2) detects a tripeptide motif found in gram-negative bacterial peptidoglycan and like *NOD2* activates NF $\kappa$ B and enhances apoptosis [27].

### IBD1

In 1996 Hugot *et al.* identified the first IBD linkage area, designated IBD1 on the pericentromeric region of chromosome 16 [28]. This was subsequently replicated in seven further linkage studies prior to the identification of the causative gene [29–35]. It was not until 2001 that three independent groups, using rather different strategies, isolated mutations in the *NOD2* gene [36–38], later renamed *CARD15* (caspase-activation recruitment domain), as being significantly associated with CD. Nuñez and Cho's group initially cloned *CARD15* and found that it subsequently mapped to the IBD1 locus. Sequencing of the gene in CD families revealed a frameshift mutation caused by a cytosine insertion (3020insC). A combination of transmission disequilibrium testing and case-control studies were then performed and showed significant association with CD [37]. Hampe *et al.* [38] followed a similar strategy aided by the knowledge of the recently cloned *CARD15*. In contrast, Hugot *et al.* [36] used pure linkage analysis methodology and found associations for the frame shift 3020insC mutation as well as two non-synonymous (amino-acid altering) SNPs (Arg702Trp and Gly908Arg), resulting in mis-sense variants of *CARD15*. Further, *CARD15* variants have been identified but 82% of mutated alleles are accounted for by these three mutations [39].

In 2001 the IBD International Genetics Consortium [40] pooled data sets from studies that did not alone show significant linkage to IBD1 and found

highly significant association with CD (logarithm of the odds (LOD) score 5.79). These apparently conflicting results merely reflect the relative underpowering of the individual studies. This is a common problem of many IBD genetic studies and accounts for much of the inter-study variability in results.

### Other IBD linkage regions

A second genome-wide scan in 1996 identified genome-wide linkage, spanning part of the p and q arms on chromosome 12 (IBD2 locus) [41]. This locus has been replicated in several [32, 42, 43], but not all, studies [29, 44–46]. On current evidence, the IBD2 locus seems to be associated more with UC than with CD [40, 47]. Attempts to identify the precise gene have so far been unsuccessful.

Immune dysregulation plays a central role in the pathogenesis of IBD [48], which has resulted in considerable interest in the human leukocyte antigen complex (HLA) on chromosome 6p (IBD3). This region is highly polymorphic and gene-dense and includes the HLA class I, II and III genes. Although there have been numerous serological studies showing associations between class I and II HLA antigens and IBD, many of these early studies were underpowered. In an early molecular study by Satsangi and colleagues [49] linkage was demonstrated for UC with the HLA class II *DRB1* locus and the *DRB1* DQB haplotype. This group then went on to show in a case-control study significant associations for UC and the *DRB1*\*0103 and *DRB1*\*12 alleles, a finding replicated in several other studies [50, 51]. For CD an American genome-wide scan provided suggestive evidence of linkage to chromosome 6p [52]. However, perhaps the most compelling evidence for linkage to this region comes from a collaborative Northern European study. In an initial genome-wide scan suggestive, but not significant, linkage to IBD3 was achieved [29]. In a subsequent follow-on study by the same group, using a higher density of markers, highly significant linkage for both CD and UC was demonstrated [20]. This finding was later independently replicated [53].

A study from Pittsburgh showed genome-wide significance to chromosome 14q (IBD4) for CD [43]. This supported previous data from two other North