Linkage of ulcerative colitis to the pericentromeric region of chromosome 16 in Italian inflammatory bowel disease families is independent of the presence of common CARD15 mutations

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C rohn’s disease (CD) and ulcerative colitis (UC) are the two main clinical subtypes of inflammatory bowel disease (IBD), a common complex disease with a frequency in Western populations of about 1 in 1000.1 A strong genetic susceptibility to IBD is supported by several epidemiological studies,2 and the existence of both specific and common susceptibility genes for CD and UC has been postulated.3

Several candidate loci for IBD have been identified following whole genome scans in different populations (reviewed in Bonen & Cho5). Among these, a locus in the pericentromeric region of chromosome 16 denoted IBD1 was found consistently in linkage to CD in several independent studies6 and in a large collaborative study by the IBD International Consortium.7 Most of these studies, with few exceptions,8 reported negative or non-significant linkage of the same locus to UC. Allelic variants of single nucleotide polymorphisms (SNPs) in the CARD15 gene, located in the IBD1 region, have since been demonstrated to confer susceptibility to CD, but not to UC in several populations9–11 (also reviewed in Bonen & Cho5).

In a previous study, we reported positive non-parametric linkage (NPL) scores in the IBD1 region in both our CD and UC families,12 with the highest scores occurring at markers D16S419 and D16S514, respectively. Marker D16S419 is located approximately 5 cm away from CARD15, while D16S514 is located almost 20 cm away on chromosome 16q. To follow up on these results, we typed 10 additional microsatellite markers in the chromosome 16 region of positive linkage in a total of 90 Italian IBD families, and repeated the linkage analysis after excluding 26 families with previously reported CARD15 SNP susceptibility alleles. The observation of a broad region of positive NPL scores in our UC families suggests that genes conferring susceptibility to this form of IBD may be located in the pericentromeric region of chromosome 16.

MATERIALS AND METHODS

Patients and families

Our linkage analysis cohort consists of 90 Italian families with two or more members affected by IBD recruited through a multicentre program of the IG-IBD (Italian Group for Inflammatory Bowel Disease) involving 12 centres throughout Italy. The cohort comprises 41 of 58 families included in our previous analysis of the IBD1 region12 for which DNA samples were still available, and 49 new families that had never before been analysed. A total of 108 Italian unrelated healthy controls were also recruited from the same regions of origin of the patients. The local ethics committees of the collaborating institutions approved this study, and informed consent was obtained from each participant.

Patients were classified as having CD or UC on the basis of clinical, endoscopic, radiological, and pathological data.12 In 27 families, all affected members had CD, in 43 families all had UC, and the remaining 20 had individuals affected by both CD and UC (mixed families). The majority of families (72 or 80%) were composed of parents and 2–4 affected siblings, and five families had one affected sibling pair and one additional more distantly related affected member. The other 13 families contained one affected relative pair other than siblings.

Genotyping

Blood samples were collected into tubes containing sodium citrate and stored at −30°C until extraction. Genomic DNA was then purified from peripheral blood leukocytes according to standard protocols13 or using a DNA isolation kit (Roche Diagnostics Co., Indianapolis, IN, USA). Eighteen different

Key points

- Allelic variants of single nucleotide polymorphisms of the CARD15 gene, located on chromosome 16q, are known to cause susceptibility to Crohn’s disease (CD), but not ulcerative colitis (UC). Previous studies suggested that linkage to the IBD1 region on chromosome 16q was present in both CD and UC families in the Italian population.
- In this study, we tested a group of Italian inflammatory bowel disease families for the three most common CARD15 single nucleotide polymorphisms known to affect risk of CD (R702W, G908R and L1007fsinsC).
- We show that NPL scores in the IBD1 region remain positive in those families that tested negative for the presence of the CARD15 susceptibility alleles, including families of patients with UC.
- Our results suggest that additional genes in the pericentromeric region of chromosome 16 may affect risk of inflammatory bowel disease.

Abbreviations: CD, Crohn’s disease; IBD, inflammatory bowel disease; NPL, non-parametric linkage; SNP, single nucleotide polymorphism; UC, ulcerative colitis
CARD15 SNPs R702W, G908R and L1007fsinsC were detected using the pyrosequencing approach. Briefly, three fragments of 106, 117 and 104 bp respectively encompassing the three SNPs were PCR amplified using 200 nmol/l of each forward and reverse primer (R702W-F: 5'-TTCCTGGCAGGGCTTGTP-3' and R: 5'-biotin-CCAGACACCAGCGGGG-3'; G908R-F: 5'-TAGAAGGGAGGAGGAAGTCGAGCAGTGTATTG-3' and R: 5'-biotin-CCCCCTCGTCACCCACT-3'; L1007fsinsC-F: 5'-biotin-TCTCTTCTCCAGGTTGTCCA-3' and R: 5'-TCTCTTACGAGCGTTCCAGGATG-3'). The biotinylated primer in each primer pair allowed subsequent immobilization on streptavidin coated beads. The amplification was performed in a total volume of 50 μl containing 1× GeneAmp Buffer II, 2.5 mmol/l MgCl₂, 0.5 mmol/l dNTP, 50 ng genomic DNA and 1.5 U Taq Gold DNA polymerase (Applied Biosystems, Foster City, CA, USA) and primers (200 nmol/l each). Conditions were 95°C for 10 min followed by 35 cycles at 95°C for 1 min, 62°C for 1 min, 72°C for 1 min and a final step at 72°C for 10 min. PCR products (2 μl) were analysed on a 3% (w/v) agarose gel to verify size and quantity of the amplified fragment. Isolation of single stranded biotinylated templates for pyrosequencing was performed as described previously using solutions provided in the PSQ HS96A Sample Preparation Kit (Pyrosequencing AB, Uppsala, Sweden), streptavidin sepharose HP beads (Amersham Pharmacia Biotech, Uppsala, Sweden) and 96 well microtitre plates. Beads with bound single stranded template were suspended in 12 μl of annealing buffer pH 7.6 (20 mmol/l Tris acetate, 2 mmol/l Mg acetate) and 0.5 μmol/l (6 pmol) of each pyrosequencing primer (R702W-F: 5'-CATCTGAGAAGGCC-3'; G908R-F: 5'-CTTCTGGCTTTCGTCAG-3'; L1007fsinsC-F: 5'-TGTCATTCCTTTCAAGGG-3') in a PSQ HS 96 plate (Pyrosequencing AB), heated at 94°C for 2 min and then cooled to room temperature to facilitate the annealing of the primer to the template. The plates were placed into the PSQ96HS 96A system following the manufacturer's recommendations. Reactions were performed at 28°C with annealed sequencing primer in addition to manufacturer supplied DNA polymerase, apyrase, luciferase, adenosine triphosphate sulphurylase, adenosine 5'-phosphosulphate and luciferin. Reactions consisted of stepwise elongation of the primer strand by one or more nucleotides upon sequential addition of the individual dNTPs following the dispensation order entered in the Pyrosequencing SNP Entry software (Pyrosequencing AB). The sequence at each elongation step was inferred by measuring light emission as an indicator of nucleotide incorporation. The resulting sequences were analysed automatically by the SNP Evaluation software v1.1 (Pyrosequencing AB). SNPs were also confirmed by DNA sequence analysis using the ABI BigDye Terminator V3.1 Cycle Sequencing Ready Reaction on a ABI 3100 DNA sequencer (Applied Biosystems) following the manufacturer’s recommendations.

### Table 1: Genotype and allele frequency distributions at three CARD15 SNPs in IBD probands and controls

<table>
<thead>
<tr>
<th>SNP</th>
<th>Genotype counts</th>
<th>Genotype frequency</th>
<th>p*</th>
<th>Rarer allele frequency</th>
<th>p+</th>
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<td>1/1 1/2 2/2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>R702W</td>
<td>CD 21 9 0</td>
<td>0.007</td>
<td>0.15</td>
<td>0.01</td>
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<td></td>
<td>UC 46 8 0</td>
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<td>0.07</td>
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<tr>
<td></td>
<td>Controls 96 11 1</td>
<td></td>
<td></td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>G908R</td>
<td>CD 27 6 0</td>
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<td>0.09</td>
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<td></td>
</tr>
<tr>
<td></td>
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<td>0.02</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Controls 103 5 0</td>
<td></td>
<td></td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>L1007fsinsC</td>
<td>CD 29 4 2</td>
<td>0.001</td>
<td>0.11</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>UC 52 2 0</td>
<td>0.02</td>
<td>1</td>
<td>0.02</td>
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</tr>
<tr>
<td></td>
<td>Controls 105 3 0</td>
<td></td>
<td></td>
<td>0.01</td>
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</table>

1/1, Homozygotes for the common variant; 1/2, heterozygotes; 2/2, homozygotes for the rare variant

* p value for difference in genotype frequencies between probands and controls by Fisher’s exact test (1/2 and 2/2 grouped together)

+ p value for difference in allele frequencies between probands and controls by Fisher’s exact test.
microsatellite linkage analysis. DNA samples from five patients failed to amplify for R702W, and DNA from one patient failed to amplify for G908R.

Genotype frequencies at the three SNPs were in Hardy–Weinberg equilibrium in all three groups except for L1007fsinsC in CD patients ($\chi^2 = 6.64, 1$ df, $p = 0.01$), which showed excess of homozygosity for the rarer variant. Allele and genotype frequencies at all three SNPs were significantly different between CD probands and controls, but not between UC probands and controls (table 1).

When genotypes at all three SNPs were combined into a single CARD15 genotype (table 2), the relative risk of CD for carriers of two variants (either in the homozygous or the compound heterozygous state) compared with non-carriers was highly significant (RR 41.41, 95% CI 4.86 to 352.95, $p = 0.00001$) whereas the relative risk for heterozygotes at only one SNP was not (RR 1.63, 95% CI 0.57 to 4.69, $p = 0.39$). A recessive mode of inheritance for susceptibility to CD linked to IBD1 has been previously suggested based on a combined linkage and segregation analysis in our patient population.

**Linkage analysis**

Multipoint model free linkage analysis was first performed using 18 microsatellite markers spanning approximately 28 cM in the pericentromeric region of chromosome 16 (average distance 1.62 cM) on all 90 families grouped according to disease status (all IBD combined, CD, UC, and mixed). Results are shown in fig 1A. The maximum multipoint NPL score occurred at the position of markers D16S408 and D16S3140 (74.44 cM in the Marshfield sex average genetic map) in all 90 families combined ($p = 0.002$), and in the 27 CD ($p = 0.01$) and 43 UC ($p = 0.01$) families. In the 20 mixed families, a non-significant peak was observed near the q-tel end of the interval at marker D16S503 (83.55 cM, $p = 0.18$).

After typing the probands for R702W, G908R and L1007fsinsC, 26 families were removed in which the proband was either heterozygote or homozygote for the rare allele at any one of the three CARD15 SNPs (13 CD, 6 UC and 7 mixed), and the linkage analysis was repeated (fig 1B). The highest multipoint NPL score in all 64 families was very similar to the one observed before and still occurred near markers D16S408 and D16S3140 (74.44 cM in the Marshfield sex average genetic map) in all 90 families combined ($p = 0.002$), and in the 27 CD ($p = 0.01$) and 43 UC ($p = 0.01$) families. In the 20 mixed families, a non-significant peak was observed near the q-tel end of the interval at marker D16S503 (83.55 cM, $p = 0.18$).

In the CD group, there was no significant evidence of linkage to this region after the CARD15 positive families were removed (all $p$ values >0.05). Interestingly, the NPL at the location of marker D16S3120, which is the nearest marker to CARD15 included in our analysis, was now negative. The maximum NPL was observed at marker D16S419 (67.40 cM, $p = 0.06$), which is about 5 cM away from CARD15.

In contrast, linkage to D16S408 was even more significant in the 37 CARD15 negative UC families ($p = 0.003$). Additional smaller peaks were observed near the ends of the genetic map, and the overall profile was very similar to that described for the whole IBD sample. In the mixed families, linkage to D16S503 near the q-tel end of our interval was more pronounced ($p = 0.04$) when families with CARD15 SNP positive probands were removed.
Linkage disequilibrium analysis

Family-based tests of association in the three groups of 14 CD, 37 UC, and 13 mixed families that were negative at the CARD15 SNP analysis did not show any significant association of any of the alleles of 18 microsatellite markers to disease status (all p values > 0.05). However, given their small size, it is possible that inability to detect associations in our samples was due to lack of power.

DISCUSSION

After its initial report by Hugot et al in 1996,1 linkage of CD to the IBD1 locus in the pericentromeric region of chromosome 16 was consistently replicated in several independent groups of patients, although with some variation in the location of the linkage peak across different studies.6 This was an unusual finding in the search for susceptibility genes in complex traits by genetic linkage analysis, which is often characterised by lack of replication of initial positive results in subsequent studies. The search for the IBD1 gene culminated in the discovery that allelic variants of SNPs in the CARD15 gene conferred an increased risk of developing CD,16,19–20 particularly when present on both homologous copies of chromosome 16 in either the homozygous or the compound heterozygous state. Once again, this finding was consistently replicated in several populations,4 including some in which linkage to the IBD1 region was less than significant.23

Linkage of UC, the other common form of IBD, to the IBD1 locus was reported usually to be negative or non-significant7 with few exceptions.7 We first reported a positive linkage of markers in the IBD1 region to both CD and UC in our Italian patient population.3 While we were extending the analysis of the IBD1 region to a larger sample of families and a more dense map of markers, the identification of the association of CD with CARD15 SNP alleles8–10 prompted us to type our families for the same SNPs, and re-evaluate our linkage findings after exclusion of those families in which the probands were carriers of CARD15 SNP alleles known to confer susceptibility to CD.

Similarly to results in other populations, all three CARD15 SNPs characterised in this study (R702W, G908R, and L1007fsinsC) showed significantly higher frequencies of the rarer alleles in the CD probands. Multipoint model free linkage analysis with markers from the IBD1 region became even more significant in our UC probands (with a peak close to marker D16S408, which is about 12 cM away from the location of CARD15) after removal of six UC families whose probands were heterozygous carriers of one of the three CARD15 SNPs. In contrast, the significance of linkage to this region was markedly reduced in our CD group after removal of the families with CARD15 positive probands, suggesting that the three known SNPs did account for most of the IBD1 linked susceptibility to CD in our families. A much smaller peak was observed in the mixed families group near the q-tel end of the interval included in our analysis (approximately 20 cM away from CARD15). In this case also, significance increased after removal of seven families in which the probands were carriers of one of the three CARD15 SNPs. These observations point to the existence of a UC susceptibility gene in the IBD1 region in our families.

The presence of additional IBD loci in the pericentromeric region of chromosome 16 independent of CARD15 has been suggested by Hampe et al20 on the basis of the observation of positive linkage in their CARD15 positive UC families. In their study, linkage was more significant in the CD families than in all IBD families combined, and was marginal in their group of UC families. While linkage was positive across a large pericentromeric region, the observation of positive association with alleles of a microsatellite marker, D16S3068, located near the centromere on 16p, led these authors to detect significant association to random SNPs in this area. The nearest markers to D16S3068 included in our study are D16S409 and D16S517, located on chromosome 16q approximately 10 cM away from D16S3068 according to the Marshfield chromosome 16 genetic map. Although we observed a small peak near these markers in the IBD and UC groups, our data point to a more distal 16q location for the susceptibility locus in our families. Interestingly, based on the observation of multiple positive linkage peaks in the intervals flanking CARD15, Hampe et al20 also suggested that more than one additional IBD gene may be located in this region.

We cannot exclude that rarer CARD15 SNPs other than those typed in this study are present in our patients and account for some of the positive linkage to this region in our families. In this respect, it is of interest that even in the CD families the maximum NPL score occurred at marker D16S408, which is about 12 cM away from CARD15, and that the minimum score occurred at D16S3120, which is the nearest marker to CARD15 included in our analysis. Nonetheless, 13 CD families out of 27 were found to be positive for the CARD15 SNPs (with five heterozygous and eight homozygous or compound heterozygous probands). This observation points to the difficulty of correctly mapping susceptibility genes for complex traits by linkage analysis.25 The relatively small sample size and the presence of both linked and unlinked families may result in a localisation of the linkage peak away from the actual susceptibility gene location. The positive linkage we observed in the IBD1 region might indicate the presence of different CARD15 SNPs from those we tested conferring susceptibility to IBD in our population. However, the involvement of rarer CARD15 SNPs in UC has been excluded in patients from several European populations, including some from Italy.26 It seems unlikely that CARD15 plays a different role in our UC patients from that observed in other populations.

In conclusion, these results point to the presence of a UC susceptibility locus in the chromosome 16 pericentromeric region in our families. Whether this is at least in part due to the presence of rarer CARD15 SNPs or to a completely independent gene, remains to be determined.

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