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Mendelian randomisation implicates hyperlipidaemia as a risk factor for colorectal cancer

Short title: Hyperlipidaemia as a risk factor for colorectal cancer

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Key words

Mendelian randomisation, hyperlipidaemia, cholesterol, colorectal cancer, risk

Abbreviations

CI: confidence interval

CRC: colorectal cancer

HDL: high-density lipoprotein

IV: instrumental variables

LDL: low-density lipoprotein

MR: Mendelian randomisation

OR: odds ratios

SNP: single nucleotide polymorphisms

TC: total cholesterol

TG: triglyceride

Novelty and Impact

While observational studies have suggested an association between blood cholesterol levels and colorectal cancer (CRC), they do not establish causality and may be influenced by confounding factors. Here we use Mendelian randomisation using genetic instrumental variables to provide evidence for a causal link between blood cholesterol levels and colorectal cancer. Thus, reducing hyperlipidaemia is an important target for primary prevention of CRC in the population.

ABSTRACT

While elevated blood cholesterol has been associated with an increased risk of colorectal cancer (CRC) in observational studies, causality is uncertain. Here we apply a Mendelian randomisation (MR) analysis to examine the potential causal relationship between lipid traits and CRC risk. We used single nucleotide polymorphisms (SNPs) associated with blood levels of total cholesterol (TC), triglyceride (TG), low-density lipoprotein (LDL), and high-density lipoprotein (HDL) as instrumental variables (IV). We calculated MR estimates for each risk factor with CRC using SNP-CRC associations from 9,254 cases and 18,386 controls. Genetically predicted higher TC was associated with an elevated risk of CRC (odds ratios (OR) per unit SD increase = 1.46, 95% confidence interval [CI]: 1.20-1.79, $P=1.68 \times 10^{-4}$). The pooled ORs for LDL, HDL, and TG were 1.05 (95% CI: 0.92-1.18, $P=0.49$), 0.94 (95% CI: 0.84-1.05, $P=0.27$), and 0.98 (95% CI: 0.85-1.12, $P=0.75$) respectively. A genetic risk score for 3-hydroxy-3-methylglutaryl-coenzyme A reductase (*HMGCR*) to mimic the effects of statin therapy was associated with a reduced CRC risk (OR=0.69, 95% CI: 0.49-0.99, $P=0.046$). This study supports a causal relationship between higher levels of TC with CRC risk, and a further rationale for implementing public health strategies to reduce the prevalence of hyperlipidaemia.

INTRODUCTION

Colorectal cancer (CRC) is the third most common cancer diagnosed in economically developed countries¹. The mortality rate from CRC has been declining over the last twenty years as a consequence of improved medical care and probably through the introduction of population screening programs for the early detection of tumours²⁻⁴. Despite this improvement in patient outcome, it is still important to understand the risk factors for CRC in order to inform public health policy.

A number of factors influenced by lifestyle have been reported to be associated with the development of CRC in epidemiological observational studies, including a positive correlation with circulating levels of plasma cholesterol and other components of the lipid profile^{5, 6}. It is, however, unclear from these studies if findings reflect a causal relationship or are simply a consequence of confounding by factors common to the aetiology of both CRC and hyperlipidaemia (*e.g.* common dietary factors) or reverse causality. Because lipid levels can be modified by lifestyle and treatment with statins, deciphering the basis for the association should be informative in formulating and optimizing prevention programs for CRC.

Evidence that statin use will effect a reduction in CRC is highly controversial^{7, 8}. Although an analysis of The Health Improvement Network (THIN) database found that statin usage was associated with reduced CRC (long term usage: odds ratio [OR] = 0.95, 95% confidence interval [CI]: 0.91-0.99; short term usage: OR= 0.92, 95% CI: 0.85-0.99); no difference was shown between continued versus discontinued therapy, suggesting indication bias⁸. Moreover a recent meta-analysis of data from eight randomized controlled trials (RCTs) failed to demonstrate a beneficial effect which was statistically significant (relative risk = 0.89, 95% CI: 0.74-1.07)⁹. Each of these RCTs, however have the same limitations of short follow-up time, few CRC cases, and ascertainment of CRC as a secondary outcome.

Mendelian randomisation (MR) provides a useful complement to the traditional epidemiological study¹⁰. This strategy makes use of genetic variants that are robustly associated with traits of interest, in this case lipid traits - total cholesterol (TC), low-density lipoprotein (LDL), high-density lipoprotein (HDL), and triglyceride (TG) - as instrumental variables (IV) to infer whether

associations between exposure and disease are causal. The use of genetic variants as IV to proxy modifiable exposure therefore avoids confounding by environmental factors, can be reflective of life-long exposure (propensity), and is not be subject to reverse causality. The strength of the IV in MR is important for power, but weak instruments can also lead to inconsistent instrumental variables estimators. Hence using a genetic score derived from a combination of single nucleotide polymorphisms (SNPs), which collectively explains more of the variance in the risk factor, mitigates against weak instrument bias thereby increasing study power.

Genetics scores derived from multiple SNPs for lipid traits have been used in MR studies to investigate associations between blood lipids and coronary heart disease¹¹, and most recently prostate cancer¹². Here we have employed MR to examine the impact of lipid traits on the risk of developing CRC.

METHODS

Colorectal cancer datasets

We investigated the relationship between genetic risk scores for lipid traits and CRC risk using data from seven previously reported genome-wide association studies (GWAS) of CRC¹³ (**Table 1**). Briefly, these GWAS were all based on individuals with European ancestry and comprise: CCFR1, CCFR2, COIN, FINLAND, UK1, Scotland1 and VQ58. All studies were approved by their respective institutional review boards and conducted with appropriate ethical criteria in each country and in accordance with the Declaration of Helsinki. Comprehensive details on the cases and controls are available in previously published work¹³⁻¹⁶.

Genotyping data

Details of the genotyping and quality control of the seven CRC GWAS have been previously published¹³. Briefly, we excluded SNPs with a minor allele frequency of <1%, low call rate <95%, SNPs violating Hardy-Weinberg equilibrium, and individuals with non-European ancestry as assessed using HapMap v2 reference data¹⁷. Imputation of untyped SNP genotypes was performed using IMPUTEv2 software¹⁸ using a merged reference panel consisting of Sequencing Initiative Suomi (for the FINLAND data) or UK10K (for the remaining data) in addition to 1000 Genomes Project data. Poorly imputed SNPs (*i.e.* INFO score of <0.8) were excluded. Summary statistics from the seven GWAS were used to calculate the ORs for lipid-related SNPs.

Gene variants used to construct genetic risk scores

Genetic risk scores as IVs for circulating lipid fractions were developed from SNPs previously identified by the Global Lipids Genetics Consortium (GLGC)¹⁹. Median and range of standard deviations of lipid trait measurements in European cohorts of the Global Lipids Genetics Consortium are shown in **Supplementary Table 1**. We considered only SNPs associated at genome-wide significance (*i.e.* $P \leq 5.0 \times 10^{-8}$) and restricted to individuals with European Ancestry. To avoid co-linearity between SNPs, we excluded SNPs that were correlated (*i.e.* r^2 value ≥ 0.01), only considering the SNP with the strongest effect on the lipid trait for inclusion in genetic risk scores. Pairwise r^2 values were calculated using PLINK v1.90 utilising samples of European ancestry from the 1000 Genomes and UK10K sequencing projects (**Supplementary Data**). This resulted in 58 SNPs for HDL, 29 SNPs for LDL, 26 SNPs for TG, and 38 SNPs for TC (**Supplementary Table 2**).

Because lipid traits share common genetic variants, in addition to calculating an ‘unrestricted allele score’ that included all SNPs associated with the lipid trait, we also calculated a ‘restricted allele score’ as *per* Holmes *et al*¹¹ based on SNPs exclusively associated with HDL (n=43), LDL (n=9), or TG (n=14) to make them as specific as possible (**Supplementary Table 3**). Risk alleles were those that were positively associated with TC, LDL and TG or negatively associated with HDL levels. For all identified SNPs, we recovered the chromosome positions, the risk alleles, association estimates and standard errors.

Statistical analysis

We performed MR analysis to assess the association between TC, LDL, HDL, TG and CRC using summary statistics as described Burgess *et al.* (2015)²⁰. The combined ratio estimate ($\hat{\beta}$) of all SNPs associated with each lipid trait on CRC was calculated under a fixed-effects model:

$$\hat{\beta} = \frac{\sum_k X_k Y_k \sigma_{Y_k}^{-2}}{\sum_k X_k^2 \sigma_{Y_k}^{-2}} .$$

X_k corresponds to the association between SNP k with the lipid trait and Y_k is the association between SNP k and CRC risk with standard error σ_{Y_k} . The standard error of the combined ratio estimate is given by:

$$se(\hat{\beta}) = \sqrt{\frac{1}{\sum_k X_k^2 \sigma_{Y_k}^{-2}}} .$$

With the statistics generated by following these calculations on the seven different cohorts in the CRC data, we performed a meta-analysis under a fixed-effects model to derive the final ORs and confidence intervals.

A key assumption for this MR analysis is there is no pleiotropism (*i.e.* a gene influencing multiple traits) between the genes influencing CRC and the lipid traits under study. Therefore, before performing the MR analysis, we performed LD regression to test for global evidence of pleiotropy as *per* Bulik-Sullivan *et al.* (2015)^{21, 22}, and subsequently implemented an MR-Egger regression to examine for violation of the standard IV assumptions in our analysis²³.

For each statistical test we considered a global significance level of $P \leq 0.05$ as being satisfactory to derive conclusions. To assess the robustness of our conclusions, we imposed a conservative Bonferroni-corrected significance threshold of 0.0125 (*i.e.* 0.05/4 lipid traits). We deemed a P -

value > 0.05 as non-significant (*i.e.* no association), a P -value ≤ 0.05 as evidence for a potential causal association, and a P -value ≤ 0.0125 as significant evidence for a causal association. All statistical analyses were undertaken using R software (Version 2.14.1).

The power of a MR investigation depends greatly on the proportion of variance in the risk factor that is explained by the IV. We estimated study power using the methodology of Burgess (2014)²⁴, utilizing published estimates of the heritability of lipid trait associated IV SNPs¹⁹ and the reported effect of each trait on CRC risk in epidemiological studies⁸.

In a subsidiary analysis we constructed a genetic risk score for 3-hydroxy-3-methylglutaryl-CoA reductase (HMGCR) using rs12916, rs17238484, rs5909, rs2303152, rs10066707 and rs2006760. These specific SNPs have previously been used to mimic statin intervention to estimate a causal association of statin use and coronary heart disease and diabetes²⁵.

RESULTS

Using LD regression, we found no evidence for global pleiotropism (*i.e.* shared genetic components) between CRC and any of the lipid traits under investigation (**Table 2**). Following on from these observations we performed MR-Egger regression tests to explicitly examine for infringement of the standard instrumental variable assumptions in our MR analysis. We did not find evidence of any violation in respect to TC, LDL, HDL or TG (**Table 2, Supplementary Figure 1**). In view of the totality of these findings we were reassured of the validity of our MR-based analysis to infer whether the relation between exposures and CRC were likely to be causal.

The associations of each unrestricted allele score for respective target lipid traits are shown in **Figure 1**. A positive correlation between variants associated with higher risk levels of TC and CRC was observed. The pooled OR meta-analysis for CRC by TC, estimated in IV analysis using the allele score was 1.46 per genetically instrumented SD increase in TC (95% CI: 1.20-1.79, $P = 1.68 \times 10^{-4}$, test for heterogeneity between studies $I^2 = 6\%$, $P_{het} = 0.38$).

The strongest reported SNP association for TC levels was provided by rs10401969 (CILP2) and rs12916 (HMGCR)¹⁹. To examine if the correlation between TC and CRC risk was primarily driven by these variants, we performed a sensitivity analysis excluding rs10401969 and rs12916. Omission of these two SNPs from the MR analysis did not appreciably affect our MR findings with results remaining significant (OR = 1.69, 95% CI: 1.25-2.28, $P = 6.76 \times 10^{-4}$). Albeit not significant, there was some support for a positive association with LDL (OR = 1.05, 95% CI: 0.92-1.18, $P = 0.49$) and CRC risk, and a negative association between HDL (OR = 0.94, 95% CI: 0.84-1.05, $P = 0.27$) and CRC risk.

Following on from these analyses, we performed a MR based analysis of LDL, HDL and TG using genetic scores derived from restricted sets of SNPs. As with the unrestricted analysis, no significant causal effect for each of these lipid traits was observed (**Supplementary Figure 2**).

Finally, genetically predicted lowered TC using the HMGCR genetic risk score was associated with 43% reduction in CRC (OR=0.69, 95% CI: 0.49-0.99, $P=0.046$, $P_{het}=I^2=56\%$).

DISCUSSION

The present study strengthens a causal inference between circulating levels of TC and risk of developing CRC that is independent of known confounding effects. The positive correlation between the IV for TC and CRC risk, remained significant even after imposing a Bonferroni-correction to account for multiple testing. It is noteworthy that none of the IV SNPs for TC also represent IVs for obesity²⁶, supporting an independent relationship between TC and CRC. As illustrated here and in previously studies of obesity and CRC^{27, 28}, insulin levels and uterine cancer²⁹, and lipid levels and coronary heart disease³⁰ MR provides an attractive means of establishing causal associations. In addition to demonstrating an association between TC and CRC risk we found that genetic variants that mimic the effect of HMGCR inhibition were associated with a reduced CRC risk, supporting findings from observational epidemiological studies that statins have beneficial effect on the population burden of CRC.

Studies in mice have shown that knocking out the cell surface cholesterol-sensing receptor gene *NPC1L1*, which plays a critical role in the absorption of intestinal cholesterol, reduces CRC risk³¹. However, the biological mechanism by which cholesterol may affect CRC risk remains to be established. Cholesterol is thought to have multiple carcinogenic/cancer promoting effects at the cellular level and several mechanisms have been variously suggested, including the cholesterol-mediated activation of the NLRP3 inflammasome³². Since statins are largely retained by hepatocytes, their effect on CRC will be indirect, via HMGCR inhibition. Intriguingly, recent data suggests that any impact of statin therapy on CRC is by prevention of progression of adenomas to frank cancers rather than their development *per se*³³. Further research on the biological relationship between cholesterol and CRC is needed to address such a proposition.

A major strength of our MR analysis is that it does not suffer from the influence of recall bias and confounding that affects traditional observational studies. Nevertheless, a primary assumption in MR is that the variants used to generate genetic scores are indeed associated with the exposure being examined. To ensure this was the case, we only made use of variants associated with each lipid trait at genome-wide significance from hypothesis-free GWAS. A second assumption is that variants are associated with CRC only through the exposure and are not confounded by shared genetic (*i.e.* pleiotropy). This would be revealed as an increasing linear relationship between SNPs and their effect size for any lipid trait and CRC risk; we did not observe such a relationship.

Although it is not possible to exclude confounding by unknown confounders, the use of multiple independent variants acting through different pathways reduces the likelihood of confounded IV-associations. Moreover by using LD regression, we have been able to exclude pleiotropism on a global basis²¹. Finally, we only made use of data from individuals of European descent in the GWAS SNPs to limit potential bias from population stratification influencing study findings.

As with any MR analysis, there are potential limitations to our findings, including the limited trait variance explained by genetic variants, restricting statistical power. This is especially relevant for null findings, since wide confidence intervals leave uncertainty over the presence of a causal effect. It is estimated that the SNPs from the Global Lipids Genetics Consortium GWAS explain approximately 8-11% of the total variation in each lipid trait¹⁹. Recent analyses of observational studies found higher impact on CRC for TC than LDL or TG; respective ORs and 95% CIs – 1.49 (1.32-1.69), 1.37 (1.11-1.69), and 1.16 (1.06-1.27)⁸. Based on these data our MR study was well-powered to demonstrate a causal relation for TC ($\approx 80\%$, stipulating a *P*-value of 0.05), but we had limited power to identify associations for other lipid traits, particularly TG and HDL (respective power estimates for TG, LDL and HDL being 13%, 68% and 31%). Hence while the ORs for CRC with LDL and TG are congruous with observational studies³⁴ larger studies are required to formally establish a relationship using MR.

There are differences in the genomic landscapes of colonic and rectal cancers which presumably may reflect differences in aetiology. Unfortunately, these data were not uniformly collected across datasets, and we therefore did not investigate the possibility of differential effects of cholesterol on risk by anatomical location within the colorectum³⁵.

In conclusion, this study provides evidence for a causal role of higher TC levels in the aetiology of CRC. Hence our findings encouragingly support the overall findings of past observational studies. Our limited power to further refine the relationship between lipid profile and CRC provides a motivational for larger MR studies, which will benefit from enhanced statistical power to demonstrate relationships for the spectrum of colorectal neoplasia. Irrespective of the exact functional basis of the association between TC and CRC risk, reducing hyperlipidaemia is an important target for primary prevention of CRC in the population. Our analysis therefore supports the hypothesis that the increasing use of statins in the population for prevention of cardiovascular disease will have the added bonus of reducing the burden of CRC.

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Conflict of interest statement: None declared.

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FIGURE LEGENDS

Figure 1: Meta-analysis odds ratios (OR) for colorectal cancer per unit increase in genetic risk score (SD trait) for each lipid trait. TC: Total cholesterol, TG: Triglyceride, LDL: low density lipoprotein, HDL: high density lipoprotein; Horizontal lines: 95% Confidence Intervals (95% CI). P_{het} : P -value for heterogeneity; I^2 : proportion of the total variation due to heterogeneity. Box: OR point estimate; its area is proportional to the weight of the study. Diamond: overall summary estimate, with confidence interval given by its width. Vertical line: null value (OR = 1.0).