Association of low income with pulmonary disease progression in smokers with and without chronic obstructive pulmonary disease

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ABSTRACT Low socioeconomic status has been associated with chronic obstructive pulmonary disease (COPD) but little is known about its impact on disease progression. We assessed the association of income to symptoms, pulmonary disease severity and progression in smokers with and without COPD.

The COPDGene cohort of 4826 smokers who reported annual income in phase 2 was analysed. Those who reported annual income <USD 15 000 per year were “low-income” and the remainder “higher income”. Baseline demographics, symptoms, computed tomography (CT) imaging, and 5-year change in spirometry and CT metrics were characterised by group.

The low income group was younger (55.7 versus 61.7, p<0.0001), had more current smokers (73% versus 36%, p<0.0001), higher rates of severe exacerbations (13% versus 7%, p<0.0001), more chronic bronchitis (22% versus 14%, p<0.0001), reduced access to preventative care and lower quality of life, but less emphysema (4.7% versus 6.2%, p<0.0001). After 5 years the low-income group had more smoking-related disease progression, without significant change in exacerbations or symptoms, than higher-income subjects. Low income was an independent predictor of decreasing forced expiratory volume in 1 s (FEV1) (p=0.001) and increased airway disease (p=0.007) after adjusting for baseline FEV1, age, sex, race, exposures and current smoking.

Income disparity beyond the effects of race and current smoking is an important factor for disease progression. Worldwide, poverty and its consequences: associated respiratory exposures, limited healthcare access, and inadequate education about smoking risks, may exacerbate chronic lung disease.
Introduction

Socioeconomic status (SES) has a broad impact on health outcomes and longevity and encompasses a variety of factors including income, education, occupation, race and social status. Lower incomes are specifically associated with reduced life expectancy, although the effect varies across geographic regions [1]. The reduction in life expectancy associated with low income is significantly influenced by regional differences in health behaviours, especially smoking [1]. Race and sex, which are strongly associated with SES, have been identified as risk factors for more severe chronic obstructive pulmonary disease (COPD) [2–5]. COPD is linked to smoking and other respiratory exposures such as gases, smoke, fumes and dust commonly found in low-income jobs. Earlier published works regarding impacts of low income and SES focused on symptoms [6, 7], disease severity [6], racial disparities [8, 9] and COPD within a general population cohort [10]. However, the effect of low income as a factor in disease progression has not been assessed comprehensively.

The COPDGene study enrolled 10 192 smokers with and without COPD (phase 1) and characterised them with spirometry, chest computed tomography (CT) scans and symptoms. Subjects returned for a 5-year follow-up visit (phase 2) to assess disease progression by repeat spirometry, CT imaging and reported symptoms. During the phase 2 visit they provided information on their current annual income, insurance status and access to medications and health care.

We assumed income stability over the 5-year interval and postulated that the lowest income subjects (earning <USD 15 000 USD per year) would have worse respiratory symptoms and decreased quality of life. We also hypothesised that low income would be associated with worse outcomes over 5 years, specifically increasing spirometric obstruction and progression of pulmonary disease on CT scans.

Methods

Study population

COPDGene (Genetic Epidemiology of COPD) is a longitudinal cohort study at 21 clinical centres across the United States. Subjects were current and former smokers aged 45–80 years at entry, non-Hispanic white or African American subjects who reported smoking histories >10 pack-years and had no other lung disease except asthma [9]. All subjects provided documentation of informed consent in writing and the study was approved at each clinical centre by their local institutional review board. Details of the phase 1 study have been presented previously [9]. In phase 2 of the study during the years 2013–2017, subjects completed a 5-year return visit. At this second visit, subjects had a comprehensive examination including repeat spirometry, a 6-min walk test, questionnaires and a CT scan. Subjects included in this analysis are those who completed an in-person phase 2 visit, passed spirometry quality control at both visits and reported income during the phase 2 visit (see figure 1 for CONSORT diagram).

The low-income group in our analysis was defined as participants earning less than the United States federal minimum wage of USD 7.25 per hour. A person earning minimum wage working 40 h per week,
52 weeks per year (just over full time) would earn USD 15 080 before taxes. Any participant who reported earning more than USD 15 000 per year was categorised as higher income.

**Aims**
Our primary aim was to assess the role of low income as a predictor of disease progression for subjects with COPD and early smoking-related lung disease after correcting for the possible confounding variables of age, sex, race, current smoking, education, baseline function and pack-years. Disease progression variables included change in percentage emphysema, change in FEV1 and change in gas trapping over a 5-year time period. Our secondary aim was to investigate the relationship of income to baseline patient variables including symptoms, spirometry and CT-based estimates of emphysema severity, airway wall thickness and gas trapping.

**Questionnaires**
Questionnaires in phase 1 included medical history, educational history, a modified American Thoracic Society respiratory questionnaire, the modified Medical Research Council (mMRC) dyspnoea score [11], St George’s Respiratory Questionnaire (SGRQ) [12] and the Medical Outcomes Study 36-item short form survey (SF-36) [13]. In phase 2, the COPD Assessment Test (CAT) and a socioeconomic questionnaire were added. The socioeconomic questionnaire queried annual income, insurance status, home ownership and access to preventative care. Education was considered as a categorical variable, with high school or less versus any education beyond high school. Comorbid disease was self-reported on the medical history questionnaire. We calculated a nonweighted comorbidity score using the methodology of Putcha et al. [14], summing the number of comorbidities.

**Functional evaluations**
Function was evaluated using post-bronchodilator spirometry to determine forced expiratory volume in 1 s (FEV1), forced vital capacity and 6-min walking distance (6MWD).

**Radiographic measures**
Inspiratory and expiratory CT scans were performed on all participants who consented. Details of the lung CT protocol and quantitative analysis have been reported elsewhere [15]. Inspiratory CT scans were analysed for emphysema as percentage low attenuation area at −950 Hounsfield Units (%LAA@−950HU) and adjusted lung density as well as for airway wall thickness. Expiratory CT scans were analysed for gas trapping using percentage low attenuation area at −856 Hounsfield Units (%LAA@−856HU). All CT scans were analysed using Thirona LungQ (Thirona, Nijmegen, the Netherlands).

**Statistical analysis**
Data were analysed using STATA 15.1 (StataCorp, College Station, TX, USA). Phase 1 to phase 2 changes were calculated for FEV1, mMRC dyspnoea score, SGRQ total score and distance walked. The percentage emphysema, adjusted lung density, gas-trapping scores and airway wall thickness at phase 1 and phase 2 were used to calculate the 5-year difference in CT variables. Comparisons between groups with categorical variables were made using a Chi-squared test and continuous variables were compared with a two-tailed t-test. p-values <0.05 were considered significant. Multivariate linear regression was used to assess the independent effects of income and education on 1) baseline imaging measures of emphysema, gas trapping and airway wall thickness and 2) the 5-year change variables: FEV1 % predicted, emphysema, gas trapping and airway wall thickness. Baseline models were fitted with age, race, sex, current smoking status, smoking pack-years, education and income; while change models added the baseline value of the change modelled (either FEV1 % pred, emphysema, gas trapping or airway wall thickness). Statistically different demographic variables (table 1) and clinically significant variables were selected a priori for regression models.

**Results**

**Demographics**
4826 subjects self-reported annual income and other information about their socioeconomic situation. Of the full cohort, 1549 (32%) subjects reported an income of <USD 15 000 per year. The low-income participants were on average younger (55.7±7.4 years versus 61.7±8.5 years, p<0.0001), more likely to be current smokers (72.6% versus 35.5%, p<0.0001), had started smoking at an earlier age (16.7±5.1 years versus 17.2±4.1 years, p=0.016), more likely to be using respiratory medications (42% versus 31%, p<0.0001) and were more likely to be African American (57% versus 16%, p<0.0001) (table 1). The two groups had similar smoking exposure (42.7±25.1 pack-years versus 42.6±22.7 pack-years, p=0.8828) at baseline. Spirometric disease severity was slightly worse in the low-income participants with mean FEV1 78.4±23.2% pred compared to 80.4±23.0% pred in the higher-income group (p=0.0042). Distribution by Global Initiative for Chronic Obstructive Lung Disease (GOLD) stage was similar between the two groups.
Symptoms, comorbid disease and quality of life

Symptoms were reported in both the phase 1 and phase 2 visits (table 2). Low-income subjects had significantly more symptoms (chronic bronchitis 22% versus 14%, severe exacerbations 13% versus 7%, mMRC dyspnoea score ≥2 49% versus 28%) in phase 1 with similar results in phase 2. Low-income subjects scored higher (worse) on the CAT in phase 2, with a mean±SD score of 15.0±9.2, compared to 10.5±7.7 for higher-income subjects. Self-report of diabetes, congestive heart failure and stroke were significantly higher at baseline in the low-income group, while cancer, osteoarthritis, high cholesterol, hay fever and gastro-oesophageal reflux disease were significantly lower. Coronary artery disease, obesity, stomach ulcers, peripheral vascular disease, sleep apnoea and hypertension were not significantly different between groups. The overall comorbidity score was significantly lower in the low income group (online supplementary table S1). The low-income group had a mean SGRQ total score of 31.7±23.3 versus 19.3±18.8 in phase 1 and 31.8±23.16 versus 19.6±19.0 when assessed at their phase 2 visit, with higher

| TABLE 1 Demographics and baseline disease severity |
|-----------------------------------------------|
|                                             |
| Low-income smokers (<USD 15 000 per year)  | Higher-income smokers (>USD 15 000 per year) | p-value |
| Subjects n                                   | 1549                                          | 3277    |
| Age years                                    | 55.7±7.4                                     | 61.7±8.5| <0.0001 |
| African American                             | 57                                            | 52      | 0.031   |
| Male                                         | 49                                            | 77      | <0.0001 |
| BMI kg·m⁻²                                    | 29.1±6.7                                     | 29.1±5.7| 0.95    |
| More than high-school education              | 45                                            | 77      | <0.0001 |
| ATS pack-years                               | 42.5±25.0                                    | 42.2±22.6| 0.66    |
| Age started smoking years                    | 16.7±5.1                                     | 17.2±4.1| 0.0016  |
| Current smoking status                       | 73                                            | 36      | <0.0001 |
| Using respiratory medications               | 42                                            | 31      | <0.0001 |
| FEV₁ % pred                                  | 78.4±23.2                                    | 80.4±23.0| 0.0042  |
| FVC % pred                                   | 87.7±17.8                                    | 89.6±16.5| 0.0002  |
| FEV₁/FVC                                     | 0.70±0.14                                    | 0.68±0.14| 0.0003  |
| Percentage emphysema LAA@-950 HU             | 4.68±7.6                                     | 6.24±8.9| <0.0001 |
| Percentage gas trapping LAA@-856 HU          | 19.3±17.9                                    | 20.5±17.8| 0.0652  |
| Airway wall thickness mm                     | 1.063±0.231                                  | 1.018±0.211| <0.0001 |

Data are presented as mean±sd or %, unless otherwise stated. BMI: body mass index; ATS: American Thoracic Society; FEV₁: forced expiratory volume in 1 s; FVC: forced vital capacity; LAA: low-attenuation areas.

In general, the distribution of income status is similar across the GOLD stages except for an excess of low-income subjects in the preserved ratio impaired spirometry group and fewer in GOLD stage 1.
SGRQ score indicating lower quality of life. Both the mental and physical component scores of the SF-36 were significantly lower (worse) in the low-income group at both time points.

Detailed analysis of respiratory medications is presented in online supplementary table S2. The low-income subjects report significantly more use of short-acting (37% versus 25%, p<0.0001) and long-acting medications (25% versus 21%, p=0.003) than higher-income subjects, probably in response to higher rates of respiratory symptoms.

Socioeconomic status
5-year follow-up phase 2 COPDGene visits were performed after implementation of the Affordable Care Act in the United States. In spite of that expansion of insurance coverage, 8% of low-income subjects lacked health insurance, compared to 2.4% of higher-income subjects (table 3). Low-income subjects were less likely to receive preventive care and more likely to seek care in emergency rooms (12% versus 3%) than higher-income subjects. In addition, educational background differed significantly, with 45% of the low-income group reporting education beyond a high school diploma compared to 77% of the higher-income group. Subjects reported stretching medications and limiting physician visits because of costs and income (table 4). Low-income subjects were twice as likely to not have gone to a doctor or not filled a prescription due to cost than higher income subjects. Low-income subjects used one or more cost-saving strategies significantly more often than higher-income subjects (25% versus 14%).

Baseline CT parameters
Emphysema and wall area percentage at the baseline visit showed differences based on income group, with less emphysema (4.68±7.6% versus 6.24±8.9%, p<0.0001) in the low-income group while airway wall thickness was greater (1.06±0.23 versus 1.01±0.21, p<0.0001) in the low-income subjects (table 1). Gas trapping was not significantly different at baseline. In multivariate linear regression models, income and educational level were highly significantly predictors of emphysema and segmental airway wall thickness at baseline, while education, but not income, was a significant factor for gas trapping (table 5). Exposures to dust and fumes were tested separately in the baseline models and were not significant predictors of baseline emphysema or gas trapping, but dust exposure was a significant factor for airway wall thickness (online supplementary tables) and income remained significant. Race was significant in all models, but after adjusting for income, African Americans had less emphysema, gas trapping and

| TABLE 2 Symptoms, function and quality of life |
|------------------------------------------------|
| Low-income smokers (<USD 15,000 per year) | Higher-income smokers (>USD 15,000 per year) | p-value |
| Phase 1 | | |
| Chronic bronchitis | 22 | 14 | <0.0001 |
| mMRC score | 1.58±1.46 | 0.93±1.24 | <0.0001 |
| mMRC score >2 | 49 | 28 | <0.0001 |
| Severe exacerbation within the past year | 13 | 7 | <0.0001 |
| SGRQ total | 31.74±23.3 | 19.3±18.8 | <0.0001 |
| 6MWD feet | 1297±381 | 1486±352 | <0.0001 |
| SF-36 PCS | 42.0±11.2 | 47.1±10.0 | <0.0001 |
| SF-36 MCS | 45.9±12.6 | 52.4±9.8 | <0.0001 |
| Phase 2 | | |
| Chronic bronchitis | 20 | 13 | <0.0001 |
| mMRC score | 1.64±1.51 | 0.99±1.29 | <0.0001 |
| mMRC score >2 | 52 | 31 | <0.0001 |
| Severe exacerbation within the past year | 14 | 7 | <0.0001 |
| SGRQ total | 31.79±23.1 | 19.6±19.0 | <0.0001 |
| 6MWD feet | 1162±438 | 1356±420 | <0.0001 |
| SF-36 PCS | 39.9±11.4 | 45.3±10.6 | <0.0001 |
| SF-36 MCS | 48.0±11.7 | 53.6±9.5 | <0.0001 |
| CAT score | 15.0±9.2 | 10.5±7.7 | <0.0001 |

Data are presented as % or mean±sd, unless otherwise stated. mMRC: modified Medical Research Council; SGRQ: St George’s Respiratory Questionnaire; 6MWD: 6-min walking distance; SF-36: Medical Outcomes Study 36-item short-form questionnaire; PCS: physical component summary; MCS: mental component summary; CAT: Chronic Obstructive Pulmonary Disease Assessment Test.

SGRQ score indicating lower quality of life. Both the mental and physical component scores of the SF-36 were significantly lower (worse) in the low-income group at both time points.

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airway wall thickness. Although we adjusted for disease severity by FEV1 in the models, the distribution of African Americans by GOLD stage differed from non-Hispanic white subjects with less severe disease. African Americans had greater proportions in GOLD 0 and PRISm categories (online supplementary figure S1).

**Disease progression**

At the 5-year visit there were no significant differences in change in dyspnoea, quality of life by the SGRQ total score or 6MWD between low-income and higher income groups (table 6). However, the low-income group showed greater progression in emphysema (0.68±3.7% versus 0.06±3.95%, p<0.0001), gas trapping (2.31±9.5% versus 0.62±8.2%, p<0.0001) and FEV1 (−3.26±12.9% pred versus −1.40±10.1% pred, p<0.0001). Change in airway wall thickness (−0.0061±0.137 versus −0.0025±0.108, p=0.409) was not significantly different.

Multivariate linear regression modelling for change outcomes (FEV1, emphysema, gas trapping and airway disease using airway wall thickness) with baseline level of the outcome, age, sex, race, smoking status, pack-years and FEV1 % pred (table 7) showed that low income was a significant predictor of disease progression in models for FEV1 and airway wall thickness, but income was not a significant predictor of change in gas trapping or emphysema. Low income predicted worsening FEV1 and increased airway wall thickness.

### TABLE 3 Socioeconomic factors beyond income

| Low-income smokers (<USD 15000 per year) | Higher-income smokers (>USD 15000 per year) | p-value |
|-----------------------------------------|---------------------------------------------|---------|
| Education beyond high school            |                                             | <0.0001|
| Residence                               |                                             |         |
| Own home                                | 45                                          | 77      |
| Rent                                    | 19                                          | 70      |
| Rent                                    | 59                                          | 22      |
| Lack a permanent home                   | 5                                           | 0.5     |
| Have health insurance                   | 90                                          | 97      |
| Access to preventative care             |                                             | <0.0001|
| Get preventative care from doctor/clinic| 88                                          | 97      |
| Get preventative care from emergency room| 8                                           | 1       |
| Do not get preventative care            | 4                                           | 2       |
| Lack a primary-care physician           | 9                                           | 3       |
| Have access to internet                 | 55                                          | 89      |
| Exposures                               |                                             | <0.0001|
| Worked in a dusty job                   | 54                                          | 40      |
| Worked in a fumes-related job           | 49                                          | 45      |
| Data are presented as %, unless otherwise stated. |

### TABLE 4 Accommodation to healthcare costs

| In the last year, because of the expense or lack of coverage, have you ... | Low-income smokers (<USD 15000 per year) | Higher-income smokers (>USD 15000 per year) | p-value |
|--------------------------------------------------------------------------|------------------------------------------|--------------------------------------------|---------|
| Not gone to your doctor when you needed to                              | 11                                       | 5                                          | <0.0001|
| Not filled a prescription                                               | 10                                       | 6                                          | <0.0001|
| Stretched out a prescription medication by taking less of it or less often than it was prescribed | 9                                        | 7                                          | 0.005   |
| Not gone to the hospital when you needed to                             | 6                                        | 1                                          | <0.0001|
| Gone to an emergency room to be treated                                 | 9                                        | 2                                          | <0.0001|
| One or more of the above                                                | 25                                       | 14                                         | <0.0001|
| Data are presented as %, unless otherwise stated.                       |                                          |                                            |         |
### TABLE 5 Adjusted relationships of income to baseline computed tomography measures

|                         | Coefficient (95% CI) | p>|t| |
|-------------------------|----------------------|------------------|
| **Baseline emphysema**  | Model $R^2$ 0.3287   |                  |
| Baseline FEV1           | −5.91 (−6.24–−5.58)  | <0.0001          |
| Height                  | 0.15 (0.11–0.18)     | <0.0001          |
| Current smoking         | −2.95 (−3.47–−2.44)  | <0.0001          |
| Female                  | −4.16 (−4.80–−3.53)  | <0.0001          |
| Age at recruitment      | −0.075 (−0.11–−0.042) | <0.0001       |
| Education beyond high school | −0.91 (−1.42–−0.40)  | <0.0001          |
| Lower income            | −0.82 (−1.37–−0.27)  | 0.004            |
| African American        | −2.21 (−2.81–−1.61)  | <0.0001          |
| Smoking pack-years      | 0.012 (0.0023–0.022) | 0.015            |
| **Baseline gas trapping**| Model $R^2$ 0.4874   |                  |
| Baseline FEV1           | −14.67 (−15.30–−14.03) | <0.0001        |
| Height                  | 0.39 (0.33–0.46)     | <0.0001          |
| Current smoking         | −3.92 (−4.93–−2.92)  | <0.0001          |
| Female                  | −9.78 (−11.02–−8.54) | <0.0001          |
| Age at recruitment      | 0.74 (0.011–0.14)    | 0.022            |
| Education beyond high school | −1.38 (−2.36–−0.37)  | 0.007            |
| Lower income            | 1.00 (−0.089–2.10)   | 0.072            |
| African American        | −5.19 (−6.40–−3.99)  | <0.0001          |
| Smoking pack-years      | 0.023 (0.003–0.042)  | 0.223            |
| **Baseline airway wall thickness** | Model $R^2$ 0.2928   |                  |
| Baseline FEV1           | −0.10 (−0.11–−0.095) | <0.0001          |
| Height                  | 0.0036 (0.0027–0.0045) | <0.0001        |
| Current smoking         | 0.080 (0.066–0.094)  | <0.0001          |
| Female                  | −0.18 (−0.20–−0.17)  | <0.0001          |
| Age at recruitment      | −0.0020 (−0.0028–−0.0011) | <0.0001   |
| Education beyond high school | −0.018 (−0.032–−0.0048) | 0.008       |
| Lower income            | 0.021 (0.0046–0.036) | 0.005            |
| African American        | −0.07 (−0.083–−0.051) | <0.0001          |
| Smoking pack-years      | 0.00069 (0.00042–0.00095) | <0.0001   |

FEV1: forced expiratory volume in 1 s.

### TABLE 6 Income status and 5-year change in spirometry, dyspnoea, health-related quality of life and imaging characteristics

|                         | Low-income smokers (<USD 15000 per year) | Higher-income smokers (>USD 15000 per year) | p-value |
|-------------------------|------------------------------------------|---------------------------------------------|---------|
| FEV1 % pred             | −3.26±12.9                               | −1.40±10.1                                  | <0.0001 |
| FEV1 mL                 | −225.6±342                               | −202.1±280                                  | 0.0115  |
| FEV1 mL per year        | −40.0±51.5                               | −35.5±50.0                                  | 0.0142  |
| Loss of >300 mL in FEV1 n (%) | 570 (36.8%)                               | 1055 (32.19%)                               | 0.002   |
| mMRC dyspnoea score*    | 0.0575±1.43                              | 0.0649±1.14                                 | 0.87    |
| SGRQ total score        | 0.0442±19.5                              | 0.298±13.2                                  | 0.6     |
| Distance walked feet†   | −130±401                                 | −128±335                                    | 0.82    |
| Adjusted lung density*  | −1.90±12.1                               | −0.35±11.5                                  | 0.0003  |
| Emphysema*  %           | 0.677±3.74                               | 0.06±3.95                                   | <0.0001 |
| Gas trapping§           | 2.31±9.52                                | 0.62±8.17                                   | <0.0001 |
| Airway wall thickness mm| −0.0061±0.137                            | −0.0025±0.108                               | 0.409   |
| Current smokers         | −0.0051                                  | −0.017                                      | 0.083   |
| Former smokers          | −0.0086                                  | 0.0051                                      | 0.0291  |

Data are presented as mean±SD, unless otherwise stated. FEV1: forced expiratory volume in 1 s; mMRC: modified Medical Research Council; SGRQ: St George’s Respiratory Questionnaire. *: n=1567 (low income), n=3271 (higher income); †: n=1583 (low income), n=3234 (higher income); ‡: n=1085 (low income), n=2489 (higher income); §: n=828 (low income), n=2133 (higher income).
Discussion

Individuals with an annual income at or below the US minimum wage level had significantly greater impacts of smoking-related disease. Although the low-income group had less emphysema at baseline, they showed greater disease progression over 5 years in FEV1 and airway wall thickness. Current smoking was a clear factor predicting disease progression, but the effect of low income on disease progression remained after adjusting for current smoking. The adjusted difference in FEV1 between the low and higher income groups was 37 mL greater loss in the low-income group. This is a similar magnitude of effect to the adjusted impact of current smoking on FEV1 at 51 mL loss. These results suggest that low income is important and that factors other than continued smoking are involved in the relationship between low income and disease.

At baseline, low-income subjects had worse quality of life, worse dyspnoea, more chronic bronchitis and a shorter 6MWD, although smoking pack-years were not significantly different. Both current smoking and respiratory exacerbations requiring an emergency room visit or hospitalisation occurred twice as often in the low-income group relative to subjects reporting higher income. Our low-income group was similar in the distribution of disease severity to the higher-income subjects, but had more respiratory symptoms and had greater impairment in 6MWD, despite being significantly younger.

Factors that we considered to explain these results include that our low-income group reported less education, potentially impeding understanding of smoking risks; were less likely to have health insurance; and less likely to get preventative care from a doctor or clinic. In addition, they were more likely to have skipped medical visits or medications due to costs. Although they did report more respiratory exposures, the effect of those exposures on disease progression was not significant after adjusting for other factors. In addition, increased exposure to air pollution may play a role, but we do not have data available to assess that. Higher rates of respiratory medication use in the low-income group may be due to greater symptoms, or it may be the result of inadequate preventive and primary care.

| TABLE 7: Associations of income and education to disease progression |
|---------------------------------------------------------------|
| **Change in FEV1 mL** | **Coefficient (95% CI) p-value** |
| Baseline FEV1 % pred | −2.78 (−3.13 to −2.41) <0.0001 |
| Current smoking | −51.36 (−70.99 to −31.73) <0.0001 |
| Female | 68.47 (51.85 to 85.09) <0.0001 |
| Age at recruitment | −0.39 (−1.54 to 0.77) 0.51 |
| Education beyond high school | −7.96 (−27.00 to 11.08) 0.41 |
| Low income | −36.58 (−57.23 to −15.93) 0.001 |
| African American race | 49.21 (27.48 to 70.93) <0.0001 |
| Smoking pack-years | −0.89 (−1.27 to −0.51) <0.0001 |

| **Change in emphysema** | **Coefficient (95% CI) p-value** |
| Baseline emphysema | −0.017 (−0.035 to 0.00073) 0.60 |
| Baseline FEV1 % pred | −0.051 (−0.058 to −0.045) <0.0001 |
| Female | 0.68 (0.39 to 0.98) <0.0001 |
| Age at recruitment | −0.039 (−0.29 to −0.21) 0.76 |
| Education beyond high school | 0.21 (−0.075 to 0.49) 0.15 |
| Low income | 0.14 (−0.17 to 0.45) 0.39 |
| African American race | 0.31 (−0.019 to 0.64) 0.065 |
| Smoking pack-years | 0.0051 (−0.0070 to 0.0111) 0.085 |

| **Change in airway wall thickness** | **Coefficient (95% CI) p-value** |
| Baseline airway wall thickness | −0.20 (−0.22 to −0.18) <0.0001 |
| Baseline FEV1 % pred | −0.00018 (−0.00036 to −0.000048) 0.044 |
| Current smoking | 0.0060 (0.0029 to 0.015) 0.185 |
| Female | −0.022 (−0.030 to −0.014) <0.0001 |
| Age at recruitment | 0.00070 (0.00019 to 0.0012) 0.008 |
| Education beyond high school | −0.0013 (−0.0099 to −0.0073) 0.76 |
| Low income | 0.013 (0.0036 to 0.022) 0.007 |
| African American race | −0.015 (−0.025 to −0.0050) 0.003 |
| Smoking pack-years | 0.00013 (−0.000042 to 0.00031) 0.136 |

FEV1: forced expiratory volume in 1 s.
Key social factors associated with low income and SES previously suggested to play a role in worse health include smoking, education, healthcare/insurance and unhealthy living conditions [17]. Smoking is much more prevalent in lower-income individuals [18] and CHETTY et al. [1] found local geographic variation in mortality that was associated with smoking behaviour. In the CHETTY et al. study, regional increased mortality linked to smoking behaviour was associated with heart disease and cancer, rather than increases in accidents, suicide or homicide. Others have identified associations between low SES and reduced lung function [6], increased hospitalisations [10] and increased mortality from respiratory disease [19]. In a systematic review, GERSHON et al. [7] identified consistently negative effects of low SES on COPD symptoms, morbidity and mortality. In that meta-analysis, measures of SES included income, education and occupation. They found that individuals of the lowest SES were twice as likely to have poor outcomes as the higher-income group. Comparing studies across multiple diseases, they found that the negative impact of SES was greatest in COPD relative to diabetes, heart disease, stroke and cancer. Our findings are consistent with these published results and add detail about access to care and impact of low income on decision-making to seek care and comply with treatment.

Our low-income group had a greater proportion of African Americans, but we did not find worse disease at baseline or greater progression in these subjects; in fact, we found less after adjusting for income. The role of race in COPD risk and progression remains unclear, potentially because of the complexities of SES and genetic factors that may influence risk of disease. EISNER et al. [6] in a study of insured health maintenance organisation subjects found that African Americans were not at increased risk of greater COPD severity after adjusting for demographics and physical characteristics. Our population varied in insurance status, but our results suggest that economics rather than race were the major factors predicting progression. African American subjects who experience exacerbations have worse quality of life than non-Hispanic white subjects with exacerbations [20], and they appear to have increased susceptibility to developing disease after smoking exposure [3], yet early work from the COPDGene study showed that African Americans had less emphysema than non-Hispanic white subjects adjusting for smoking pack-years, age and current smoking [4].

Education may influence decisions to continue smoking as well as interactions with the medical profession and compliance with treatment. A Norwegian study showed an association of lower educational level with greater emphysema but not airway wall thickness in COPD patients within a racially homogenous, rural population [21]. A previous COPDGene study relating parental COPD to risk of disease found that race was not significant, but education was an independent predictor of COPD [22]. Persistent smoking is associated with both lower income levels and lower educational attainments [18, 23]. Overall, the complex interplay of income, education, comorbidities and other factors increase the difficulty of defining solutions to continued smoking. The prominent role of continued smoking in low-income individuals suggests that strategies to improve outcomes must be linked to smoking cessation programmes. Smoking cessation programmes should be targeted to the needs and issues of low-income smokers.

Strengths of this study include the large cohort size, geographic diversity of the 21 clinical centres, extensive longitudinal clinical and radiographic data and the enhanced enrolment of African Americans. Limitations to generalisability include a US population that has unique and incomplete insurance coverage. Additionally, income level was documented at the phase 2 visit, not the initial visit when all of the other baseline variables were evaluated. While metrics of SES such as income and education have some stability over time [24], reverse causality cannot be excluded in this analysis. Those with faster disease progression may have been forced to retire, subsequently reducing their income from baseline to the reported level at the phase 2 visit. If they fell into the lowest category, this would bias the estimate of the difference between the low-income and the high-income group away from the null (overestimating the effect). However, the mean social security payment in the US is ∼USD 16,000 per year and retirement will not necessarily result in a drop into the lowest income category.

The information on income, education, comorbid disease, medication use and symptoms are all self-reported. Although verification of income and education would be ideal, it is uncommon to have that type of validation. Since subjects were offered the option to decline to answer these questions, we assume that responses are reflective of their social and economic situation. Although the lower comorbidity score in the low-income group may be accurate (possibly due to the lower average age), there may also be an ascertainment bias in that these subjects have reduced access to primary preventative care and may not have had an opportunity for physician diagnosis of asymptomatic conditions such as hypertension and high cholesterol. Additionally, while we have data on which medications subjects are prescribed, we do not have information on adherence, though our data on accommodations to healthcare costs suggest that low-income subjects may have lower adherence (more likely to not fill prescriptions, more likely to stretch out a prescription). Lower adherence rates may influence exacerbation rates and disease progression.
We chose to study the relationship of low income to a breadth of smokers both with and without spirometric COPD. Smoking impacts on the lung including emphysema, gas trapping and airway wall thickening are identified in smokers without obstruction [25]. We used CT metrics, reported symptoms and spirometry to provide a comprehensive analysis of baseline disease and progression.

The economic burden of smoking-related lung disease and COPD in the United States is sizeable, estimated to be USD 38.8 billion in 2005 [26]. As the third leading cause of death in the United States, there is value in improving outcomes of care for COPD. Worldwide, smoking and other respiratory exposures are common, and COPD is the fourth leading cause of death. Poverty and inadequate education are key issues to consider in order to reduce the burden of respiratory disease. Beyond smoking cessation, we identified a range of factors that could be addressed, including access to primary care and preventive care, access to health insurance and better information about health conditions. Although this study is based on data from the United States, similar associations of low SES to worse COPD have been identified in European cohorts, as well as around the world [7, 10, 21, 27]. Recognising and addressing the role of poverty in increased burden of disease, worse outcomes and more rapid disease progression represents an important strategy for all societies.

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