C reactive protein and chronic obstructive pulmonary disease: a Mendelian randomisation approach

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ABSTRACT

Background It is unclear whether elevated plasma C reactive protein (CRP) is causally related to chronic obstructive pulmonary disease (COPD). The authors tested the hypothesis that genetically elevated plasma CRP causes COPD using a Mendelian randomisation design.

Methods The authors measured high-sensitivity CRP in plasma, genotyped for four single nucleotide polymorphisms in the CRP gene, and screened for spirometry-defined COPD and hospitalisation due to COPD in 7974 individuals from the Copenhagen City Heart Study and in 32 652 individuals from the Copenhagen General Population Study.

Results Elevated plasma CRP >3 mg/l compared with <1 mg/l was associated with risk estimates of 1.8 and 2.8 for spirometry-based COPD and of 1.6 and 1.8 for hospitalisation due to COPD in the Copenhagen City Heart Study and the Copenhagen General Population Study, respectively. Genotype combinations of the four CRP polymorphisms were associated with up to a 62% increase in plasma CRP. However, these genotype combinations did not associate with increased risk of COPD or hospitalisation due to COPD in either cohort or in the two cohorts combined. On instrumental variable analysis, a doubling of plasma CRP versus a doubling of genetically elevated CRP resulted in ORs for COPD of 1.27 (95% CI 1.25 to 1.30) versus 1.01 (0.81 to 1.26) and for COPD hospitalisation of 1.47 (1.43 to 1.51) versus 0.82(0.59 to 1.13).

Conclusion Although elevated CRP is related to both a diagnosis of COPD and subsequent hospital admission, genetically elevated plasma CRP is not associated with an increased risk of clinical COPD. This suggests that the association between CRP levels and COPD is not causal.

INTRODUCTION

Chronic obstructive pulmonary disease (COPD) remains the fourth leading cause of death in the World.[1 2] The diagnosis of COPD is based on a lung function test showing obstruction of lung airflow, but the disease also comprises airway inflammation, mucociliary dysfunction, structural changes and extrapulmonary effects. New markers that describe these other components of COPD are being explored with the aim to improve the clinical assessment of COPD.[3−5]

One important inflammatory marker in COPD is elevated plasma C reactive protein (CRP). Small increases in this acute phase reactant are associated with both disease activity and future risk of hospitalisation and death from COPD.[6−16] Van Durme et al has found that CRP haplotypes do not associate with increased risk of COPD,[16] but whether CRP is causally related to COPD or solely a marker of the disease activity is not totally clear.[17] The answer to this question has clinical importance as drugs that specifically lower CRP are being developed.[18]

One approach to testing for causality between CRP and COPD would be to perform an intervention study with a CRP lowering drug. However, an alternative concept termed 'Mendelian randomisation' can also be used. This design can assess gene-related risk factors for causal association with clinical outcomes. This is because individuals inherit gene variants randomly from their parents.[19] Thus, genetic variants in the CRP gene that increase plasma concentrations of CRP are an ideal system for testing whether elevated plasma CRP is causally related to COPD.

To test whether genetically elevated plasma CRP is associated with an increased risk of COPD, we have asked the following three questions: (1) is elevated plasma CRP associated with increased risk of COPD, (2) are single nucleotide polymorphisms in the CRP gene associated with increased plasma CRP and (3) is genetically elevated plasma CRP associated with increased risk of COPD. To answer these questions, we measured high-sensitivity CRP in plasma, genotyped for single nucleotide polymorphisms in the CRP gene, screened for COPD using spirometric criteria and obtained information on hospitalisation due to COPD in 7974 individuals from the Copenhagen City Heart Study and 32 652 individuals from the Copenhagen General Population Study.[7 20]

METHODS

We studied two independent cohorts of white individuals of Danish descent. The two groups were defined so that no individual appears twice in any of the groups, thus permitting independent findings in each group. The studies were approved by Herlev Hospital and by Danish ethics committees, and were conducted according to the Declaration of Helsinki. Written informed consent was obtained from all participants.

Study cohorts

The Copenhagen City Heart Study[7 21] is a prospective study of a cohort of individuals 20 years and older randomly selected from the population of Copenhagen. Data were available from this study on COPD ($FEV_1/FVC < 0.7$ and $FEV_1 < 80\%$ of predicted, excluding individuals with self-reported asthma) and on rate of hospitalisation

due to COPD (WHO ICD8: 491—492; ICD10: J41—J44) ascertained from 1976 to 2009. From this study, 10 230 participants were included in the present analysis.

The Copenhagen General Population Study[20 22] is a cross-sectional study of individuals 20 years and older selected like those in the Copenhagen City Heart Study, from the population of Copenhagen. Data were available from this study on COPD ($FEV_1/FVC < 0.7$ and $FEV_1 < 80\%$ of predicted, excluding individuals with self-reported asthma) and on prevalence of COPD hospitalisation (WHO ICD8: 491—492; ICD10: J41—J44) ascertained from 1976 to 2009. From this study, 36 036 participants were included in the present analysis. We did not have longitudinal data with repeated examinations for the Copenhagen General Population Study and did not perform time-dependent analyses for this cohort.

Genotyping, biochemical analyses and other covariates

Blood samples were routinely collected for the two source studies. The ABI PRISM® 7900HT Sequence Detection System (Applied Biosystems Inc., Foster City, California, USA) was used to genotype for four single nucleotide polymorphisms in the CRP gene (rs3091244, rs1130864, rs1205, rs3093077).[20 23] Genotyping was verified by DNA sequencing in >30 individuals with each genotype. High-sensitivity CRP was measured using nephelometry or turbidimetry. CRP levels were classified as low (<1.0 mg/l), average (1.0—3.0 mg/l), or high (>3.0 mg/l). If subjects with CRP levels >10 mg/l were excluded from the analyses, the results were similar to those presented in this study, except for a significantly decreased OR for COPD hospitalisation among individuals with CRP genotype combination #9 when combining the two cohorts. Physical activity during leisure time was assessed by The Copenhagen City Heart Study Leisure Time Physical Activity Questionnaire.[24] Asthma medication was an affirmative answer to the question 'Do you daily take medication for asthma and/or bronchitis?'.

Statistics

We used Stata for all analyses and NCSS-PASS for power calculations. For trend tests the different groupings of subjects by CRP level, genotype or genotype combination were coded 1, 2, 3, etc, and ranked according to increasing CRP levels. From the four CRP polymorphisms we generated all possible genotype combinations and ranked the nine most common combinations according to increasing plasma CRP levels.

To examine our study hypothesis, we first analysed the relationship between plasma CRP and risk of COPD and hospitalisation due to COPD. Logistic regression estimated ORs for COPD in the Copenhagen City Heart Study and the Copenhagen General Population Study. Cox regression estimated HRs for COPD hospitalisation in the prospective Copenhagen City Heart Study,[25] and logistic regression estimated ORs for COPD hospitalisation in the Copenhagen General Population Study. The proportional hazard assumption for Cox regression was tested by visual inspection of ln(−ln[survival]) versus ln(analysis time) for all comparisons; no major violations were observed. The models were adjusted for (1) age, sex and smoking or (2) age, sex, smoking, body mass index, physical activity, asthma medication and ischaemic heart disease (ICD8: 410—414; ICD10: I20—I25); the models for hospitalisation due to COPD were also adjusted for $FEV_1\%$ predicted. Overall p values are test for trend of risk estimates (ORs or HRs) where CRP groups with increasing level of plasma CRP has been coded 1, 2 and 3.

Second, we analysed the relationship between CRP polymorphisms and polymorphism combinations and plasma CRP

in the cross-sectional Copenhagen General Population Study. Analyses were performed using Kruskal—Wallis analysis of variance. p Values are for test of trend of mean CRP levels, where CRP genotype/combination groups ranked according to increasing CRP levels have been coded 1, 2, 3 and so forth.

Third, we analysed the relationship between CRP polymorphisms and risk of COPD outcomes. Logistic regression estimated ORs for COPD in the Copenhagen City Heart Study and the Copenhagen General Population Study. Cox regression estimated HRs for COPD hospitalisation in the prospective Copenhagen City Heart Study,[25] and logistic regression estimated ORs for COPD hospitalisation in the Copenhagen General Population Study. The models were adjusted for (1) age, sex and smoking or (2) age, sex, smoking, body mass index, physical activity, asthma medications and ischaemic heart disease; the models for hospitalisation due to COPD were also adjusted for $FEV_1\%$ predicted. p Values are for test of trend of mean CRP levels, where CRP genotype/combination groups ranked according to increasing CRP levels have been coded 1, 2, 3 and so forth.

Fourth, the increase in HRs for COPD for a 1% increase in CRP levels in the Copenhagen City Heart Study was used to predict theoretical HRs for COPD for the change in CRP levels caused by the combined genotypes. Observed and theoretically predicted HRs as a function of plasma CRP levels were corrected for regression dilution bias.[26 27] Logistic regression analysis was used to calculate a combined OR for COPD and hospitalisation due to COPD as a function of genotype for both studies combined.

Finally, the estimated causal OR for COPD in the two cohorts combined was calculated according to Greenland et al[28 29] and compared with the observed OR[30]; for this purpose, we used generalised least-squares regression.

To address possible misclassification of COPD in younger and older adults from the use of the fixed FEV_1/FVC threshold, we performed a sensitivity analysis defining COPD based on the fifth percentile lower limit of normal. These analyses using the lower limit of normal definition of COPD yielded similar results to those presented in this study for COPD defined by $FEV_1/FVC < 0.7$ and $FEV_1 < 80\%$ of predicted.

RESULTS

Table 1 presents the distribution of clinical characteristics among the individuals who were free from COPD, had COPD according to spirometry or were hospitalised due to COPD in the Copenhagen City Heart Study and Copenhagen General Population Study. As would be expected, the individuals who had any COPD outcome were more likely males and smokers, were older, and had lower percentage predicted FEV_1. More than half of the patients who had spirometry-defined COPD or were hospitalised due to COPD in the Copenhagen City Heart Study did not fulfil the spirometry-based definition of COPD when they entered the study.

Plasma CRP and COPD

Plasma CRP>3 mg/l versus <1 mg/l was associated with an OR of 1.4 (95% CI 1.1 to 1.9) for COPD and HR of 2.4 (1.6 to 3.6) for hospitalisation due to COPD in the Copenhagen City Heart Study (figure 1). After multifactorial adjustment the equivalent values were 1.8 (1.4—2.3) and 1.6 (1.1—2.5), respectively. The p values for trend were <0.001 for all analyses.

Plasma CRP>3 mg/l versus <1 mg/l was associated with ORs of 1.7 (1.6 to 1.9) and 2.4 (2.1 to 2.9) for COPD and

Table 1 Characteristics of participants

	Copenhagen City Heart Study			Copenhagen General Population Study		
	No event	COPD spirometrically defined	COPD hospitalisation	No event	COPD spirometrically defined	COPD hospitalisation
Women/men	4221/3344	845/735	590/495	16890/14640	1517/1575	658/577
Age, years	42 (32—52)	49 (42—56)	50 (44—55)	57 (47—66)	67 (57—74)	68 (60—75)
Never smokers, %	28	12	5	54	29	19
Ex-smokers, %	18	12	9	29	32	41
Current smokers, %	54	76	86	17	39	40
Pack years	5.0 (0—18)	18 (8.8—30)	23 (14—34)	2.0 (0—18)	19 (2.6—40)	28 (5.7—45)
Body mass index, kg/m^2	24 (22—26)	24 (22—27)	24 (22—27)	26 (23—29)	25 (23—28)	26 (23—29)
Plasma CRP	1.6 (1.1—2.7)	1.9 (1.3—3.7)	2.4 (1.5—5.0)	1.5 (1.0—2.6)	2.0 (1.2—4.4)	2.5 (1.3—5.4)
Minimum—maximum	0.1—103	0.1—164	0.1—103	0.1—330	0.1—122	0.1—71
FEV$_1$, % predicted	94 (85—104)	78 (68—89)	80 (67—93)	92 (83—101)	65 (55—73)	62 (48—79)
FVC, % predicted	93 (84—104)	88 (77—97)	85 (75—97)	93 (84—102)	80 (70—89)	75 (62—88)
FEV$_1$/FVC	0.83 (0.78—0.87)	0.74 (0.67—0.81)	0.76 (0.70—0.83)	0.79 (0.75—0.83)	0.64 (0.58—0.67)	0.66 (0.56—0.74)

Values are median (IQR) or percentage. Values for the Copenhagen City Heart Study are pre-outcome values taken prior to the development of COPD. COPD spirometrically defined=FEV$_1$/FVC<0.7 and FEV$_1$<80% of predicted, excluding asthmatics. COPD hospitalisation=ICD8:491—492; ICD10:J41—J44. We used the Copenhagen City Heart Study to test question 1 (CRP level is associated with COPD risk) and question 3 (CRP genotype is associated with COPD risk), and the Copenhagen General Population Study to test question 2 (CRP genotype is associated with CRP level) and retest question 3.

hospitalisation due to COPD in the Copenhagen General Population Study (figure 1). After multifactorial adjustment the equivalent values were 2.8 (2.4 to 3.1) and 1.8 (1.4 to 2.3). The p values for trend were <0.001 for all analyses. The CRP results for COPD hospitalisation in the Copenhagen City Heart Study describe pre-outcome CRP levels, while the Copenhagen General Population Study describes simultaneous or post-outcome levels. The association between CRP levels and risk of COPD, stratified for smoking status, is shown in Supplementary figure 1.

CRP polymorphisms and plasma CRP
In line with our previous results[20] the CRP polymorphism rs1205 AA genotype was associated with decreased plasma CRP levels of 24% compared with the GG genotype (figure 2, Trend p<0.001). The rs1130864 TT genotype versus CC genotype was associated with a 25% increase in plasma CRP level, rs3091244

AA genotype versus CC genotype with a 71% increase, and rs3093077 GG genotype versus TT genotype with a 55% increase (all Trend p<0.001). Combining the genotypes resulted in up to 62% increase in plasma CRP levels between the highest and lowest levels among the nine most common genotype combinations (figure 2). Partial r^2 values for the different CRP polymorphisms ranged from 0.4% to 1.8%.

CRP polymorphisms and COPD
The ORs for COPD as a function of genotype in the Copenhagen City Heart Study and the Copenhagen General Population Study did not differ from 1.0 for any of the individual CRP polymorphisms, or for genotype combinations (p for trend 0.24—0.80; figure 3A). Similarly, the HR for COPD hospitalisation in the Copenhagen City Heart Study and the OR for COPD hospitalisation in the Copenhagen General Population

Figure 1 Risk of chronic obstructive pulmonary disease (COPD) according to plasma levels of C reactive protein (CRP). High-sensitivity CRP level was measured in 8974 individuals participating in the 1991—1994 examination of the Copenhagen City Heart Study and subsequently correlated with spirometry-defined COPD or followed with respect to hospitalisation due to COPD. High-sensitivity CRP level was also measured in 32 652 individuals participating in the Copenhagen General Population Study and subsequently correlated with COPD and hospitalisation due to COPD. Multiple adjustment was for age, sex, smoking, body mass index, physical activity, asthma medication and ischaemic heart disease; models for hospitalisation due to COPD were also adjusted for FEV$_1$% predicted. Overall p values are test for trend of risk estimates (ORs or HRs), where CRP groups with increasing level of plasma CRP have been coded 1, 2 and 3.
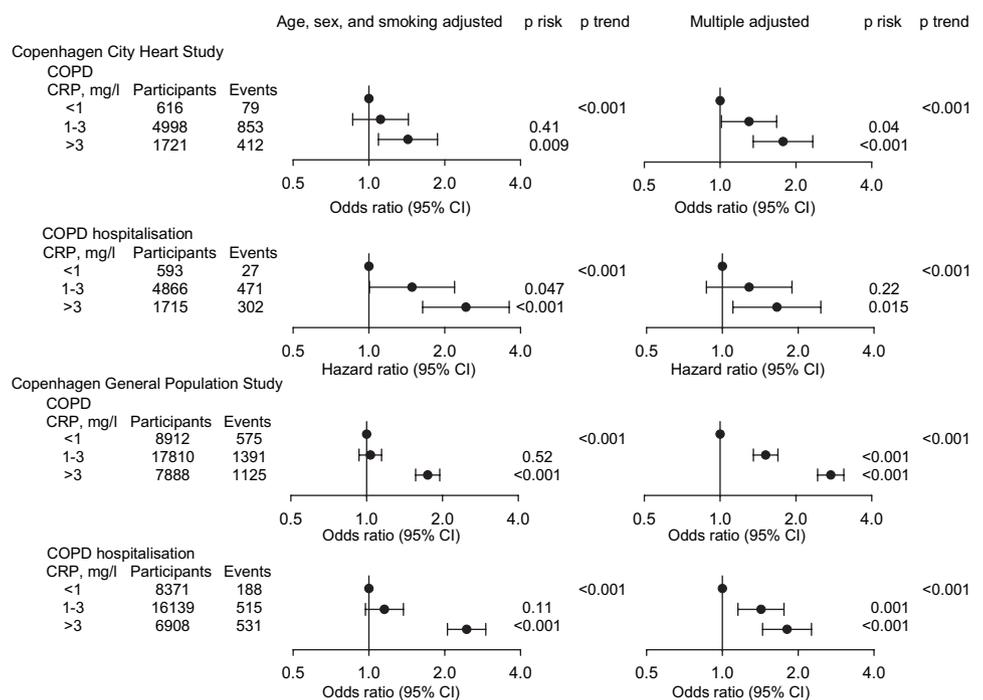
Figure 2 Plasma levels of C reactive protein (CRP) according to CRP genotype and genotype combinations in the Copenhagen General Population Study. High-sensitivity CRP levels and CRP genotyping was determined in 36 036 individuals. Partial r^2 values were after adjustment for variation in plasma CRP levels due to age, gender, smoking and body mass index. p Values are for Cuzick non-parametric test for trend of mean CRP levels, where CRP genotype/combination groups ranked according to increasing CRP levels have been coded 1, 2, 3 and so forth.
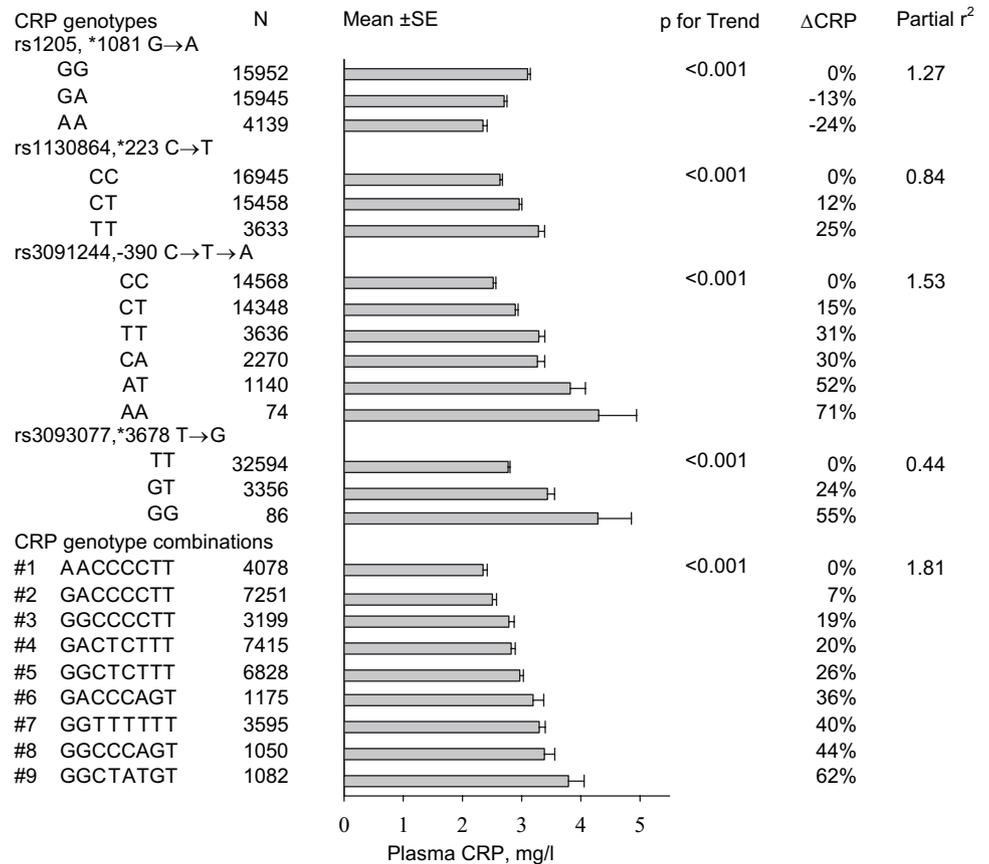
Study did not differ consistently from 1.0 for any of the individual CRP polymorphisms, or for genotype combinations (p for trend 0.12–0.78; figure 3B).

When analysing the annual decline in FEV_1 among individuals with COPD in the Copenhagen City Heart Study, there was no significant difference for any of the individual CRP polymorphisms, or for genotype combinations (p for trend 0.19 to 0.65; figure 4). Partial r^2 values for the different CRP polymorphisms ranged from 0.09% to 0.81%.

Predicted versus observed risk of COPD

We assumed that genetically elevated plasma CRP levels confer the same OR for COPD as that observed for plasma CRP levels in the general population. Based on this assumption, increments in plasma CRP levels of up to 62% as a function of CRP genotype combinations theoretically predicted ORs of up to 1.16 (1.09 to 1.23) for COPD and 1.35 (1.28 to 1.42) for hospitalisation due to COPD (figure 5). However, when COPD events and controls from all studies shown in figure 3 were combined to achieve the maximal statistical power, the observed ORs for COPD and hospitalisation due to COPD as a function of genotype combinations did not differ from 1.0 (figure 5). Genotype combinations #7–9 versus #1 resulted in an increase in plasma CRP of 45% and thus theoretically predicted an OR of 1.11 (1.07 to 1.16) for COPD and 1.25 (1.20 to 1.29) for hospitalisation due to COPD (figure 5). However, the observed ORs for COPD and hospitalisation due to COPD for genotype combinations #7–9 versus #1 were 1.05 (0.93 to 1.19) and 0.92 (0.77 to 1.10), respectively. Combining all individuals with COPD or hospitalisation due to COPD from the two studies, the #7–9 versus #1 genotype combinations had 80% power to detect ORs of 1.16 for spirometrically defined COPD and 1.22 for hospitalisation due to COPD (figure 5).

On instrumental variable analysis a doubling of plasma CRP resulted in an OR of 1.27 (1.25 to 1.30) for COPD, while a doubling of genetically elevated CRP resulted in an OR of 1.01 (0.81 to 1.26) for COPD (p=0.04 for the comparison between the two ORs). Corresponding ORs for COPD hospitalisation were 1.47 (1.43 to 1.51) and 0.82 (0.59 to 1.13) (p=0.001).

DISCUSSION

To examine whether genetically elevated plasma CRP is causally related to COPD, this study has measured high-sensitivity CRP in plasma, genotyped for variants in the CRP gene, and screened for COPD in 40 626 individuals from two ethnically homogenous Danish populations. Three salient findings are provided by the study: (1) plasma CRP above 3 mg/l is associated with increased risk for clinical COPD, (2) variants in the CRP gene are associated with elevated levels of plasma CRP and (3) analysing this data using a Mendelian randomisation design, we find that genetically elevated plasma CRP is not associated with risk of clinical COPD. This suggests that elevated plasma CRP is not causally related to COPD, but more likely serves as a marker of disease severity in COPD.

Consistent with our results van Durme et al have found that three tagging polymorphisms in the CRP gene (1184, 2042, 2911) are not associated with altered risk of COPD.[16] In contrast to this, Sunyer et al found that the rs1205 polymorphism in the CRP gene and two haplotypes tagged by the rs1205 and rs1800947 polymorphisms were associated with better lung function.[31] It is uncertain whether the two previous studies had enough genetic CRP range and study size to examine for causality between CRP and features of COPD. On instrumental variable analysis we now find that a doubling of plasma CRP resulted in an elevated risk for COPD outcomes, while
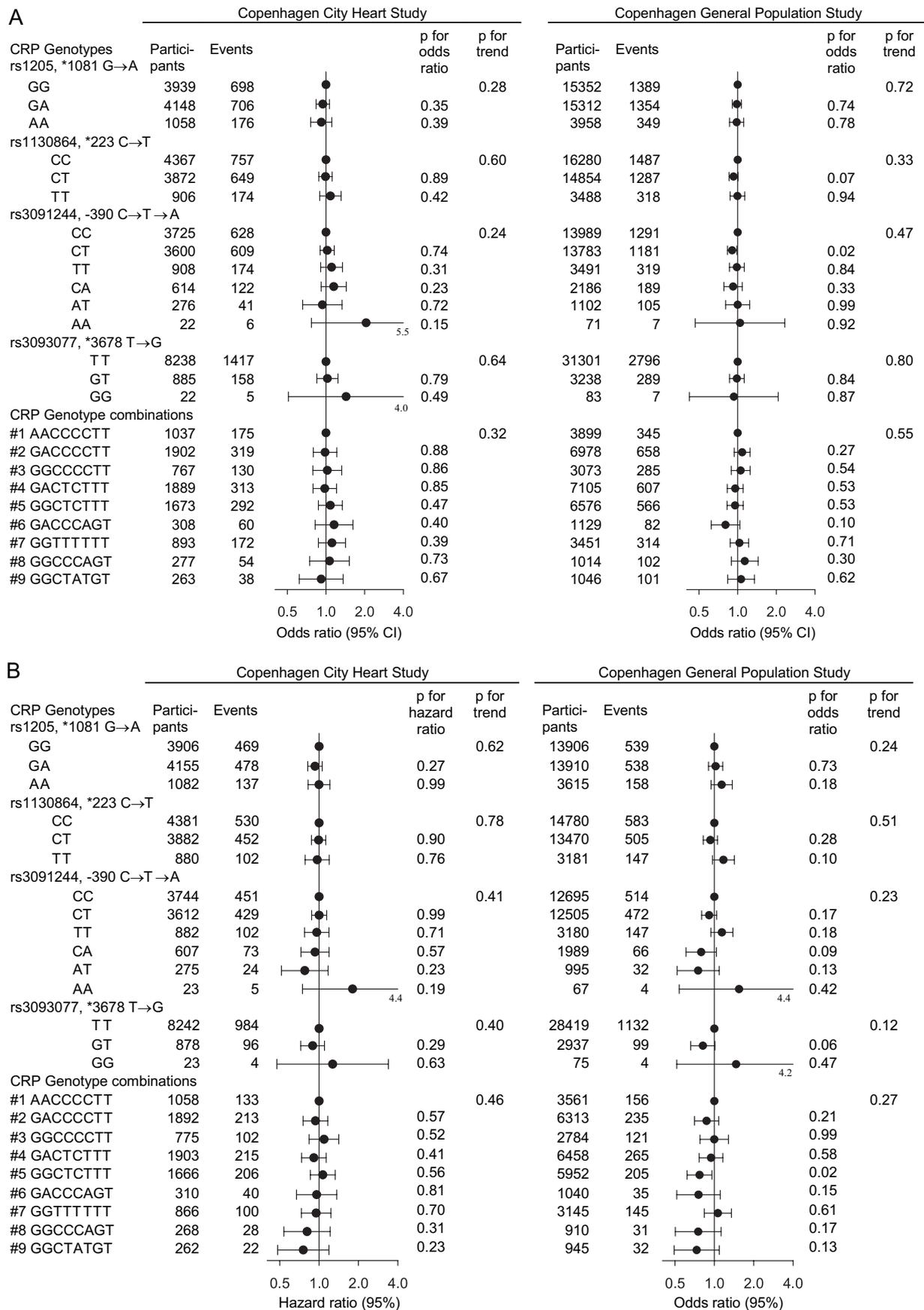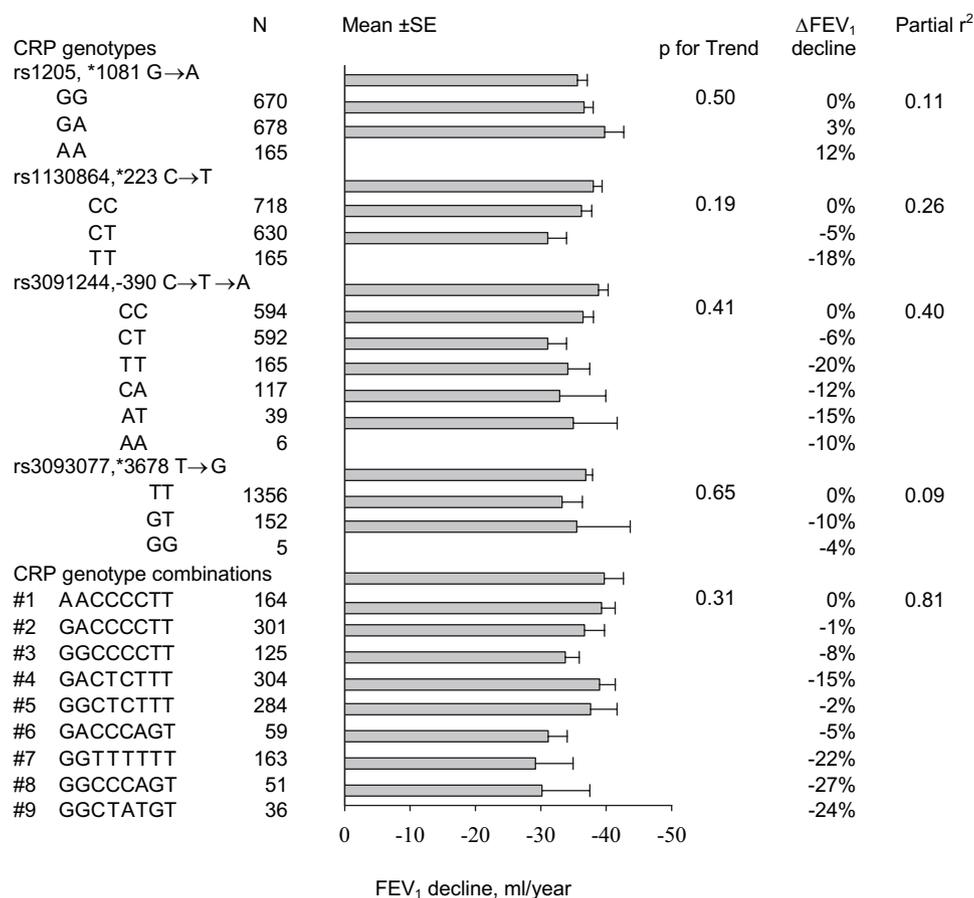
A

	Copenhagen City Heart Study						Copenhagen General Population Study					
CRP Genotypes	Partici-pants	Events		p for odds ratio	p for trend		Partici-pants	Events		p for odds ratio	p for trend	
rs1205, *1081 G→A												
GG	3939	698			0.28		15352	1389			0.72	
GA	4148	706		0.35			15312	1354		0.74		
AA	1058	176		0.39			3958	349		0.78		
rs1130864, *223 C→T												
CC	4367	757			0.60		16280	1487			0.33	
CT	3872	649		0.89			14854	1287		0.07		
TT	906	174		0.42			3488	318		0.94		
rs3091244, -390 C→T→A												
CC	3725	628			0.24		13989	1291			0.47	
CT	3600	609		0.74			13783	1181		0.02		
TT	908	174		0.31			3491	319		0.84		
CA	614	122		0.23			2186	189		0.33		
AT	276	41		0.72			1102	105		0.99		
AA	22	6	5.5	0.15			71	7		0.92		
rs3093077, *3678 T→G												
T T	8238	1417			0.64		31301	2796			0.80	
GT	885	158		0.79			3238	289		0.84		
GG	22	5	4.0	0.49			83	7		0.87		
CRP Genotype combinations												
#1 AACCCCTT	1037	175			0.32		3899	345			0.55	
#2 GACCCCTT	1902	319		0.88			6978	658		0.27		
#3 GGCCCCTT	767	130		0.86			3073	285		0.54		
#4 GACTCTTT	1889	313		0.85			7105	607		0.53		
#5 GGCTCTTT	1673	292		0.47			6576	566		0.53		
#6 GACCCAGT	308	60		0.40			1129	82		0.10		
#7 GGTTTTTT	893	172		0.39			3451	314		0.71		
#8 GGCCCAGT	277	54		0.73			1014	102		0.30		
#9 GGCTATGT	263	38		0.67			1046	101		0.62		

Odds ratio (95% CI): 0.5 1.0 2.0 4.0

B

	Copenhagen City Heart Study						Copenhagen General Population Study					
CRP Genotypes	Partici-pants	Events		p for hazard ratio	p for trend		Partici-pants	Events		p for odds ratio	p for trend	
rs1205, *1081 G→A												
GG	3906	469			0.62		13906	539			0.24	
GA	4155	478		0.27			13910	538		0.73		
AA	1082	137		0.99			3615	158		0.18		
rs1130864, *223 C→T												
CC	4381	530			0.78		14780	583			0.51	
CT	3882	452		0.90			13470	505		0.28		
TT	880	102		0.76			3181	147		0.10		
rs3091244, -390 C→T→A												
CC	3744	451			0.41		12695	514			0.23	
CT	3612	429		0.99			12505	472		0.17		
TT	882	102		0.71			3180	147		0.18		
CA	607	73		0.57			1989	66		0.09		
AT	275	24		0.23			995	32		0.13		
AA	23	5	4.4	0.19			67	4	4.4	0.42		
rs3093077, *3678 T→G												
T T	8242	984			0.40		28419	1132			0.12	
GT	878	96		0.29			2937	99		0.06		
GG	23	4		0.63			75	4	4.2	0.47		
CRP Genotype combinations												
#1 AACCCCTT	1058	133			0.46		3561	156			0.27	
#2 GACCCCTT	1892	213		0.57			6313	235		0.21		
#3 GGCCCCTT	775	102		0.52			2784	121		0.99		
#4 GACTCTTT	1903	215		0.41			6458	265		0.58		
#5 GGCTCTTT	1666	206		0.56			5952	205		0.02		
#6 GACCCAGT	310	40		0.81			1040	35		0.15		
#7 GGTTTTTT	866	100		0.70			3145	145		0.61		
#8 GGCCCAGT	268	28		0.31			910	31		0.17		
#9 GGCTATGT	262	22		0.23			945	32		0.13		

Hazard ratio (95%): 0.5 1.0 2.0 4.0
Odds ratio (95%): 0.5 1.0 2.0 4.0

Figure 3 (A, B) Risk of chronic obstructive pulmonary disease (COPD) according to C reactive protein (CRP) genotype and genotype combinations. The ORs and HRs were adjusted for age, sex and smoking. After multiple adjustment for age, sex, smoking, body mass index, physical activity, asthma medication, ischaemic heart disease and/or FEV_1% predicted, the risk estimates were similar to those presented. Overall p values are test for trend of risk estimates (ORs or HRs), where CRP genotype/combination groups ranked according to increasing CRP levels have been coded 1, 2, 3 and so forth.

Figure 4 Annual FEV$_1$ decline according to C reactive protein (CRP) genotype and genotype combinations among individuals with spirometry-defined chronic obstructive pulmonary disease in the Copenhagen City Heart Study. Annual FEV$_1$ decline and CRP genotyping was determined in 1513 individuals with COPD. Partial r^2 values were after adjustment for variation in annual FEV$_1$ decline due to age, gender, smoking and body mass index. p Values are for Cuzick non-parametric test for trend of mean FEV$_1$ decline, where CRP genotype/combination groups ranked according to increasing CRP levels have been coded 1, 2, 3 and so forth.

CRP genotypes	N	Mean ±SE	p for Trend	ΔFEV$_1$ decline	Partial r^2
rs1205, *1081 G→A					
GG	670		0.50	0%	0.11
GA	678			3%	
AA	165			12%	
rs1130864,*223 C→T					
CC	718		0.19	0%	0.26
CT	630			-5%	
TT	165			-18%	
rs3091244,-390 C→T →A					
CC	594		0.41	0%	0.40
CT	592			-6%	
TT	165			-20%	
CA	117			-12%	
AT	39			-15%	
AA	6			-10%	
rs3093077,*3678 T→G					
TT	1356		0.65	0%	0.09
GT	152			-10%	
GG	5			-4%	
CRP genotype combinations					
#1 AACCCCTT	164		0.31	0%	0.81
#2 GACCCCTT	301			-1%	
#3 GGCCCCTT	125			-8%	
#4 GACTCTTT	304			-15%	
#5 GGCTCTTT	284			-2%	
#6 GACCCAGT	59			-5%	
#7 GGTTTTTT	163			-22%	
#8 GGCCCAGT	51			-27%	
#9 GGCTATGT	36			-24%	

FEV$_1$ decline, ml/year

a doubling of genetically elevated plasma CRP had no relation to COPD. This strongly suggests that the association between CRP levels and COPD is reverse causal or confounded by a third factor like inflammation in general.

Our results do not preclude clinical use for plasma CRP in the assessment of COPD. Plasma CRP may be a marker of prognosis in COPD as small increases are associated with a poor COPD prognosis in the present study and other studies.[7] [12] Plasma CRP may also be a marker of the efficacy of COPD therapy. Anti-inflammatory treatments that are beneficial towards COPD are linked with reduction in plasma CRP level in some[14] [32] [33] but not all studies.[34] It is possible that elevated plasma CRP in combination with other risk markers of lung disease can be used to categorise individuals with low, medium and high risk of future COPD or be used after further validation to guide the efficacy of therapy in COPD.[32] [33]

The cause for the increased level of plasma CRP in COPD patients is not totally clear. One hypothesis suggests that plasma CRP is raised as a result of IL-6 production from the inflamed lungs in COPD. Cigarette smoking is the most commonly encountered risk factor for COPD and contributes to both lung inflammation and elevated CRP in COPD patients. Asthma, passive smoking, inhalation of outdoor and indoor air pollutants, obesity and physical inactivity could also cause lung inflammation and raise plasma CRP levels, and this could be particularly relevant among non-smoking COPD patients.

The potential limitations of the study also need to be considered. Mendelian randomisation can be used for the study of causation between modifiable exposures and disease, provided the following six criteria are fulfilled.[35]

1. The presence of suitable genetic variants for the study of the modifiable exposure of interest: the CRP variant rs3091244 modulates transcription factor binding to the CRP gene and is the single most important polymorphism influencing CRP levels, while the CRP variants rs1130864, rs1205 and rs3093077 can be used as tag single nucleotide polymorphisms together describing most of the variation in plasma CRP levels.[20]

2. Reliable genotype-intermediate-phenotype and genotype-disease associations can be established: we showed that the four CRP polymorphisms are associated with elevated plasma CRP levels, but not with risk of COPD in two independent studies analysing data from up to 44 359 individuals.

3. There is no confounding of these relationships: linkage disequilibrium could not be detected between the four CRP polymorphisms used in our study and other known nearby genes potentially influencing plasma CRP and/or risk of COPD.[20]

4. There are no pleiotropic effects of the genetic variants of interest: we are not aware of any known association of the four CRP polymorphisms with a phenotype besides changes in CRP level that could influence the risk of COPD.

5. There is no compensation by other genes during development (canalisation)[35] [36]: canalisation and compensation by other genes during development are generally difficult to assess; however, we are not aware of any such potential effects.

6. Population admixture that differs between cases and controls: we studied two large and ethnically homogenous populations of Danish descent, and effectively can exclude admixture.

Hence, classical limitations of the Mendelian randomisation do not appear to be of major importance in the present study.

A large percentage of CRP variability depends on other non-genetic factors, and this could limit the Mendelian randomisation approach. Genetically determined CRP concentrations
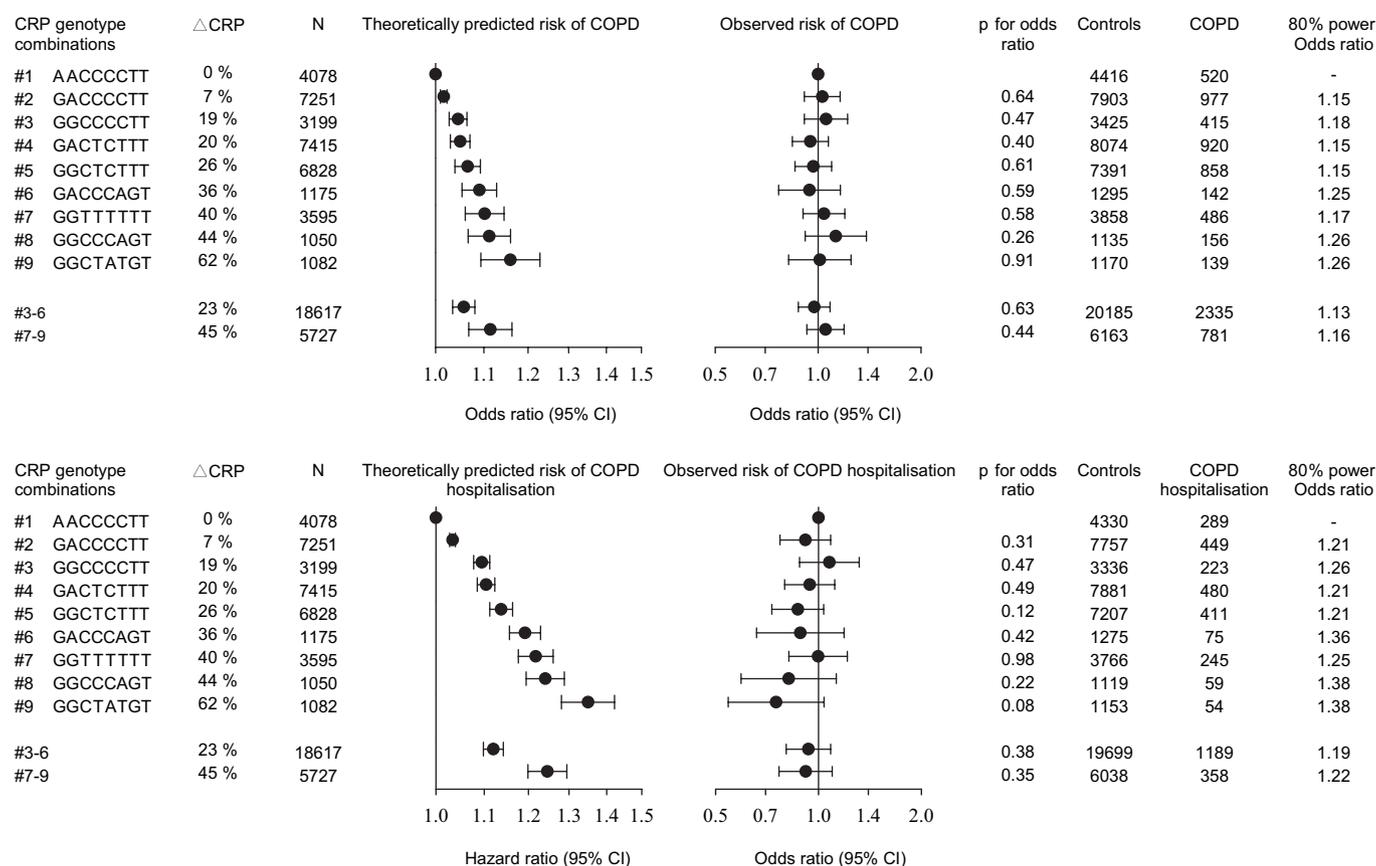
CRP genotype combinations	△CRP	N	Theoretically predicted risk of COPD	Observed risk of COPD	p for odds ratio	Controls	COPD	80% power Odds ratio
#1 AACCCCTT	0 %	4078				4416	520	-
#2 GACCCCTT	7 %	7251			0.64	7903	977	1.15
#3 GGCCCCTT	19 %	3199			0.47	3425	415	1.18
#4 GACTCTTT	20 %	7415			0.40	8074	920	1.15
#5 GGCTCTTT	26 %	6828			0.61	7391	858	1.15
#6 GACCCAGT	36 %	1175			0.59	1295	142	1.25
#7 GGTTTTTT	40 %	3595			0.58	3858	486	1.17
#8 GGCCCAGT	44 %	1050			0.26	1135	156	1.26
#9 GGCTATGT	62 %	1082			0.91	1170	139	1.26
#3-6	23 %	18617			0.63	20185	2335	1.13
#7-9	45 %	5727			0.44	6163	781	1.16

Odds ratio (95% CI): 1.0 1.1 1.2 1.3 1.4 1.5 — 0.5 0.7 1.0 1.4 2.0

CRP genotype combinations	△CRP	N	Theoretically predicted risk of COPD hospitalisation	Observed risk of COPD hospitalisation	p for odds ratio	Controls	COPD hospitalisation	80% power Odds ratio
#1 AACCCCTT	0 %	4078				4330	289	-
#2 GACCCCTT	7 %	7251			0.31	7757	449	1.21
#3 GGCCCCTT	19 %	3199			0.47	3336	223	1.26
#4 GACTCTTT	20 %	7415			0.49	7881	480	1.21
#5 GGCTCTTT	26 %	6828			0.12	7207	411	1.21
#6 GACCCAGT	36 %	1175			0.42	1275	75	1.36
#7 GGTTTTTT	40 %	3595			0.98	3766	245	1.25
#8 GGCCCAGT	44 %	1050			0.22	1119	59	1.38
#9 GGCTATGT	62 %	1082			0.08	1153	54	1.38
#3-6	23 %	18617			0.38	19699	1189	1.19
#7-9	45 %	5727			0.35	6038	358	1.22

Hazard ratio (95% CI): 1.0 1.1 1.2 1.3 1.4 1.5 — Odds ratio (95% CI): 0.5 0.7 1.0 1.4 2.0

Figure 5 Predicted versus observed risk of chronic obstructive pulmonary disease (COPD) as a function of C reactive protein (CRP) genotype combination. The OR used for calculating the theoretically predicted risk of COPD was adjusted for age, sex, and smoking status. The ORs for the observed risk of COPD were adjusted for age, sex and smoking status. In order to achieve maximal statistical power, we combined all individuals with the nine most common CRP genotype combinations from the Copenhagen City Heart Study and the Copenhagen General Population Study (4613 COPD cases vs 38 667 controls and 2285 individuals hospitalised due to COPD vs 37 824 controls). The right column shows the OR at one-sided p<0.05 that can be detected in these combined studies at 80% statistical power.

varied less than plasma CRP levels. It could be that plasma CRP causes COPD or protects from the disease at CRP levels beyond those determined by the CRP genotype data. However, there is a linear relationship between levels of CRP and risk of COPD in this study and there was sufficient statistical power to exclude a causal association between plasma CRP and COPD even within the limited plasma CRP range determined by the genotype data (figures 3 and 5). CRP is an acute phase reactant and was only measured once in our two cohorts. However, the results of the two studies were similar and when analysing only those subjects with CRP<10 mg/l the results were similar to those presented in this study.

We used both cross-sectional and prospective study designs to confirm our data in two independent cohorts and to achieve maximal statistical power for assessing a causal relationship between CRP and COPD. Since an established COPD implies the development of systemic inflammation, a cross-sectional study design does not seem to be the best option to explore causality using conventional epidemiology. On the contrary, the prospective study offers an excellent design to explore the relationship between CRP levels and incident COPD cases and hospitalisations. Therefore, even though the results obtained from both studies are similar, the results from the prospective study are the most important in this manuscript for the association between common CRP levels and COPD; for genetically derived CRP levels, the cross-sectional study is valid indeed, because the effect of the CRP single nucleotide polymorphisms on plasma CRP

levels is lifelong. The phenotype of COPD differs by the two definitions used in our study; however, the results for the two definitions were also similar. We studied only Caucasian people and our results may not necessarily apply to other ethnic groups.

In conclusion, we find that lifelong genetically elevated CRP is not associated with risk of having COPD. This suggests that the association between CRP levels and COPD is not causal. The finding is similar to those from studies in cardiovascular disease where elevated CRP is associated with cardiovascular disease, but genetic variants of CRP were not associated with disease risk.[20 37] Thus, our finding is not exclusive to COPD. It may be that for all chronic diseases associated with chronic inflammation, it is not the chronic inflammation with CRP elevation that causes disease but that the disease is driving chronic inflammation and CRP elevation.

REFERENCES

1. **Mannino DM,** Buist AS. Global burden of COPD: risk factors, prevalence, and future trends. *Lancet* 2007;**370**:765—73.
2. **Mathers CD,** Loncar D. Projections of global mortality and burden of disease from 2002 to 2030. *PLoS Med* 2006;**3**:e442.
3. **Cazzola M,** MacNee W, Martinez FJ, et al. Outcomes for COPD pharmacological trials: from lung function to biomarkers. *Eur Respir J* 2008;**31**:416—69.
4. **Dahl M,** Nordestgaard BG. Markers of early disease and prognosis in COPD. *Int J Chron Obstruct Pulmon Dis* 2009;**4**:157—67.
5. **Vestbo J,** Anderson W, Coxson HO, et al. Evaluation of COPD longitudinally to identify predictive surrogate end-points (ECLIPSE). *Eur Respir J* 2008;**31**:869—73.
6. **Aronson D,** Roterman I, Yigla M, et al. Inverse association between pulmonary function and C-reactive protein in apparently healthy subjects. *Am J Respir Crit Care Med* 2006;**174**:626—32.
7. **Dahl M,** Vestbo J, Lange P, et al. C-reactive protein as a predictor of prognosis in chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 2007;**175**:250—5.
8. **de Torres JP,** Cordoba-Lanus E, Lopez-Aguilar C, et al. C-reactive protein levels and clinically important predictive outcomes in stable COPD patients. *Eur Respir J* 2006;**27**:902—7.
9. **Gan WQ,** Man SF, Senthilselvan A, et al. Association between chronic obstructive pulmonary disease and systemic inflammation: a systematic review and a meta-analysis. *Thorax* 2004;**59**:574—80.
10. **Hancox RJ,** Poulton R, Greene JM, et al. Systemic inflammation and lung function in young adults. *Thorax* 2007;**62**:1064—8.
11. **Karadag F,** Kirdar S, Karul AB, et al. The value of C-reactive protein as a marker of systemic inflammation in stable chronic obstructive pulmonary disease. *Eur J Intern Med* 2008;**19**:104—8.
12. **Man SF,** Connett JE, Anthonisen NR, et al. C-reactive protein and mortality in mild to moderate chronic obstructive pulmonary disease. *Thorax* 2006;**61**:849—53.
13. **Olafsdottir IS,** Gislason T, Thjodleifsson B, et al. Gender differences in the association between C-reactive protein, lung function impairment, and COPD. *Int J Chron Obstruct Pulmon Dis* 2007;**2**:635—42.
14. **Pinto-Plata VM,** Mullerova H, Toso JF, et al. C-reactive protein in patients with COPD, control smokers and non-smokers. *Thorax* 2006;**61**:23—8.
15. **Shaaban R,** Kony S, Driss F, et al. Change in C-reactive protein levels and FEV1 decline: a longitudinal population-based study. *Respir Med* 2006;**100**:2112—20.
16. **van Durme YM,** Verhamme KM, Aarnoudse AJ, et al. C-reactive protein levels, haplotypes, and the risk of incident chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 2009;**179**:375—82.
17. **Vestbo J.** Systemic inflammation and progression of COPD. *Thorax* 2007;**62**:469—70.
18. **Lowe GD,** Pepys MB. C-reactive protein and cardiovascular disease: weighing the evidence. *Curr Atheroscler Rep* 2006;**8**:421—8.
19. **Smith GD,** Lawlor DA, Harbord R, et al. Clustered environments and randomized genes: a fundamental distinction between conventional and genetic epidemiology. *PLoS Med* 2007;**4**:e352.
20. **Zacho J,** Tybjaerg-Hansen A, Jensen JS, et al. Genetically elevated C-reactive protein and ischemic vascular disease. *N Engl J Med* 2008;**359**:1897—908.
21. **Schnohr P,** Jensen G, Lange P, et al. The Copenhagen City Heart Study. Østerbroundersøgelsen. Tables with data from the third examination 1991—1994. *Eur Heart J* 2001;**3**(Suppl H):H1—83.
22. **Dahl M,** Bowler RP, Juul K, et al. Superoxide dismutase 3 polymorphism associated with reduced lung function in two large populations. *Am J Respir Crit Care Med* 2008;**178**:906—12.
23. **Miller DT,** Zee RY, Suk DJ, et al. Association of common CRP gene variants with CRP levels and cardiovascular events. *Ann Hum Genet* 2005;**69**:623—38.
24. **Lee J,** Nordestgaard BG, Dahl M. Elevated ACE activity is not associated with asthma, COPD, and COPD co-morbidity. *Respir Med* 2009;**103**:1286—92.
25. **Klein J,** Moeschberger ML. *Refinements of the Semiparametric Proportional Hazards Model. Survival Analysis. Techniques for Censored and Truncated Data.* New York, USA: Springer-Verlag, Inc, 2003:295—325.
26. **Clarke R,** Shipley M, Lewington S, et al. Underestimation of risk associations due to regression dilution in long-term follow-up of prospective studies. *Am J Epidemiol* 1999;**150**:341—53.
27. **MacMahon S,** Peto R, Cutler J, et al. Blood pressure, stroke, and coronary heart disease. Part 1, Prolonged differences in blood pressure: prospective observational studies corrected for the regression dilution bias. *Lancet* 1990;**335**:765—74.
28. **Greenland S,** Longnecker MP. Methods for trend estimation from summarized dose-response data, with applications to meta-analysis. *Am J Epidemiol* 1992;**135**:1301—9.
29. **Harbord RM,** Lawlor DA, Smith GD. Genetically elevated C-reactive protein and vascular disease. *N Engl J Med* 2009;**360**:933—5.
30. **Altman DG.** Bland JM. Interaction revisited: the difference between two estimates. *BMJ* 2003;**326**:219.
31. **Sunyer J,** Pistelli R, Plana E, et al. Systemic inflammation, genetic susceptibility and lung function. *Eur Respir J* 2008;**32**:92—7.
32. **Lee TM,** Lin MS, Chang NC. Usefulness of C-reactive protein and interleukin-6 as predictors of outcomes in patients with chronic obstructive pulmonary disease receiving pravastatin. *Am J Cardiol* 2008;**101**:530—5.
33. **Sin DD,** Lacy P, York E, et al. Effects of fluticasone on systemic markers of inflammation in chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 2004;**170**:760—5.
34. **Sin DD,** Man SF, Marciniuk DD, et al. The effects of fluticasone with or without salmeterol on systemic biomarkers of inflammation in chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 2008;**177**:1207—14.
35. **Davey SG,** Ebrahim S. 'Mendelian randomization': can genetic epidemiology contribute to understanding environmental determinants of disease? *Int J Epidemiol* 2003;**32**:1—22.
36. **Nitsch D,** Molokhia M, Smeeth L, et al. Limits to causal inference based on Mendelian randomization: a comparison with randomized controlled trials. *Am J Epidemiol* 2006;**163**:397—403.
37. **Elliott P,** Chambers JC, Zhang W, et al. Genetic Loci associated with C-reactive protein levels and risk of coronary heart disease. *JAMA* 2009;**302**:37—48.

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