CONCISE REPORT

Genetic contribution to radiographic severity in osteoarthritis of the knee

Ana M Valdes,1 Sally Doherty,2 Kenneth R Muir,3 Weiya Zhang,4 Rose A Maciewicz,5 Margaret Wheeler,2 Nigel Arden,6 Cyrus Cooper,7 M Doherty2

INTRODUCTION

Osteoarthritis (OA) is the most common joint disorder1 and has an important genetic component associated with its development.2,3 Many genes contribute modestly to the risk for developing OA.2,3 To date, variants in three genes have been reproducibly associated in European-descent populations with knee OA with p<5×10–8. These are: a variant in the GDF5 cluster in chromosome 7 including the component of oligomeric golgi complex 5 (OFCG5) gene,4 a variant mapping to a gene cluster in chromosome 7 including the component of oligomeric golgi complex 5 (OFCG5) gene and a variant in the MCF2 cell-line-derived transforming sequence-like (MCF2L) gene.6 The role of GDF5 in the pathogenesis of OA has been widely explored7 but little is known about the biological processes influenced by the other two variants.

The most common definition of OA for genetic studies has been a radiographic one, based on the Kellgren-Lawrence (K/L) system8 using the cut-off value of 2 as a case definition, which corresponds to x-ray-revealed presence of definite osteophytes and possible joint space narrowing. However, the presence of osteophytes is extremely common in the general population,9 and a K/L grade=2 is not necessarily of clinical concern and, in fact, it rarely leads to total joint replacement.10–12 An important aspect to investigate is the extent to which genetic variation influences radiographic severity. In three independent study cohorts from the UK, we have investigated the role of the variants so far identified to be reproducibly associated with knee OA in Caucasians. We have assessed their role among individuals with radiographic evidence of knee OA to the extent of radiographic damage, as defined by the K/L grade, at both the tibiofemoral and patellofemoral compartments.

SUBJECTS AND METHODS

Patients

Knee OA patients, taken from two case-control cohorts, Genomics of Osteoarthritis and Lifestyle (GOAL) Study and the Nottingham Case-Control Study, were included. Patients recruited from the community selected from a population-based study, the Hertfordshire Cohort Study, were also included. A description of each cohort is detailed in the online supplementary methods.

Genotyping

Genotyping of the rs143383, rs4730250 and rs11842874 single nucleotide polymorphisms (SNPs) was carried out by Kbioscience Ltd, Hertfordshire, UK, using the KASPar chemistry. Further details on quality control in the genotyping are shown in the online supplementary methods.

Statistical analysis

The association between SNPs and radiographic severity of knee OA was first assessed by linear regression using as outcome variables, the K/L grade at the tibiofemoral and patellofemoral compartments, and as independent variables the number of risk alleles (0,1 or 2) at each SNP. Age, sex and body mass index (BMI) were included as covariates. Mean K/L values adjusted for covariates and cohort of origin for each genotype were derived from ANOVA.

Significant results were also tested using logistic regression analyses (adjusting for age, sex and BMI) comparing patients with K/L=2 with patients with K/L≥3. Meta-analyses of data from different cohorts were performed using R V2.13.1 (http://
RESULTS

The descriptive characteristics of the study cohorts, including the distribution of K/L grades at the tibiofemoral and patellofemoral grades, are presented in Table 1.

The individual association between the polymorphisms and the measures of severity of knee OA for each cohort adjusting for age, sex and BMI were computed, and the resulting coefficients were meta-analysed (table 2). Of the three variants, the risk allele at the GDF5 SNP is significantly associated with higher tibiofemoral K/L grade even after adjusting for the six tests carried out. The MCF2L variant was only nominally significantly associated with patellofemoral K/L and is not significant if adjusted for multiple tests (table 2).

The test results with K/L grade might be reflecting the already known association with risk of OA. We therefore performed a sub-analyses on tibiofemoral K/L and GDF5 and patellofemoral K/L and MCF2L only among patients affected at the tibiofemoral and patellofemoral compartments, respectively (K/L≥2 at the relevant compartment). There is a clear linear relationship between the mean tibiofemoral K/L grade (adjusted for covariates) and the number of predisposing T alleles carried at rs143838 (figure 1A). The difference observed between genotypes is 0.055 of K/L grade, and the current study has a power of 69% to detect such difference with p<0.05. The rs11842874 homozygote for the protective G allele does not have a lower mean patellofemoral K/L than the heterozygote carrier of the risk allele A. The average difference between genotypes is 0.027 of K/L grade. The study has a power of 10% for such an effect size given the allele frequency (figure 1B). The forest plots illustrating the association coefficients and the overall meta-analysis summary statistic of the individual cohort, are also shown for this sub-analysis in figure 1C for rs143838 and tibiofemoral K/L, achieving a p=0.0011 by meta-analysis; in figure 1D, we show the association between rs11842874 and patellofemoral K/L which achieves a p=0.027 by meta-analysis.

K/L grade is a discrete measure and it is not truly normally distributed. We therefore ran logistic regressions for the two nominally significant results. We assessed the GDF5 effect including knee OA cases with tibiofemoral K/L=2 versus K/L≥3 (figure 1E) and the MCF2L effect comparing patellofemoral K/L=2 versus K/L≥3 (figure 1F). The GDF5 result remains statistically significant (p=0.008), but the association of MCF2L with patellofemoral grade is not statistically significant (p=0.08). Thus, the association between GDF5 and tibiofemoral grade is not a statistical artifact due to the non-normality of the distribution of K/L grades.

DISCUSSION

We have shown that two of the three genes which have, to date, been convincingly implicated in genetic risk of knee OA also correlate with the extent of radiographic damage at the

| Table 2 | Individual study genetic association estimates with patellofemoral (PF) and tibiofemoral (TF) K/L grade and meta-analysis summary statistics. All results are adjusted for age, sex and body mass index |
|----------|--------------------------------------------------|----------------------|---------------------|
| Gene     | Variant | Cohort       | β    | SE    | p Value | β    | SE    | p Value |
| GDF5     | rs143838 | GOAL         | 0.024| 0.036| 0.512   | 0.042| 0.037| 0.263   |
|          |         | HCS          | 0.103| 0.056| 0.064   | 0.077| 0.058| 0.180   |
|          |         | Nottingham   | -0.007| 0.044| 0.876   | 0.060| 0.030| 0.049   |
|          |         | Summary      | 0.033| 0.045| 0.463   | 0.058| 0.021| 0.006   |
| COG5     | rs4730250 | GOAL        | -0.006| 0.054| 0.908   | 0.001| 0.056| 0.986   |
|          |         | HCS          | 0.175| 0.086| 0.041   | 0.108| 0.089| 0.225   |
|          |         | Nottingham   | 0.021| 0.047| 0.657   | 0.016| 0.037| 0.655   |
|          |         | Summary      | 0.030| 0.066| 0.649   | 0.020| 0.550| 0.971   |
| MCF2L    | rs11842874 | GOAL       | 0.068| 0.070| 0.368   | 0.199| 0.078| 0.011   |
|          |         | HCS          | 0.190| 0.112| 0.091   | -0.119| 0.117| 0.312   |
|          |         | Nottingham   | 0.084| 0.100| 0.402   | -0.108| 0.069| 0.121   |
|          |         | Summary      | 0.099| 0.050| 0.048   | -0.005| 0.048| 0.920   |

GOAL, Genetics of Osteoarthritis and Lifestyle study; HCS, Hertfordshire Cohort Study; Nottingham, Nottingham Case-Control Study.
Clinical and epidemiological research

![Graph A: Mean TF K/L grade](image)

![Graph B: Mean PF K/L grade](image)

![Graph C: Regression coefficient for association of rs143383 with tibiofemoral K/L grade](image)

![Graph D: Regression coefficient for association of rs11842874 with patellofemoral K/L grade](image)

**Figure 1** Association between knee K/L grade and gene variants: (A) mean tibiofemoral (TF) K/L grade ± SE for each GDF5 rs143388 genotype adjusted for cohort, age, sex and BMI. (B) mean patellofemoral (PF) K/L grade ± SE for each MCF2L rs11842874 genotype adjusted for cohort, age, sex and body mass index. (C) Forest plot for association between TF K/L and rs143388 for each study cohort, and fixed-effects meta-analysis summary statistics. Only patients with TF K/L ≥2 are included. (D) Forest plot for association between PF K/L and rs11842874 for each study cohort and fixed-effects meta-analysis summary statistics. Only patients with PF K/L ≥2 are included. (E) Forest plot for association between TF K/L = 2 cases versus TF K/L ≥3 and rs143388 for each study cohort, and fixed-effects meta-analysis summary statistics. (F) Forest plot for association between PF K/L = 2 cases versus PF K/L ≥3 and rs11842874 for each study cohort, and fixed-effects meta-analysis summary statistics. All results are adjusted for age, sex and body mass index.

Tibiofemoral or patellofemoral compartments. This observation suggests that the mechanisms by which GDF5 influences risk of OA underlie biological processes involved in joint damage, which may be due to a decrease in the incidence or progression of OA. This may be due to an influence of genotype on the risk of developing OA or the progression of OA.

The rs143383 variant maps to the promoter in the GDF5 gene and has been shown to influence expression levels of the gene product, with the predisposing allele T resulting in lower expression of this chondroprotective growth factor. On the other hand, the MCF2L gene product has been implicated in peripheral nervous system cell migration as modulated by neurotrophins and, hence, it has been hypothesised that its role in OA could be via an effect on nociception. The weak correlation found with patellofemoral radiographic grade, suggests that this gene might play a role in joint damage and indicates the need for studies on the functional relevance of this molecule in the biology of joints. No genetic studies have been published specifically on either of the knee compartments, and the association we report with severity does not reach genome-wide significance. However, our results suggest that genetic variation may influence the risk of OA.
influence specific joint compartments and, given the differences in biomechanics between tibiofemoral and patellofemoral compartments and the integral functioning of the patella within the quadriceps mechanism, this warrants further research into the genetic contribution to both forms of disease. We observed no association with the COG5 SNP. The role of this variant in OA remains unknown although it has been convincingly associated with risk of knee OA. Given the strong linkage disequilibrium in the region it is not possible, genetically, to determine which of the five genes in this gene cluster is the functional one.

We note some study limitations. Our study has only tested samples from the UK; thus, our results may not generalise with respect to other ethnic groups. The association between patellofemoral grade and the MCF2L SNP is only nominally significant (p=0.027) using a linear regression approach, is not significant when severity is analysed as a binary trait, and does not stand a correction for multiple tests. Although potentially of interest, this observation needs to be validated in independent cohort studies.

On the other hand, the association between GDF5 and tibiofemoral grade remains significant after adjustment for multiple tests and, moreover, is statistically significant in the population-based cohort alone (Hertfordshire Cohort Study, p<0.006) and in the two case-control cohorts combined (p=0.028). This association remained significant when a binary definition of severity was used indicating that the lack of normality of the distribution of K/L grades was not a statistical artefact. Our data show a continuous effect between gene dosage and, presumably, the extent of joint damage detected by x-ray. In conclusion, we find that COG5 influences the extent of radiographic damage, but not the other two genes reported to affect risk of knee OA.

Contributors All authors contributed to the study design, data interpretation and the final manuscript. In addition, AMV analysed and interpreted the data and prepared the manuscript. SD, MW, NA, MD and CC evaluated the study subjects. AMV and MD finalised the manuscript. In addition, AMV analysed and interpreted the data and prepared the final manuscript. SD, MW, NA, MD and CC evaluated the study subjects. AMV and MD supervised the study.

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Competing interests RAM is an employee and owns stock of AstraZeneca plc. All other authors declare no conflict of interest.

Patient Consent Obtained.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES
Supplementary Section

Study cohorts:

**Genetics of Osteoarthritis and Lifestyle (GOAL) study.** Cases with clinically severe knee OA were recruited from hospital orthopaedic surgery TKR lists in the Nottingham area as previously described [1]. Approval for recruitment was obtained from the research ethics committees of Nottingham City Hospital and North Nottinghamshire. Anteroposterior weight bearing and skyline knee radiographs were examined to confirm the diagnosis and to grade for changes of OA and scored for individual radiographic features of OA by a single observer and graded 0-4 according to a standard atlas using the Kellgren and Lawrence (K/L) grade for each knee joint for both the tibiofemoral and patellofemoral compartments [2]. Only individuals of European descent were included in the genetic study.

**The Nottingham case-control study:** Individuals affected by knee OA were recruited in Nottingham both from families with a history of OA and from clinic populations [3,4]. Approval for recruitment of index knee OA cases was obtained from the research ethics committees of Nottingham City Hospital and North Nottinghamshire. All had been referred to the hospital with symptomatic, clinically severe knee OA and the majority had undergone unilateral or bilateral TKR within the previous 5 years. Pre-operative knee radiographs were examined to confirm the diagnosis. Grading of X-rays of the tibiofemoral and patellofemoral compartment of the index knee was undertaken by the same observer as in GOAL and was available for all subjects included. Controls were age-matched individuals from the same catchment area free from radiographic OA as for controls in the GOAL cohort. Further details on this cohort can be found in [5].
**Hertfordshire Cohort Study** (HCS) is a large population-based study. Details of the study design have been published previously [6]. Ethical approval was obtained from East and North Hertfordshire ethical committees. Men and women were recruited and attended a clinic for further investigation; a subgroup underwent knee X-rays. Both anteroposterior weight bearing and sky line X-rays were taken for both knees and a K/L grade was assigned for each compartment using an atlas [2].

**Genotyping QC**

The overall call rate was 97.3%. In control samples not affected with OA from the same three study cohorts these polymorphisms were in Hardy-Weinberg equilibrium (p>0.05) as follows:

<table>
<thead>
<tr>
<th>cohort</th>
<th>rs143383</th>
<th>rs4730250</th>
<th>rs11842874</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCS</td>
<td>0.472</td>
<td>0.2712</td>
<td>0.997</td>
</tr>
<tr>
<td>GOAL</td>
<td>0.883</td>
<td>0.6828</td>
<td>0.6201</td>
</tr>
<tr>
<td>Nottingham</td>
<td>0.298</td>
<td>0.1501</td>
<td>0.7661</td>
</tr>
</tbody>
</table>

52 samples were genotyped in duplicate for each SNP (average concordance rate was 99.4%).

**References:**


