Association between chronic obstructive pulmonary disease and systemic inflammation: a systematic review and a meta-analysis

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METHODS

Search for relevant studies

Using MEDLINE (1966–2003), EMBASE, CINAHL (1982–2003), and the Cochrane databases we conducted a systematic literature search to identify relevant studies published before 1 November 2003 which evaluated the potential relationship between stable COPD and various markers of systemic inflammation. Disease-specific search terms (COPD, bronchitis, emphysema, forced expiratory volume, or vital capacity) were combined with inflammatory marker-specific search terms (systemic inflammation, biological markers, C-reactive protein, fibrinogen, leucocyte, interleukin, interleukin-8, interleukin-6, or tumour necrosis factor-α) in all our searches. The electronic searches were supplemented by scanning the reference lists from retrieved articles to identify additional studies that may have been missed during the initial search. We also contacted the primary authors for additional data and/or clarification of data, when necessary, to ensure that all relevant articles were represented in the meta-analysis. It was decided a priori to include only those studies in which stable patients (or individuals) were studied. All acute exacerbation studies were therefore discarded, as were those that did not have a suitable comparator group.

Study selection and data abstraction

The primary outcome of this systematic review was to compare serum CRP, fibrinogen, leucocyte, tumour necrosis factor (TNF)-α, interleukin 6 (IL-6), and interleukin 8 (IL-8) levels between study participants with and without stable COPD. From each relevant article two investigators (WQG, DDS) abstracted the following information: source of the data, study design, baseline characteristics of study participants including age, predicted forced expiratory volume in 1 second (FEV₁), and smoking status. We also evaluated the laboratory methods used to determine the levels of systemic inflammatory markers. Any questions or discrepancies regarding these data were resolved through iteration and consensus

Abbreviations: COPD, chronic obstructive pulmonary disease; CRP, C-reactive protein; FEV₁, forced expiratory volume in 1 second; IL, interleukin; TNF-α, tumour necrosis factor-α
COPD and systemic inflammation was observed \( p < 0.05 \). Studies using a Cochran Q test. If significant heterogeneity of outcomes we tested the heterogeneity of results across the studies. fibrinogen, and other inflammatory cytokines. For each gene, a fixed effects model was used. As a sensitivity analysis we also pooled the data together using a weighted mean difference technique. The heterogeneity in results across the studies using a Cochran Q test. If significant heterogeneity was observed \( p < 0.10 \), a random effects model—which assigns a weight to each study based on individual study variance as well as between study variance—was used to pool the results together. In the absence of significant heterogeneity a fixed effects model was used. As a sensitivity analysis we also pooled the data together using a weighted mean difference technique. All analyses were conducted using Review Manager version 4.2 (Revman; The Cochrane Collaboration, Oxford, UK).

**RESULTS**

A summary of the search strategy is shown in fig 1. The original search yielded 911, 666, 279, and 16 citations in MEDLINE, EMBASE, CINAHL, and the Cochrane Databases, respectively. The abstracts of these articles were selected and reviewed. Of these, 19 articles were retrieved for a detailed review: seven for CRP, six for fibrinogen, six for leucocytes, six for TNF-\( \alpha \), and two for IL-6. Five studies were excluded for the following reasons: two studies were publications of the same cohort, two provided data on leucocytes based only on a linear regression model which made it impossible to ascertain the relationship between COPD and leucocytes, one study diagnosed chronic bronchitis based only on symptoms (without spirometry). This process left 14 original studies meeting the inclusion and exclusion criteria which were then used for the analyses: five for CRP, four for fibrinogen, four for TNF-\( \alpha \), three for leucocytes, two for IL-8, and one for IL-6. The relevant baseline data from each of the selected studies are summarised in table 1.

Patients with COPD had higher levels of CRP than control subjects in all studies. Overall, the standardised mean difference in the CRP level between COPD and control subjects of each study by its standard deviation. The same technique was used to calculate standardised mean differences for leucocytes, fibrinogen, and other inflammatory cytokines. For each outcome we tested the heterogeneity of results across the studies using a Cochran Q test. If significant heterogeneity was observed \( p < 0.10 \), a random effects model—which assigns a weight to each study based on individual study variance as well as between study variance—was used to pool the results together. In the absence of significant heterogeneity a fixed effects model was used. As a sensitivity analysis we also pooled the data together using a weighted mean difference technique. All analyses were conducted using Review Manager version 4.2 (Revman; The Cochrane Collaboration, Oxford, UK).

Similarly, patients with COPD had higher fibrinogen levels than control subjects. Overall, the standardised mean difference in the fibrinogen level was 0.47 units (95% CI 0.29 to 0.65) or 0.37 g/l (95% CI 0.18 to 0.56) using a weighted mean difference technique. As with the CRP results, there was some heterogeneity in the results between the studies (test for heterogeneity, \( p = 0.001 \)). However, all studies (both large and small) showed that fibrinogen levels were higher in COPD than in control subjects. For population based studies the standardised mean difference between the lowest quartile group and the highest quartile group of predicted FEV\(_1\) among smokers was 0.43 units (95% CI 0.24 to 0.61). Overall, circulating leucocytes were higher in patients with COPD than in control subjects. The standardised mean difference was 0.44 units (95% CI 0.20 to 0.67; test for heterogeneity, \( p = 0.003 \)) or 0.88 \( \times 10^8 \) cells/l (95% CI 0.36 to 1.40) using a weighted mean difference technique (fig 4). Likewise, serum TNF-\( \alpha \) levels were higher in patients with COPD than in control subjects. The standardised mean difference was 0.59 units (95% CI 0.29 to 0.89; test for heterogeneity, \( p = 0.87 \)) or 2.64 pg/ml (95% CI –0.44 to 5.72) using a weighted mean difference technique (fig 5).

There was only one study with analysable data for IL-6. Compared with healthy controls (N = 22), patients with COPD (N = 39) had significantly raised serum levels of IL-6 (mean difference 13.10 pg/ml; 95% CI 7.23 to 18.97).

**Statistical methods**

To accommodate differences in the way in which inflammatory markers were measured and reported across various laboratories, the absolute levels of the above inflammatory markers were converted into a common unit by calculating standardised effect sizes. Standardised effect sizes were derived by dividing the mean difference in CRP levels between COPD and control subjects of each study by its standard deviation. The same technique was used to calculate standardised mean differences for leucocytes, fibrinogen, and other inflammatory cytokines. For each outcome we tested the heterogeneity of results across the studies using a Cochran Q test. If significant heterogeneity was observed \( p < 0.10 \), a random effects model—which assigns a weight to each study based on individual study variance as well as between study variance—was used to pool the results together. In the absence of significant heterogeneity a fixed effects model was used. As a sensitivity analysis we also pooled the data together using a weighted mean difference technique. All analyses were conducted using Review Manager version 4.2 (Revman; The Cochrane Collaboration, Oxford, UK).
Table 1 Baseline information on individual studies included in the meta-analysis

<table>
<thead>
<tr>
<th>Source</th>
<th>Study design and original purposes</th>
<th>COPD patients</th>
<th>Controls</th>
<th>Inflammatory marker and laboratory measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alessandri⁴⁴</td>
<td>Conducted in Italy. To test whether a hypercoagulability state is present in patients with COPD</td>
<td>(1) FEV₁/FVC &lt; 0.7. (2) Haematocrit value &lt; 50%. (3) No comorbid diseases</td>
<td>Healthy volunteers without any disease</td>
<td>Fibrinogen: Clauss method using Kaogulab 32-S coagulometer.</td>
</tr>
<tr>
<td>Dahl⁴⁵</td>
<td>Population based study conducted in Denmark. To test whether increased fibrinogen concentrations correlate with lung function and COPD hospitalisation rates in adults</td>
<td>Lowest quartile group of FEV₁ % pred</td>
<td>Highest quartile group of FEV₁ % pred</td>
<td>Fibrinogen: standard colorimetric assay</td>
</tr>
<tr>
<td>de Godoy⁴¹</td>
<td>Conducted in the US. Age matched healthy volunteers as controls. To examine whether TNF-α and IL-1β produced by peripheral blood monocytes are increased in weight losing COPD patients</td>
<td>(1) FEV₁ &lt; 50%. (2) At least 6 wk stability. (3) Exclusion of patients receiving oral corticosteroids or with comorbid diseases</td>
<td>Age matched healthy volunteers</td>
<td>TNF-α: enzyme linked assay (R&amp;D System)</td>
</tr>
<tr>
<td>Dentener⁴⁶</td>
<td>Conducted in the Netherlands. To test the hypothesis that the chronic inflammatory process present in COPD is due to a defective endogenous anti-inflammatory mechanism</td>
<td>(1) FEV₁ &lt; 80% predicted. (2) β₂ agonist reversibility of &lt;15% or 200 ml. (3) FEV₁/FVC ratio &lt; 70%. (4) Stable clinical condition. (5) Exclusion of patients with comorbid diseases</td>
<td>Healthy subjects with no evidence of COPD</td>
<td>CRP: polyclonal ELISA</td>
</tr>
<tr>
<td>De Francia⁴²</td>
<td>Conducted in France. 30 patients met the criteria were consecutively admitted. To test whether serum levels of TNF-α are related to weight loss in patients with COPD</td>
<td>(1) FEV₁/FVC &lt; 0.6. (2) Irreversibility of airflow obstruction. (3) Creatine clearance in the normal range. (4) Stable clinical condition. (5) Exclusion of patients with comorbid diseases</td>
<td>Healthy laboratory staff members</td>
<td>TNF-α: immunoradiometric method</td>
</tr>
<tr>
<td>Eid⁴⁷</td>
<td>Conducted in the UK. Community based patients recruited from a hospital respiratory clinic. To test whether skeletal muscle loss is associated with inflammatory and catabolic responses in COPD</td>
<td>(1) History of cigarette smoking. (2) Respiratory symptoms. (3) β₂ agonist bronchodilator reversibility &lt; 10%. (4) Further confirmation during 1 year follow up. (5) Stable clinical condition. (6) Exclusion of patients with comorbid diseases</td>
<td>Healthy age and sex related subjects free of lung disease</td>
<td>CRP: enzyme linked immunosorbent assays</td>
</tr>
<tr>
<td>Engstrom⁴⁸</td>
<td>Population based study conducted in Sweden. To explore whether plasma levels of fibrinogen and other inflammation sensitive plasma proteins are related to FVC and whether these proteins contribute to the increased incidence of MI and death among men with reduced FVC</td>
<td>Participants in the lowest quartile group of FVC% pred (≤ 85%) without comorbid diseases. Men with reported long term cough associated with increased mucus production were excluded</td>
<td>Participants in the highest quartile group of FVC% pred (&gt; 105%).</td>
<td>Fibrinogen: immunochemical method</td>
</tr>
<tr>
<td>James⁴⁹</td>
<td>Cross sectional survey of adults aged 25–79 years in Busselton, Western Australia. To investigate whether lung function and respiratory illness were related to leucocytes</td>
<td>Participants in the lowest quartile group of FEV₁ % pred and with FEV₁/FVC ratio &lt; 0.7</td>
<td>Participants in the highest quartile group of FEV₁ % pred and with FEV₁/FVC ratio &gt; 0.7</td>
<td>Leucocyte: NR</td>
</tr>
<tr>
<td>Mannino⁵⁰</td>
<td>Cross sectional, multistage probability representative sample of civilian non-institutionalised US population. To assess the relation of impaired lung function to circulating levels of CRP and fibrinogen in adults</td>
<td>FEV₁/FVC &lt; 0.7</td>
<td>FEV₁/FVC ≥ 0.7, FVC% ≥ 80, free of lung disease</td>
<td>Fibrinogen: immunochemical method</td>
</tr>
</tbody>
</table>

Leucocyte: standard method
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Mendall</td>
<td>Caerphilly Prospective Heart Disease Study conducted in South Wales. To examine whether the low grade inflammation indicated by CRP may be the mechanism whereby non-circulating risk factors may influence pathogenesis of ischaemic heart disease.</td>
<td>Participants in lowest 25th percentile of FEV$_1$</td>
<td>Participants in highest 25th percentile of FEV$_1$</td>
<td>CRP: in-house ELISA method</td>
</tr>
<tr>
<td>Schols</td>
<td>Conducted in Netherlands. To investigate whether the increased resting energy expenditure seen in some COPD patients is related to systemic inflammatory response.</td>
<td>(1) Moderate to severe COPD (FEV$_1$ % pred of 37%). (2) β$_2$ agonist bronchodilator (400 µg salbutamol) reversibility of &lt;10%. (3) Stable clinical condition. (4) Resting energy expenditure &lt;105% or &gt;120% predicted</td>
<td>Randomly selected from a population sample in the same area as the patients; aged over 50 years</td>
<td>IL-6: EUSA assay with detectable limit of 10 pg/ml IL-8: EUSA assay with detectable limit of 20 pg/ml</td>
</tr>
<tr>
<td>Takabatake</td>
<td>Conducted in Japan. To test whether systemic hypoxaemia observed in men with COPD might contribute to activation of TNF-α system and therefore cause weight loss</td>
<td>Diagnosed according to ATS criteria: (1) Irreversible chronic airflow obstruction. (2) Stable for at least 3 months. (3) Exclusion of patients with conditions known to affect serum TNF-α levels</td>
<td>Age matched healthy male volunteers</td>
<td>TNF-α: enzyme linked immunosorbent assay (EUSA) kits</td>
</tr>
<tr>
<td>Vernooy</td>
<td>Conducted in Netherlands. To elucidate the relationship between local and systemic inflammation in smoking induced COPD</td>
<td>Diagnosed according to ATS criteria: (1) Stable clinical condition. (2) Predicted FEV$_1$ &gt;70%. (3) β$_2$ agonist bronchodilator reversibility of &lt;11% or 200 ml. (4) Previous history of at least 20 pack-years smoking. (5) Exclusion of patients receiving inhaled steroids or with comorbid diseases</td>
<td>17 subjects with normal FEV$_1$ and no medical history of lung disease. Smoking history of at least 15 pack years used as criterion for inclusion</td>
<td>IL-8: specific sandwich EUSA with detectable limit of 8 pg/ml</td>
</tr>
<tr>
<td>Yasuda</td>
<td>Conducted in Japan. To test whether the concentrations of sFas-L and sFas are related to CRP, TNF-α, or IL-6</td>
<td>Diagnosed by history, physical examination, radiographic examination and lung function tests. Conditions: (1) Stable clinical condition. (2) No recent change of drugs. (3) Normal left ventricular ejection fraction. (4) Normal plasma creatinine concentration. (5) Absence of other pathological conditions</td>
<td>Healthy age and sex matched volunteers without any disease</td>
<td>CRP: latex nephelometric immunoassay with detection limit of 0.3 mg/l TNF-α: sandwich EUSA kit</td>
</tr>
</tbody>
</table>

COPD = chronic obstructive pulmonary disease; FEV$_1$ = forced expiratory volume in 1 second; FVC = forced vital capacity; CRP = C-reactive protein; TNF-α = tumour necrosis factor-α; IL = interleukin; pred = predicted; NR = not reported, MI = myocardial infarction; sFas-L = soluble Fas/Apo-1 receptor ligand; sFas = soluble Fas/Apo-1 receptor.
There were two studies on IL-8. One study showed that 17 of 30 patients with COPD had a detectable IL-8 level whereas none of the 26 healthy controls had detectable serum IL-8 (using an assay with a detectable limit of 20 pg/ml). Another study reported that four out of 18 patients with COPD had detectable IL-8 levels in their serum compared with none of 17 healthy controls (using an assay with detectable limit of 8 pg/ml).

DISCUSSION
In this systematic review we found that, compared with healthy controls, individuals with chronic airflow limitation had significantly raised levels of CRP, fibrinogen, leucocytes, and TNF-α, indicating that persistent systemic inflammation is present in COPD. Even among non-current smokers there was evidence for low grade systemic inflammation in those with chronic airflow limitation. This suggests that, once

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**Figure 2** Relationship between C-reactive protein (CRP) and COPD. Continuous variables are expressed as mean (SD) unless otherwise specified. *Imputed from the regression coefficient between mean FEV₁ (25–75th percentile) and CRP.

**Figure 3** Relationship between fibrinogen and COPD. Continuous variables are expressed as mean (SD) unless otherwise specified. *FEV₁ in litres. †Based on forced vital capacity. ‡Estimated.

**Figure 4** Relationship between leucocytes and COPD. Continuous variables are expressed as mean (SD) unless otherwise specified. *Data from smokers only. WBC = white blood cells.
COPD and systemic inflammation

COPD develops, cessation of smoking may not fully attenuate the inflammatory process associated with this condition.

How and why individuals with COPD develop systemic inflammation is uncertain and unknown. COPD is characterised by an intense inflammatory process in the airways, parenchyma, and pulmonary vasculature. It is possible in some cases that the inflammatory process may “spill” over into the systemic circulation, promoting a generalised inflammatory reaction. It is also possible that there are common genetic or constitutional factors that may predispose individuals with COPD to both systemic and pulmonary inflammation. Furthermore, while we believe that COPD is responsible for the systemic inflammation, there exists the possibility of reverse causation. The possibility that systemic inflammation causes injuries to the airways leading to COPD may not represent the general pool of COPD patients. Even within the COPD group, some were selected on the basis of weight loss or poor nutritional status and, as such, may not fully attenuate airflow limitation had, on average, higher levels of systemic inflammatory markers than healthy controls. This suggests that selection and sampling biases were unlikely to be responsible for the observed associations. Thirdly, there was a marked paucity of studies that evaluated the relationship between COPD and IL-6 or IL-8. IL-6 has been implicated in the pathogenesis of atherosclerosis while IL-8 may be an important signalling molecule for neutrophils which may have significance in the pathophysiology of COPD. In view of their potential relevance in COPD, more studies are needed in the future to determine whether the systemic expression of these cytokines is increased in COPD.

In summary, there is now a large body of evidence to indicate that systemic inflammation is present in patients with stable COPD. This finding may explain, at least in part, the high prevalence of systemic complications such as cachexia, osteoporosis, and cardiovascular diseases among patients with COPD. Future studies are needed to determine whether attenuation of the systemic inflammatory process can modify the risk of these complications in COPD.

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