BMJ Open Socioeconomic circumstances and respiratory function from childhood to early adulthood: a systematic review and meta-analysis

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To cite: Rocha V, Soares S, Stringhini S, *et al*. Socioeconomic circumstances and respiratory function from childhood to early adulthood: a systematic review and meta-analysis. *BMJ Open* 2019;**9**:e027528. doi:10.1136/bmjopen-2018-027528

► Prepublication history and additional material for this paper are available online. To view please visit the journal online (<http://dx.doi.org/10.1136/bmjopen-2018-027528>).

Received 2 November 2018

Revised 11 April 2019

Accepted 22 May 2019

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ABSTRACT

Objective Disadvantaged socioeconomic circumstances in early life have the potential to impact lung function. Thus, this study aimed to summarise evidence on the association between socioeconomic circumstances and respiratory function from childhood to young adulthood.

Design Systematic review and meta-analysis.

Methods Following the Preferred Reporting Items for Systematic Review and Meta-analysis guidelines, Medline, ISI-Web of Science and Scopus were searched from inception up to January 2018. Original studies on the association between socioeconomic circumstances and respiratory function in early ages (ie, participants younger than 25 years of age) were investigated. Two investigators independently evaluated articles, applied the exclusion criteria, extracted data and assessed the risk of bias using the Newcastle–Ottawa Scale. A meta-analysis of the standardised mean difference and 95% CI in respiratory function between participants from different socioeconomic circumstances was conducted, using a random-effects model.

Results Thirty-three papers were included in this review and 23 showed that disadvantaged socioeconomic circumstances were significantly associated with reduced respiratory function. The meta-analysis including seven papers showed a significant difference of -0.31 (95% CI -0.42 to -0.21) litres in forced expiratory volume in the first second between children, adolescents and young adults from disadvantaged versus advantaged socioeconomic circumstances. Specifically a difference of -0.31 (95% CI -0.51 to -0.10) litres in girls and -0.43 (95% CI -0.51 to -0.35) litres in boys was observed.

Conclusions Children, adolescents and young adults from disadvantaged socioeconomic circumstances had lower respiratory function, and boys presented higher respiratory health inequalities. This information contributes to explain the social patterning of respiratory diseases, and might enable health policy makers to tackle respiratory health inequalities at early ages.

INTRODUCTION

Disadvantaged socioeconomic circumstances have been associated with worse respiratory health outcomes, as for instance, underdeveloped lungs and a higher risk of respiratory disease in later life.^{1–3} Studies on adult and

Strengths and limitations of this study

- This study is the first systematic review and meta-analysis quantifying the magnitude of difference in respiratory function in early ages due to disadvantaged socioeconomic circumstances.
- It includes a broad literature search, screening and data extraction performed in duplicate, a firm study quality assessment and a comprehensive data analysis, including numerous sensitivity analysis.
- The review protocol has been developed in accordance with the Preferred Reporting Items for Systematic Review and Meta-analysis statement.
- The study limitations included the different estimates of forced expiratory volume in the first second presented in the studies and the high heterogeneity in the statistical analysis which also makes comparisons difficult. Nevertheless, we were able to perform the meta-analysis with two different estimates, showing that the effect size was quite similar independently of the estimate used.

older populations have demonstrated that individuals with lower socioeconomic position presented poorer respiratory function and a faster decline of lung volumes over time.^{3–5} Low social class was also previously associated with a reduction in forced expiratory volume in the first second (FEV₁) of more than 300 ml among men, and more than 200 ml among women.³

In the period from childhood to early adulthood, the association between socioeconomic circumstances and lung function has also been explored,^{6–10} and disadvantaged socioeconomic circumstances were associated with poorer lung function attainment.^{6,7} Growing evidence shows that childhood and adolescence constitute a critical time window for subsequent respiratory health¹¹ for several reasons. First, in this period lungs are growing,¹² and are highly susceptible to adverse influences, (eg, indoor and outdoor pollution, tobacco smoke, poor nutrition)

which might restrain lung development, modulate respiratory function and induce airway diseases.^{3 11 13 14} Additionally, it is becoming evident that respiratory diseases have part of their origins in early childhood,¹⁵ thus tracking respiratory function since this period has the potential to detect early life differences in respiratory growth, which might be influenced by the social context and the social determinants of health.^{16 17} Moreover, it has been demonstrated that lung volumes tend to increase from birth until early adulthood,^{12 18} therefore by studying this period we are able to assess inequalities in the maximal lung function attained.

Prior studies also suggest that there are sex differences in lung physiology and development, and these differences impact the incidence, susceptibility and severity of several lung diseases.^{19 20} Specifically in spirometry tests, the studies demonstrated that throughout childhood and adolescence, boys have 7%–8% larger lungs, but girls have faster lung rates (shorter expiratory time constants), judged from the FEV₁/forced vital capacity (FVC) ratio.^{12 21}

Therefore, ascertaining the impact of early life socioeconomic circumstances on respiratory function is crucial to prevent uneven lung function growth among the different socioeconomic groups, which could result in unequal prevalence of respiratory diseases over the life course. Hence, this study aimed to systematically review the published evidence on the association between socioeconomic circumstances and respiratory function in children, adolescents and young adults, stratified by sex. Specifically, we aimed to assess the direction of this association, and to quantify its magnitude by conducting a meta-analysis, if possible, due to the nature of the studies.

METHODS

This systematic review and meta-analysis was performed and is reported in accordance with Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) guidelines.²²

Search strategy

A search in Medline, ISI-Web of Science and Scopus was conducted from inception up to 22 January 2018. The search expression included numerous MESH terms and other relevant words and expressions ('Lung function' OR spirometry OR 'FEV₁' OR 'Forced Expiratory Volume' OR 'Forced Vital Capacity' OR 'FVC' OR 'pulmonary function' OR 'respiratory function' OR 'total lung capacity' OR tlc) AND ('socioeconomic factors' OR 'socioeconomic position' OR 'social class' OR 'socioeconomic determinants' OR 'socioeconomic class' OR poverty OR education OR income OR occupation OR wealth OR deprivation OR overcrowding OR unemployment) AND (infant OR child* OR 'preschool child*' OR adolesc* OR youth OR teenager OR young OR 'young adult'). Further details on the search expression can be seen in (online supplementary table S1). Early life was considered the

period from childhood to early adulthood, which also matches the period of lung growth.^{12 23} Evidence suggests that FEV₁ and FVC keep increasing from birth till 25 years of age, that is, young adulthood, then remain stable for about 5–10 years, and start declining in later adulthood.¹² Two researchers (Vânia Rocha and Sara Soares) independently screened all titles, abstracts and keywords, removed articles clearly failing to meet the inclusion criteria, and retrieved potentially eligible articles for full-text review. The reference lists of the reviewed articles were also screened for potentially relevant articles that the electronic search failed to identify. Any disagreement between the researchers was sorted out by consulting a third investigator (Sílvia Fraga).

Eligibility criteria

The screening process occurred in three steps: first, articles were excluded based on title, abstract and keywords. In step 2, full texts of the articles were evaluated to determine eligibility based on previously defined criteria. And, in step 3, the selected articles were re-evaluated to determine their adequacy for data extraction. Therefore, during the whole screening process the investigators consecutively applied the following criteria to exclude studies: (1) That were not original peer-reviewed observational studies of the general population. (2) Not written in English, French, Portuguese or Spanish. (3) Not involving humans (eg, in vitro or animal studies). (4) That were review articles, editorials, methodological studies, conference or meeting abstracts, case reports or case studies, commentaries and letters or book chapters without original data. (5) With subjects older than 25 years. (6) That did not address respiratory function by different socioeconomic circumstances. (7) That did not report respiratory function with at least one spirometry value (eg, FEV₁; FVC; ratio between FEV₁ and FVC, FEV₁/FVC; forced expiratory flow, FEF) by at least one socioeconomic indicator (ie, education, income, occupation, etc). (8) In which socioeconomic factors or respiratory function variables were just used for adjustments.

Data extraction

Data extraction was undertaken independently by the researchers in order to retrieve information on: authors and year; country; study design; sample size (total and number of subjects involved in the analysis of socioeconomic circumstances and respiratory function); female proportion; participants' age range or mean age with SD; information on diseases and/or respiratory symptoms; socioeconomic indicators; respiratory function indices, with the respective reference equations; and the relationship between socioeconomic circumstances and respiratory function indices.

Quality assessment

The risk of bias of each study was assessed independently by two reviewers using the Newcastle–Ottawa Scale (NOS).²⁴ For longitudinal studies, the original eight-item

NOS for cohort studies was used to assess the three key areas of potential bias—selection of participants, comparability and measurements. For cross-sectional studies, only the relevant items were used assessing selection of participants, comparability and the associated factors.^{24 25} More details on the items assessed can be found in online supplementary text S1 and S2. The NOS for cohort studies ranges between zero and nine stars and for cross-sectional studies ranges between zero and six. Any disagreements between the two reviewers were resolved by discussion with a third investigator (Sílvia Fraga).

Data analysis

As summary measures, we extracted the direction of the association (eg, inexistent, positive or negative) and the magnitude of the association between the socioeconomic indicators and respiratory function indices. A positive association was considered when advantaged socioeconomic circumstances were associated with an increase in respiratory function or disadvantaged socioeconomic circumstances led to a decrease in respiratory function; a negative association was considered when advantaged socioeconomic circumstances were associated to a decrease in respiratory function or disadvantaged socioeconomic circumstances led to an increase in respiratory function.

Owing to the heterogeneity in the studies analyses, only articles that reported means and SD between advantaged and disadvantaged socioeconomic circumstances groups were brought forward into the meta-analysis. The estimates from articles reporting means and SD were transformed into standardised mean differences (SMDs) between advantaged and disadvantaged socioeconomic groups.

In the meta-analysis we also narrowed our focus to FEV₁ measurements, as this respiratory function indicator has been the most widely reported and best understood index in the medical literature.¹² Pooled SMDs and corresponding 95% CIs were calculated by the DerSimonian-Laird method assuming a random-effects model, to account for both within-study and between-study variances.²⁶ Between-study heterogeneity was quantified using I-squared (I²) statistic. This statistic describes the percentage of variation across studies due to heterogeneity rather than chance.²⁷ Visual inspection of the funnel plot, the Egger's regression asymmetry test and the Beggs' test were used for publication bias assessment.²⁸ A broadly symmetrical plot indicated a lower risk of bias against the publication of negative results.

Sensitivity analyses

Sensitivity analyses were carried out in seven ways: (1) Applying a fixed-effects model, assuming an equal effect size across studies. (2) Conducting the meta-analysis including studies which reported the association between socioeconomic circumstances and lung function with β -coefficients from linear regression along with CIs, to test if the use of a different statistical measure would

Figure 1 Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) flow diagram of the literature search.

lead to different results. (3) Presenting the effect size by type of study. (4) Presenting the effect size by socioeconomic indicator. (5) Showing the effect size separately for healthy participants versus those who reported respiratory symptoms and diseases. (6) Showing the effect size separately for studies which presented adjusted values of FEV₁ and those who did not perform adjustments. (7) Repeating the meta-analysis with each study removed sequentially. The analyses were carried out with STATA (V.11.0, StataCorp, College Station, Texas, USA).

Patient and public involvement

No patients were involved in this study, since we used data from previously published papers. However, this study aimed to raise awareness among the scientific community and policy makers on the effect of socioeconomic circumstances in respiratory function since the early ages, with a potential impact on respiratory health throughout the life course.

RESULTS

Figure 1 presents the literature search flow diagram. The systematic database search identified 5359 publications; after removing duplicates, the title, abstract and keywords were screened in 3308 papers. Five hundred and twenty-eight were full-text screened, and from these thirty-three papers were included. The reference list screening did not retrieve any additional manuscript. The results of the quality assessment with NOS showed that from the 33 papers included, only two papers^{29 30} had less than the median stars that can be attributed to each

study, that is, scored as low quality (online supplementary table S2a,b).

Table 1 shows the characteristics of the included articles, 14 longitudinal and 19 cross-sectional studies. Samples sizes ranged from 77³¹ to 24010³² participants, and the majority of studies reported lung function results for both sexes together, with the exception of six studies^{6 9 33–36} that reported their findings separately for boys and girls, and one study³⁷ that merely included girls. Participants' age ranged from 5 to 24 years old. Countries classified as high, upper-middle, lower-middle and low-income levels were included, and no significant differences were found between them. Most of the included studies were performed in high-income countries, as for example, USA^{9 31 32 34 38–42} or the UK,^{7 8 43–46} or a lower-middle income country as India.^{35 45}

From the 33 articles incorporated in this review, 27 used education as the socioeconomic indicator, or as part of an index of socioeconomic circumstances; reporting mainly both parents' education^{29 31 32 35–39 44 47–51} or the mothers' education.^{9 37 40–42 46 52–54} Occupation and income were reported in 12 studies, mainly as both parents' occupation^{30 35 36 38 44 46 47 53} and family or household income.^{6 31 35 36 39 41 42 44 50 51}

All the included studies reported estimates for FEV₁, either as mean values of volume,^{6 9 10 30 35 36 46 48–50 52 54} mean difference,^{34 44 46} percentages,^{29 39} percentage of predicted,^{31 37 38 40–43 45 46 51 53 55} percentage of change,^{7 32 33 56} z-scores,^{8 45} and/or the relation between FEV₁ and FVC.^{29 30 33 35 37 47 50}

A positive association between the socioeconomic circumstances and the respiratory function indices was found in 23^{6 7 29–31 33–37 39 41–46 48 50 51 53 54 56} of the 33 articles, showing a reduced respiratory function in children, adolescents and young adults from disadvantaged socioeconomic circumstances, followed by no association observed in 9 studies,^{8 9 32 38 40 47 49 52 55} and a negative association in 1 study.¹⁰

Figure 2 illustrates the meta-analysis of SMD in FEV₁ between disadvantaged and advantaged socioeconomic groups by sex, including seven studies.^{6 30 35 36 50 54 57} Overall, children, adolescents and young adults from disadvantaged socioeconomic circumstances presented a significantly lower FEV₁ of −0.31 (95% CI −0.42 to −0.21) litres when compared with those from advantaged socioeconomic circumstances. This trend was observed in both girls and boys, but the effect size was higher in boys (SMD −0.43; 95% CI −0.51 to −0.35 litres). The I² of the subanalysis in boys showed no heterogeneity (I² 0.0%, p=0.664), in contrast with the high heterogeneity between the studies of girls (I² 71.2%, p=0.002). The effect size for both sexes together was lower, being an SMD of −0.16 (95% CI −0.24 to −0.08) litres between participants from disadvantaged versus advantaged socioeconomic circumstances. A funnel plot was computed to assess publication bias (figure 3), and its visual inspection did not indicate the presence of small-study effects. Egger's regression asymmetry test did not suggest significant small-study

effects (p=0.473) and Beggs' test also confirmed the absence of publication bias (p=0.458).

In the first sensitivity analysis, the use of a fixed-effects models slightly increased the pooled effect size in the meta-analysis (SMD −0.34; 95% CI −0.38 to −0.29 litres) (online supplementary figure S1). Then, five further studies^{7 10 33 42 56} were grouped into a meta-analysis of β -coefficients, showing that a decrease in one unit of socioeconomic circumstances leads to a reduction of −0.35 (−0.77 to 0.07) litres in FEV₁, which is very similar to the effect size found in the meta-analysis of the means and SD (online supplementary figure S2). Grouping studies by design had no influence on the pooled effect size and we observed that the effect sizes of the subanalysis were very similar in both cross-sectional (−0.30; 95% CI −0.44 to −0.16 litres) and longitudinal (−0.33; 95% CI −0.52 to −0.14 litres) studies (online supplementary figure S3). Presenting the effect size by socioeconomic indicators had no influence on the pooled effect size, nevertheless it slightly reduced the heterogeneity in the subanalyses (online supplementary figure S4). We also observed that the effect size of socioeconomic disadvantage in FEV₁ was almost double in participants with respiratory symptoms and diseases (−0.44; 95% CI −0.52 to −0.36) when compared with those without symptoms and diseases (−0.24; 95% CI −0.37 to −0.10) (online supplementary figure S5). Grouping studies by adjusted estimates or not showed a higher effect size in the group of studies with adjusted estimates (−0.36; 95% CI −0.51 to −0.21 vs −0.25; 95% CI −0.42 to −0.09) (online supplementary figure S6). The adjustment variables were mainly age, sex, height and weight. Finally, excluding each study sequentially did not alter the final results (online supplementary figure S7).

DISCUSSION

This study systematically reviewed the evidence on the association between socioeconomic circumstances and respiratory function in children, adolescents and young adults considering sex differences. From the 33 papers included, 23 showed that disadvantaged socioeconomic circumstances were associated with lower respiratory function in early ages. In the meta-analysis, which included seven studies, we also found a mean difference of −0.31 litres in FEV₁ between participants from disadvantaged versus advantaged socioeconomic circumstances, specifically a difference of −0.31 litres among girls and −0.43 litres among boys. To the best of our knowledge, this is the first meta-analysis to quantify the association between socioeconomic circumstances and respiratory function in children, adolescents and young adults, and results are close to the findings reported in a previous non-systematic review in adults, which showed a lower FEV₁ of more than 0.2 litres among women and of more than 0.3 litres among men.³

Additionally, we observed that this difference was higher in boys, with boys of poorer socioeconomic circumstances presenting an overall difference of −0.43 litres in FEV₁

Table 1 Characteristics of the included studies

Reference, year	Country	Study design	Sample size*	Percentage of women	Age (range/mean±SD)	Information on diseases/symptoms	Socioeconomic indicator	Respiratory function indices†	Relationship between respiratory function and socioeconomic indicators
Ware <i>et al</i> , 1984 ³⁸	USA	Longitudinal	7145	n.m.	6–9	Respiratory symptoms	SES Index, parental education and occupation	FEV ₁ , FVC (Dockery <i>et al</i> , 1983 equations)	No association
Goren and Goldsmith, 1986 ²⁹	Israel	Cross-sectional	n.m.	n.m.	Second and fifth grade	Respiratory symptoms	Crowding Index, parental education	FVC, FEV ₁ , FEV ₁ /FVC, PEF	Positive association—higher crowding index and lower maternal education was associated with reduced respiratory function measured by FEV ₁ /FVC
Kauffmann <i>et al</i> , 1989 ⁵²	France	Cross-sectional	1160 (828)	48	6–10	n.m.	Maternal education	FEV ₁ , FVC, FEF _{25–75}	No association
Azizi and Henry, 1990 ⁵⁵	Malaysia	Cross-sectional	1214	42.1	7–12	Respiratory symptoms	Paternal education	FEV ₁ , FVC, FEF _{25–75}	No association
Kitchen <i>et al</i> , 1992 ⁵³	Australia	Longitudinal	223	≈50	8	Asthma and respiratory symptoms	Social class (parental occupation), maternal education	VC, FVC, FEV ₁	Positive association—lower social class was associated with reduced respiratory function measured by FVC and FEV ₁ /FVC
Demissie <i>et al</i> , 1996 ³³	Canada	Cross-sectional	989 (916)	n.m.	5–13	n.m.	SES Score (parental income, education, occupation)	FEV ₁ , FVC, FEV ₁ /FVC	Positive association—low SES was associated with reduced respiratory function measured by FEV ₁ and FVC, in boys
Lercher and Schmitzberger, 1997 ⁵⁴	Austria	Cross-sectional	644	n.m.	7.5–11	n.m.	Maternal education	FVC, FEV ₁ , PEF, MEF ₂₅ , MEF ₅₀ , MEF ₇₅	Positive association—low maternal education was associated with reduced respiratory function measured by FEV ₁
Hancox <i>et al</i> , 2004 ¹⁷	New Zealand	Longitudinal	1037 (980)	48	0–26	Asthma and respiratory symptoms	SES (parental occupation, education, income), parental income	FEV ₁ /FVC	No association
Harik-Khan <i>et al</i> , 2004 ³⁴	USA	Cross-sectional	752	50.9	8–12	Healthy	Family head education, Poverty Index	FEV ₁ , FVC (Hankinson <i>et al</i> , 1999 equations)	Positive association—poverty in boys and lower parental education in girls was associated with reduced respiratory function measured by FEV ₁ , FVC
Raju <i>et al</i> , 2005 ³⁵	India	Cross-sectional	2616	40	5–15	Healthy	SES with Modified Kuppuswamy Scale (parental education and occupation, family income)	FEV ₁ , FVC, FEV ₁ /FVC, PEFR	Positive association—lower SES was associated with reduced respiratory function measured by all indices

Continued

Table 1 Continued

Reference, year	Country	Study design	Sample size*	Percentage of women	Age (range/mean±SD)	Information on diseases/symptoms	Socioeconomic indicator	Respiratory function indices†	Relationship between respiratory function and socioeconomic indicators
Balmer <i>et al</i> , 2008 ³¹	USA	Longitudinal	77	55	6–8.9	Cystic fibrosis	Advantage Index (household income, parental education, social capital)	FEV ₁ (Wang <i>et al</i> , 1993 equations)	Positive association—lower scores in the advantage index was associated with reduced respiratory function measured by FEV ₁
Bennett <i>et al</i> , 2008 ³⁹	USA	Cross-sectional	87	56.3	7–18	Cystic fibrosis	SES (parental education, occupation)	FEV ₁	Positive association—lower SES was associated with reduced respiratory function measured by FEV ₁
Suglia <i>et al</i> , 2008 ⁹	USA	Cross-sectional	313	50	6–7	Respiratory symptoms	Maternal education	FVC, FEV ₁ , FEF _{25–75}	No association
Trabelsi <i>et al</i> , 2008 ³⁰	Tunisia	Cross-sectional	756	48.7	6–16	Healthy	SES (parental occupation)	FVC, FEV ₁ , FEV ₁ /FVC, PEF, MEF ₅₀ , MMEF _{25–75}	Positive association—lower SES was associated with reduced respiratory function measured by all indices
Tennant <i>et al</i> , 2010 ⁷	UK	Longitudinal	252	47.2	14	Respiratory symptoms	Social class (paternal occupation), housing conditions	FEV ₁ (Pistelli <i>et al</i> , 2000 equations)	Positive association—lower social class was associated with reduced respiratory function measured by FEV ₁
Yogev-Baggio <i>et al</i> , 2010 ⁴⁶	Israel	Longitudinal	1181	≈55	9.3±1.6	Healthy and respiratory symptoms	Paternal education, housing density	Changes in FVC and FEV ₁	Positive association—lower fathers' education was associated with reduced respiratory function measured by FEV ₁ in healthy children
Menezes <i>et al</i> , 2011 ⁶	Brazil	Longitudinal	4005	51	14–15	Asthma and respiratory symptoms	Family income	FEV ₁ , FVC	Positive association—lower family income was associated with reduced respiratory function measured by FEV ₁ and FVC, in girls
Slachetova <i>et al</i> , 2011 ³²	Multiplet†	Cross-sectional	24 010	48.9	6–12	n.m.	Parental education	FEV ₁ , FVC, PEF, MMEF	No association
Wu <i>et al</i> , 2012 ¹⁰	Taiwan	Cross-sectional	3994	49.3	12.4±0.6	n.m.	Area-level SES (occupation, income, education)	FEV ₁ , FVC, FEF _{25–75} , PEF	Negative association—higher SES was associated with reduced respiratory function measured by FEV ₁ , FVC, FEF _{25–75}
Taylor-Robinson <i>et al</i> , 2013 ⁴³	UK	Longitudinal	8055 (5324)	47	<18	Cystic fibrosis	Index of multiple deprivation based on area of residence	FEV ₁ % predicted	Positive association—reduced respiratory function measured by FEV ₁ was found in the most deprived quintile when compared with the least deprived quintile

Continued

Table 1 Continued

Reference, year	Country	Study design	Sample size*	Percentage of women	Age (range/mean±SD)	Information on diseases/symptoms	Socioeconomic indicator	Respiratory function indices	Relationship between respiratory function and socioeconomic indicators
Rebacz-Maron and Parafiniuk, 2014 ⁴⁸	Tanzania	Cross-sectional	255	n.m.	12.8–24.0	n.m.	Family material situation, parental education	FEV ₁ , FVC	Positive association—lower family material situation was associated with reduced respiratory function measured by FEV ₁ and FVC (<17.5 years)
Siniarska et al, 2014 ⁴⁹	Poland	Cross-sectional	444	50.7	13–16	n.m.	SES (parental education, number of rooms, sibling size)	VC, FEV ₁ , TV, MV, IRV, ERV, AP, RR	No association
Cogen et al, 2015 ⁴⁰	USA	Longitudinal	946	49.7	6–12	Cystic fibrosis	Maternal education, household income	FEV ₁ (Wang et al 1993 and Hankinson et al 1999 equations)	No association
Galobardes et al, 2015 ⁴⁴	UK	Longitudinal	6378	49.8	7–8	Asthma and respiratory symptoms	Parental education and occupation, household income, housing tenure	FEV ₁ , FVC, FEF _{25–75}	Positive association—low paternal education was associated with reduced respiratory function measured by FEV ₁
Lum et al, 2015 ⁸	UK	Longitudinal	2171 (1901)	≈50	5.2–11.8	Asthma and respiratory symptoms	Receiving free school meals, family affluence scale, index of multiple deprivation;	FEV ₁ , FVC (equations for multiethnic schoolchildren, 2012)	No association
Martínez-Briseño et al, 2015 ⁵⁰	Mexico	Longitudinal	2641 (1671)	n.m.	8–17	Healthy	Monthly family income, parental education	FEV ₁ , FVC, FEV ₁ /FVC (Martínez-Briseño et al 2013 equations)	Positive association—lower income and education was associated with reduced respiratory function measured by all indices
Sanders et al, 2015 ⁴¹	USA	Longitudinal	484	≈50	6–7	Cystic fibrosis	Maternal education, household income	FEV ₁ (Wang et al 1993 equations)	Positive association—low maternal education was associated with reduced respiratory function measured by FEV ₁
Cakmak et al, 2016 ⁵¹	Canada	Cross-sectional	2328 (1528)	≈50	9–11	Asthma and respiratory symptoms	Parental education, family income	FEV ₁ , FVC	Positive association—lower education and income was associated with reduced respiratory function measured by FEV ₁ , FVC
Lum et al, 2016 ⁴⁵	UK, India	Cross-sectional	8124 (2549)	43.7	5–17	n.m.	Socioeconomic circumstances	FEV ₁ , FVC (GLI equations, 2012)	Positive association—lower SEC was associated with reduced lung function measured by respiratory function z-scores in Hyderabad

Continued

Table 1 Continued

Reference, year	Country	Study design	Sample size*	Percentage of women	Age (range/mean±SD)	Information on diseases/symptoms	Socioeconomic indicator	Respiratory function indices†	Relationship between respiratory function and socioeconomic indicators
Kuti <i>et al</i> , 2017 ³⁶	Nigeria	Cross-sectional	250	50.8	9–17	n.m.	Overcrowding, socioeconomic class (parental occupation and education)	FEV ₁ , FVC, FEV ₁ /FVC (Knudson <i>et al</i> 1983 equations)	Positive association—lower social class was associated with reduced lung function measured with FEV ₁ and FVC in male participants from urban areas
Nowakowski <i>et al</i> , 2017 ³⁷	Poland	Cross-sectional	152	100	19–24	n.m.	SES Index (size of dwelling place, number of siblings, parental education)	FEV ₁ , FVC, FEV ₁ /FVC	Positive association—lower father's education and SES was associated with reduced respiratory function measured by FEV ₁ /FVC
Ong <i>et al</i> , 2017 ⁴²	USA	Longitudinal	1375 (1050)	50	6–13	Cystic fibrosis	Maternal education, household income	FEV ₁ (Wang <i>et al</i> 1993 and Hankinson <i>et al</i> 1999 equations)	Positive association—lower education and income was associated with reduced respiratory function measured by FEV ₁
Saad <i>et al</i> , 2017 ⁴⁶	UK	Cross-sectional	90	52.2	18–23	Asthma and respiratory symptoms	Socioeconomic status (parental and grand parental education and occupation)	FEV ₁ , FVC, FEV ₁ /FVC (NHANES III reference equations)	Positive association—higher maternal education and higher paternal occupation were associated with higher respiratory function measured by FVC.

*Total sample size (and the number of participants included in the analysis of lung function indices by SES indicator).

†When respiratory function indices were computed using reference equations, it is mentioned in brackets.

‡Multiple countries: Poland, Hungary, Slovakia, The Czech Republic, Netherlands, Germany, Austria, USA.

AP, apnoea; ERV, expiratory reserve volume; FEF, forced expiratory flow; FEV₁, forced expiratory volume during first second; FEV₁/FVC, ratio between FEV₁ and FVC; FVC, forced vital capacity; GLI, Global Lung Function Initiative; IRV, inspiratory reserve volume; MEF, maximal expiratory flow; MMEF, maximum mid-expiratory flow; MV, minute ventilation; n.m., not mentioned; NHANES, National Health and Nutrition Examination Survey; PEF, peak expiratory flow; PEFR, peak expiratory flow rate; RR, respiration rate per minute; SEC, socioeconomic circumstances; SES, socioeconomic status; TV, tidal volume; VC, vital capacity.

Figure 2 Forest plot of the meta-analysis of the standardised mean difference (SMD) in forced expiratory volume in the first second (FEV₁) between disadvantaged and advantaged socioeconomic groups, by sex. Note: Weights are from random effects analysis; SES(1): socioeconomic status classified using more than one socioeconomic indicator as education, occupation or/and income.

when compared with those of advantaged socioeconomic circumstances. Sex has previously been referred to as an important predictor of lung function, and standard morphometric methods confirmed that boys had larger lung size, more respiratory bronchioles and wider airway diameters compared with girls of the same age and stature, which explains their increased lung volumes.^{12 58 59} However these anthropometric differences were not enough to clarify the differences found between boys from different socioeconomic circumstances. There is some prior evidence showing that socioeconomic inequalities in health, including outcomes of respiratory development and disease, are more pronounced in men of different age groups.^{19 20 60} Several explanations

Figure 3 Funnel plot from the meta-analysis of forced expiratory volume in the first second by socioeconomic circumstances.

have been proposed, either showing that with regards to health outcomes men are more sensitive to socioeconomic inequalities between groups,⁶⁰ or supporting the existence of biological and anatomical differences between men and women which lead to differences in lung function between the sexes.^{19 61 62} Prior studies have reported that since the prenatal period lung maturation is more advanced in female fetuses than in the male,⁶¹ that lung growth during adolescence is faster in girls than in boys,⁶² or that the prevalence of respiratory diseases in childhood, for instance asthma and allergic rhinitis, is higher in boys.¹⁹ All these hypotheses may help explain differences between boys and girls even at early ages; nevertheless further studies are needed to investigate this tendency. Sex differences seem to play an important role in both healthy and diseased lungs from very early life,¹⁹ and considering these differences in epidemiological studies might be imperative to obtain reliable estimates on respiratory health inequalities.

FEV₁ has been the most widely reported index of respiratory function in the included studies. This finding confirmed previous evidence^{12 63} suggesting that FEV₁ is by far the most reported index in medical literature as it provides information on airflow based on airway calibre and elasticity.⁶⁴ Moreover, it allows determine FEV₁/FVC ratio, which is used to detect the presence of airway obstruction and to diagnose respiratory diseases.⁶⁵ Indeed, spirometry has been used as a pivotal screening test of general respiratory health, as it is simple, non-invasive, relatively inexpensive, and can provide information with the potential to prevent, identify and quantify respiratory diseases.^{63 66} Nevertheless, we also observed that spirometry assessment has been mostly directed to specific populations, such as patients with respiratory symptoms,^{7 29 38 55 57} asthma^{6 8 44 47 51 53} or cystic fibrosis,^{31 39-43} and its use in healthy children and adolescents^{30 34 35 50 56} to monitor lung growth has been less explored. In fact, our sensitivity analysis confirmed that the effect of disadvantaged socioeconomic circumstances in participants with respiratory symptoms and disease are almost double compared with the effect on healthy participants, supporting the need for respiratory screening and continuous monitoring of these populations. However, evidence showed that the two respiratory diseases with the largest burden on patients and on society (asthma and chronic obstructive pulmonary disease) have part of their origins in early life^{15 67} and tracking respiratory function in healthy children since this period might also have potential to detect early life differences in respiratory growth and in the maximal lung function attainment at early adulthood with clinical significance for future respiratory diseases.

Education, occupation and income were the most used socioeconomic indicators associated with respiratory function. These three indicators have been extensively referred to as most common to characterise socioeconomic position and to describe and evaluate health inequalities,⁶⁸⁻⁷⁰ as single indicators^{4 42} or as combination

into SES indexes.^{35 47} Even though using different socioeconomic indicators may result in gradients of varying slopes, no single best socioeconomic indicator is suitable for all study aims and each indicator may be more or less relevant to the different health outcomes at different stages of the life course.⁷¹ The SES indexes are intended to incorporate and therefore to adjust for different aspects of socioeconomic position but the effect from each single indicator remains unknown.⁷¹ A single measure will not encompass the entire effect of socioeconomic circumstances on health, but it might be most appropriate for understanding the specific mechanisms of socioeconomic inequalities in health.⁷¹ In fact, education was one of the most reported SES indicator, as either parents' education or maternal education. Maternal education is a good example of how socioeconomic factors might have an indirect effect on respiratory function, as previous studies have shown, this indicator is highly correlated with the nurture provided to the children, either by ensuring adequate nutritional intake,^{72 73} which influences lung growth, or by avoiding health risk factors (eg, smoking during pregnancy or passive smoking, physical inactivity, etc)⁷⁴ with immediate or long-term consequences on respiratory health.

Additionally, maternal education was associated with children's height for age,⁷⁵ which is related with respiratory function;^{6 76 77} however only 13^{6 8–10 32 33 35 46 49 52 54–56} of the 33 included studies made adjustments for height. Therefore this study is an alert to the need for considering height when assessing lung function since higher height is associated with larger lung capacity,⁷⁸ and there is evidence that height is strongly socially patterned since childhood.⁷⁵ Age and sex are also important determinants of lung volumes and capacities.⁵⁸ However, only 13 studies^{6–8 10 32 42 44 46 47 50 55 56 79} adjusted for sex and 15 adjusted for age.^{6 8 10 29 32 33 41 42 44 46 47 50 52 54 56} These results were in line with our sensitivity analysis comparing studies with and without adjusted estimates that showed a higher effect size in the group of studies with adjusted estimates. Age, sex and height, considered the main predictors of lung function, were the more frequent adjustment variables, following previously established guidelines recommending that spirometry indices should account for these predictors to increase accuracy and reduce biased estimations.^{12 80}

Other limitations should be acknowledged. The interpretation of spirometry results is also largely dependent on the use of appropriate reference values,⁶⁵ which was only mentioned by about a third (12 in 33) of the included studies. The high variability in the indicators of socioeconomic position reduced the power to detect statistically significant differences, making comparisons difficult. To address this issue we did a sensitivity analysis grouping studies by socioeconomic indicators, however, these results showed that grouping studies by these indicators would not influence the overall pooled effect size, although it slightly reduced heterogeneity in subanalyses. The different estimates of FEV₁ presented in

the studies (mean values, predicted values, percentages, z-scores) and the high heterogeneity in the statistical analysis make it difficult to compare studies, introducing a potential source of selection bias where only studies with extractable and comparable results are included in the meta-analysis. We addressed this in two ways, first by contacting authors for further data; and then by assessing publication bias with visual inspection of funnel plots and Egger's and Beggs' tests, which confirmed the absence of publication bias. Moreover, computing the meta-analysis with a different statistical measure (β -coefficients) showed a very similar result.

The studies included in both qualitative and quantitative syntheses mainly had a cross-sectional design (n=19) rather than longitudinal (n=14). We could expect that studies with longitudinal designs would show higher effects of disadvantaged socioeconomic circumstances in lung function since these studies collected data over time and are more appropriate to assess causal relationships; nevertheless, the effect sizes by type of study were quite similar for both cross-sectional and longitudinal studies. Moreover, as the exposure and the outcome are both measured in early ages, we hypothesise that the effects are not yet completely established, and perhaps if the outcome was measured during adulthood the differences would be more pronounced.

Finally, the reporting quality of the included articles should be considered. Nevertheless, only two articles were scored as low quality, having less than three stars in a maximum of six for cross-sectional studies. Therefore, we did not expect that the quality of articles had relevant implications in our conclusions.

CONCLUSIONS

This systematic review and meta-analysis shows that children, adolescents and young adults from disadvantaged socioeconomic circumstances presented lower respiratory function, and respiratory health inequalities are higher among boys. These results highlight the implications of early disadvantaged socioeconomic circumstances for respiratory health. This evidence also contributes to explain the social patterning of respiratory diseases during adulthood and at older ages, and might enable health policy makers to tackle respiratory health inequalities at early ages.

Contributors Vânia Rocha contributed to the study conceptualisation, conducted the literature search, data analysis and interpretation, and drafted the manuscript. Sara Soares conducted the literature search and data analysis. Silvia Stringhini contributed to data analysis, interpretation and critical revision. Silvia Fraga performed the study conceptualisation, contributed to data analysis, interpretation, critical revision and editing of the review. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

Funding This work was supported by FEDER through the Operational Programme Competitiveness and Internationalization and national funding from the Foundation for Science and Technology (FCT; Portuguese Ministry of Science, Technology and Higher Education) under the EPIUnit, Instituto de Saúde Pública da Universidade do Porto, Portugal (POCI-01-0145-FEDER-006862; Reference: UID/DTP/04750/2013) and within the projects "How childhood social adversity

shapes health: The biology of social adversity" (POCI-01-0145-FEDER-016838; Reference: PTDC/DTP-EPI/1687/2014) and "When do health inequalities start? Understanding the impact of childhood social adversity on health trajectories from birth to early adolescence" (POCI-01-0145-FEDER-029567; Reference: PTDC/SAU PUB/29567/2017). It is also supported by the LIFEPAth Consortium (Horizon 2020 grant n° 633666), the FCT PhD grants SFRH/BD/103726/2014 (Vânia Rocha) and SFRH/BD/108742/2015 (Sara Soares), and the FCT Investigator contracts DL57/2016/CP1356/CT0001 (Sílvia Fraga) co-funded by the FCT and the POCH/FSE Programme.

Competing interests None declared.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement Extracted data are available upon request to the corresponding author.

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REFERENCES

1. The Lancet Respiratory Medicine. Health inequality: a major driver of respiratory disease. *Lancet Respir Med* 2017;5:235.
2. Ellison-Loschmann L, Sunyer J, Plana E, et al. Socioeconomic status, asthma and chronic bronchitis in a large community-based study. *Eur Respir J* 2007;29:897–905.
3. Hegewald MJ, Crapo RO. Socioeconomic status and lung function. *Chest* 2007;132:1608–14.
4. Tabak C, Spijkerman AM, Verschuren WM, et al. Does educational level influence lung function decline (Doetinchem Cohort Study)? *Eur Respir J* 2009;34:940–7.
5. Gaffney AW, Hang JQ, Lee MS, et al. Socioeconomic status is associated with reduced lung function in China: an analysis from a large cross-sectional study in Shanghai. *BMC Public Health* 2016;16:96.
6. Menezes AM, Dumith SC, Perez-Padilla R, et al. Socioeconomic trajectory from birth to adolescence and lung function: prospective birth cohort study. *BMC Public Health* 2011;11:596.
7. Tennant PW, Gibson GJ, Parker L, et al. Childhood respiratory illness and lung function at ages 14 and 50 years: childhood respiratory illness and lung function. *Chest* 2010;137:146–55.
8. Lum S, Bountziouka V, Sonnappa S, et al. Lung function in children in relation to ethnicity, physique and socioeconomic factors. *Eur Respir J* 2015;46:1662–71.
9. Suglia SF, Ryan L, Laden F, et al. Violence exposure, a chronic psychosocial stressor, and childhood lung function. *Psychosom Med* 2008;70:160–9.
10. Wu YF, Wu CK, Chen DR, et al. Association of area socioeconomic status with lung function in children. *Prev Med* 2012;55:644–9.
11. Dratva J, Zemp E, Dharmage SC, et al. Early life origins of lung ageing: early life exposures and lung function decline in adulthood in two European cohorts aged 28–73 years. *PLoS One* 2016;11:e0145127.
12. Quanjer PH, Stanojevic S, Stocks J, et al. Changes in the FEV₁/FVC ratio during childhood and adolescence: an intercontinental study. *Eur Respir J* 2010;36:1391–9.
13. Apostol GG, Jacobs DR, Tsai AW, et al. Early life factors contribute to the decrease in lung function between ages 18 and 40. *Am J Respir Crit Care Med* 2002;166:166–72.
14. Liao SY, Lin X, Christiani DC. Occupational exposures and longitudinal lung function decline. *Am J Ind Med* 2015;58:14–20.
15. Cukic V, Lovre V, Dragisic D, et al. Asthma and Chronic Obstructive Pulmonary Disease (COPD) - differences and similarities. *Mater Sociomed* 2012;24:100–5.
16. Williams DR, Sternthal M, Wright RJ. Social determinants: taking the social context of asthma seriously. *Pediatrics* 2009;123:S174–S184.
17. Stocks J, Sonnappa S. Early life influences on the development of chronic obstructive pulmonary disease. *Thorax* 2013;7:161–73.
18. Melén E, Guerra S. Recent advances in understanding lung function development. *F1000Res* 2017;6:726.
19. Carey MA, Card JW, Voltz JW, et al. It's all about sex: male-female differences in lung development and disease. *Trends Endocrinol Metab* 2007;18:308–13.
20. Matthews S, Manor O, Power C. Social inequalities in health: are there gender differences? *Soc Sci Med* 1999;48:49–60.
21. Merkus PJ, ten Have-Opbroek AA, Quanjer PH. Human lung growth: a review. *Pediatr Pulmonol* 1996;21:383–97.
22. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Ann Intern Med* 2009;151:264–9.
23. Berry CE, Billheimer D, Jenkins IC, et al. A distinct low lung function trajectory from childhood to the fourth decade of life. *Am J Respir Crit Care Med* 2016;194:607–12.
24. Wells GA, Shea B, O'Connell D, et al. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp (Accessed 15 Oct 2018).
25. Lee CS, Liew TM. Inappropriate prescribing among older persons in primary care: protocol for systematic review and meta-analysis of observational studies. *BMJ Open* 2017;7:e015395.
26. Harris RJ, Deeks JJ, Altman DG, et al. Metan: fixed- and random-effects meta-analysis. *Stata J* 2008;8:3–28.
27. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. *Stat Med* 2002;21:1539–58.
28. Sterne JAC, Gavaghan D, Egger M. Publication and related bias in meta-analysis. *J Clin Epidemiol* 2000;53:1119–29.
29. Goren AI, Goldsmith JR. Epidemiology of childhood respiratory disease in Israel. *Eur J Epidemiol* 1986;2:139–50.
30. Trabelsi Y, Pariès J, Harrabi I, et al. Factors affecting the development of lung function in Tunisian children. *Am J Hum Biol* 2008;20:716–25.
31. Balmer DF, Schall JI, Stallings VA. Social disadvantage predicts growth outcomes in preadolescent children with cystic fibrosis. *J Cyst Fibros* 2008;7:543–50.
32. Slachetova H, Gehring U, Hoek G, et al. Parental education and lung function of children in the PATY study. *Eur J Epidemiol* 2011;26:45–54.
33. Demissie K, Ernst P, Hanley JA, et al. Socioeconomic status and lung function among primary school children in Canada. *Am J Respir Crit Care Med* 1996;153:719–23.
34. Harik-Khan RI, Muller DC, Wise RA. Racial difference in lung function in African-American and White children: effect of anthropometric, socioeconomic, nutritional, and environmental factors. *Am J Epidemiol* 2004;160:893–900.
35. Raju PS, Prasad KV, Ramana YV, et al. Influence of socioeconomic status on lung function and prediction equations in Indian children. *Pediatr Pulmonol* 2005;39:528–36.
36. Kuti BP, Oladimeji OI, Kuti DK, et al. Rural-urban disparity in lung function parameters of Nigerian children: effects of socio-economic, nutritional and housing factors. *Pan Afr Med J* 2017;28.
37. Nowakowski D, Kłis K, Żurawiecka M, et al. Influence of socioeconomic and anthropometric factors on respiratory function in female university students. *Adv Exp Med Biol* 2017;968:41–48.
38. Ware JH, Dockery DW, Spiro A, et al. Passive smoking, gas cooking, and respiratory health of children living in six cities. *Am Rev Respir Dis* 1984;129:366–74.
39. Bennett DS, Snooks Q, Llera S, et al. Monitoring and internalizing symptoms among youths with cystic fibrosis. *J Child Health Care* 2008;37:278–92.
40. Cogen J, Emerson J, Sanders DB, et al. Risk factors for lung function decline in a large cohort of young cystic fibrosis patients. *Pediatr Pulmonol* 2015;50:763–70.
41. Sanders DB, Emerson J, Ren CL, et al. Early childhood risk factors for decreased FEV₁ at age six to seven years in young children with cystic fibrosis. *Ann Am Thorac Soc* 2015;12:1170–6.
42. Ong T, Schechter M, Yang J, et al. Socioeconomic status, smoke exposure, and health outcomes in young children with cystic fibrosis. *Pediatrics* 2017;139:e20162730.
43. Taylor-Robinson DC, Smyth RL, Diggle PJ, et al. The effect of social deprivation on clinical outcomes and the use of treatments in the UK cystic fibrosis population: a longitudinal study. *Lancet Respir Med* 2013;1:121–8.
44. Galobardes B, Granell R, Sterne J, et al. Childhood wheezing, asthma, allergy, atopy, and lung function: different socioeconomic patterns for different phenotypes. *Am J Epidemiol* 2015;182:763–74.
45. Lum S, Bountziouka V, Quanjer P, et al. Challenges in collating spirometry reference data for South-Asian children: an observational study. *PLoS One* 2016;11:e0154336.
46. Saad NJ, Patel J, Minelli C, et al. Explaining ethnic disparities in lung function among young adults: a pilot investigation. *PLoS One* 2017;12:e0178962.
47. Hancox RJ, Milne BJ, Taylor DR, et al. Relationship between socioeconomic status and asthma: a longitudinal cohort study. *Thorax* 2004;59:376–80.

48. Rębacz-Marón E, Parafiniuk M. Spirometry results (FEV1 and FVC) in young Bantu men from Tanzania vs environmental and family characteristics. *Ann Hum Biol* 2014;41:15–22.
49. Siniarska A, Strzyżewska D, Koziel S. Variation in indicators of respiratory functions among Warsaw adolescents in relation to ambient air pollution and smoking. *Coll Antropol* 2014;38:195–200.
50. Martínez-Briseño D, Fernández-Plata R, Gochicoa-Rangel L, et al. Socioeconomic status and longitudinal lung function of healthy Mexican children. *PLoS One* 2015;10:e0136935.
51. Cakmak S, Hebborn C, Cakmak JD, et al. The modifying effect of socioeconomic status on the relationship between traffic, air pollution and respiratory health in elementary schoolchildren. *J Environ Manage* 2016;177:1–8.
52. Kauffmann F, Tager IB, Muñoz A, et al. Familial factors related to lung function in children aged 6–10 years. Results from the PAARC epidemiologic study. *Am J Epidemiol* 1989;129:1289–99.
53. Kitchen WH, Olinsky A, Doyle LW, et al. Respiratory health and lung function in 8-year-old children of very low birth weight: a cohort study. *Pediatrics* 1992;89(6 Pt 2):1151–8.
54. Lercher P, Schmitzberger R. Birth weight, education, environment, and lung function at school age: a community study in an alpine area. *Eur Respir J* 1997;10:2502–7.
55. Azizi BH, Henry RL. Effects of indoor air pollution on lung function of primary school children in Kuala Lumpur. *Pediatr Pulmonol* 1990;9:24–9.
56. Yogev-Baggio T, Bibi H, Dubnov J, et al. Who is affected more by air pollution-sick or healthy? Some evidence from a health survey of schoolchildren living in the vicinity of a coal-fired power plant in Northern Israel. *Health Place* 2010;16:399–408.
57. Franco Suglia S, Gryparis A, Schwartz J, et al. Association between traffic-related black carbon exposure and lung function among urban women. *Environ Health Perspect* 2008;116:1333–7.
58. Lutfi MF. The physiological basis and clinical significance of lung volume measurements. *Multidiscip Respir Med* 2017;12:3.
59. Thurlbeck WM. Postnatal human lung growth. *Thorax* 1982;37:564–71.
60. Mustard CA, Etches J. Gender differences in socioeconomic inequality in mortality. *J Epidemiol Community Health* 2003;57:974–80.
61. LoMauro A, Aliverti A. Sex differences in respiratory function. *Breathe* 2018;14:131–40.
62. Hibbert M, Lannigan A, Raven J, et al. Gender differences in lung growth. *Pediatr Pulmonol* 1995;19:129–34.
63. Miller MR, Hankinson J, Brusasco V, et al. Standardisation of spirometry. *Eur Respir J* 2005;26:319–38.
64. Piccioni P, Tassinari R, Carosso A, et al. Lung function changes from childhood to adolescence: a seven-year follow-up study. *BMC Pulm Med* 2015;15:31.
65. Brazzale D, Hall G, Swanney MP. Reference values for spirometry and their use in test interpretation: a position Statement from the Australian and New Zealand Society of Respiratory Science. *Respirology* 2016;21:1201–9.
66. Hnizdo E, Glindmeyer HW, Petsonk EL. Workplace spirometry monitoring for respiratory disease prevention: a methods review. *Int J Tuberc Lung Dis* 2010;14:796–805.
67. Carraro S, Scheltema N, Bont L, et al. Early-life origins of chronic respiratory diseases: understanding and promoting healthy ageing. *Eur Respir J* 2014;44:1682–96.
68. Galobardes B, Lynch J, Smith GD. Measuring socioeconomic position in health research. *Br Med Bull* 2007;81-82:21–37.
69. Arcaya MC, Arcaya AL, Subramanian SV. Inequalities in health: definitions, concepts, and theories. *Glob Health Action* 2015;8:27106.
70. Daly MC, Duncan GJ, McDonough P, et al. Optimal indicators of socioeconomic status for health research. *Am J Public Health* 2002;92:1151–7.
71. Galobardes B, Shaw M, Lawlor DA, et al. Indicators of socioeconomic position (part 1). *J Epidemiol Community Health* 2006;60:7–12.
72. van Ansem WJ, Schrijvers CT, Rodenburg G, et al. Maternal educational level and children's healthy eating behaviour: role of the home food environment (cross-sectional results from the INPACT study). *Int J Behav Nutr Phys Act* 2014;11:113.
73. Lakshman R, Zhang J, Zhang J, et al. Higher maternal education is associated with favourable growth of young children in different countries. *J Epidemiol Community Health* 2013;67:595–602.
74. Güneş PM. The role of maternal education in child health: evidence from a compulsory schooling law. *Econ Educ Rev* 2015;47:1–16.
75. Howe LD, Tilling K, Galobardes B, et al. Socioeconomic differences in childhood growth trajectories: at what age do height inequalities emerge? *J Epidemiol Community Health* 2012;66:143–8.
76. Desai S, Alva S. Maternal education and child health: is there a strong causal relationship? *Demography* 1998;35:71–81.
77. Gray LA, Leyland AH, Benzeval M, et al. Explaining the social patterning of lung function in adulthood at different ages: the roles of childhood precursors, health behaviours and environmental factors. *J Epidemiol Community Health* 2013;67:905–11.
78. Gunnell D, Whitley E, Upton MN, et al. Associations of height, leg length, and lung function with cardiovascular risk factors in the Midspan Family Study. *J Epidemiol Community Health* 2003;57:141–6.
79. Taylor-Robinson DC, Smyth R, Diggle PJ, et al. A longitudinal study of the impact of social deprivation and disease severity on employment status in the UK cystic fibrosis population. *PLoS One* 2013;8:e73322.
80. Quanjer PH, Stanojevic S, Cole TJ, et al. Multi-ethnic reference values for spirometry for the 3–95-yr age range: the global lung function 2012 equations. 2012;40:1324.