

Increased Respiratory Morbidity in Individuals with Interstitial Lung Abnormalities

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Abstract

Background Interstitial lung abnormalities (ILA) are common in participants of lung cancer screening trials and broad population-based cohorts. They are associated with increased mortality, but less is known about disease specific morbidity and healthcare utilisation in individuals with ILA.

Methods We included all participants from the screening arm of the Danish Lung Cancer Screening Trial with available baseline CT scan data (n=1990) in this cohort study. The baseline scan was scored for the presence of ILA and patients were followed for up to 12 years. Data about all hospital admissions, primary healthcare visits and medicine prescriptions were collected from the Danish National Health Registries and used to determine the participants' disease specific morbidity and healthcare utilisation using Cox proportional hazards models.

Results The 332 (16.7%) participants with ILA were more likely to be diagnosed with one of several respiratory diseases, including interstitial lung disease (HR: 4.9, 95% CI: 1.8–13.3, p=0.008), pneumonia (HR: 2.0, 95% CI: 1.4–2.7, p<0.001), lung cancer (HR: 2.7, 95% CI: 1.8–4.0, p<0.001) and respiratory failure (HR: 1.8, 95% CI: 1.1–3.0, p=0.03) compared with participants without ILA. These findings were confirmed by increased hospital admission rates with these diagnoses and more frequent prescriptions for inhalation medicine and antibiotics in participants with ILA.

Conclusions Individuals with ILA are more likely to receive a diagnosis and treatment for several respiratory diseases, including interstitial lung disease, pneumonia, lung cancer and respiratory failure during long term follow-up. The broadly increased respiratory morbidity can help explain the increased mortality in this population.

Introduction

Interstitial lung abnormalities (ILA) are a group of radiological findings visible on computed tomography (CT) of the lung in individuals without a diagnosis of interstitial lung disease (ILD).⁽¹⁾ They are common in participants of lung cancer screening trials, patients with chronic obstructive pulmonary disease (COPD) and broad population based cohorts. ^(2–8) These radiologic findings are also present in several interstitial lung diseases (ILDs), including idiopathic pulmonary fibrosis (IPF), and can precede onset of disease symptoms and diagnosis by several years.^(1,9,10)

ILA are associated with increased mortality as well as reduced lung volumes and exercise capacity. ^(6,7,11) In addition, radiologic progression of ILA has been shown in longitudinal studies and it has been suggested that ILA represent subclinical ILD in some patients.^(1,2,4,8,12) However, the prevalence of ILA is much higher than the prevalence of ILDs as clinical entities and only a few of all people with ILA develop clinical disease.^(7,13–16) The role of ILA in the early detection of ILD remains to be established.

Several ILDs are known to lead to an increase in healthcare utilisation, including diagnostic procedures, hospital admissions, emergency department visits, medical treatment and lung transplantations.^(17–19)

However, data about the development of specific diseases and healthcare utilisation in individuals with ILA are still limited.

The objective of this study was to investigate the association between incidental findings of ILA and disease specific morbidity such as the diagnosis of ILD and other diseases, hospital admission rates, primary care contacts and medicine use.

Methods

Study population

All participants in the intervention arm of the Danish Lung Cancer Screening Trial (DLCST) with available CT scan data (n = 1990) were eligible for this registry-based follow-up cohort study. Methods of the DLCST, including criteria of eligibility, have been published previously and are briefly detailed below.⁽²⁰⁾ It was a 4-year, 5-round prospective randomized controlled screening trial. From 2004 to 2006, 4104 men and women aged 50–75 years with a smoking history of at least 20 pack-years were included in the study. Participants were recruited by newspaper ads. If participants were former smokers, they had to have quit after the age of 50 years and within the previous 10 years. Spirometry was performed by professionally trained and experienced hospital-based pulmonary function technicians or nurses, and were expressed in absolute values and as a percentage of predicted values according to European reference equations.⁽²¹⁾ To be eligible for inclusion, FEV1 had to be at least 30% of the predicted value at baseline. Participants had to be able to climb two flights of stairs (total of 36 steps) without pausing. Exclusion criteria were weight over 130 kg, history of cancer diagnosis and treatment, lung tuberculosis, shortened life expectancy less than 10 years (according to the judgement of the recruiting physician), and chest CT performed during the past year for any reason.

Imaging and image review

Details about the imaging procedure have previously been published and are briefly described below.⁽²⁰⁾ The screening group was examined annually, using a multi-slice CT system (16 rows Philips Mx 8000, Philips Medical Systems). Scans were performed supine at full inspiration with a low-dose technique (120 kV and 40mAs). Visual assessment was performed on thin slices reconstructed with hard algorithm. Two different sets of all scans in random order were created, and each set was evaluated by one of two observers (MMWW and LHT) who were blinded to person identification and date of scan. Interstitial lung abnormalities were registered as either absent or present, and if present further categorized as centrilobular, pleural, or paraseptal nodules, ground-glass attenuation, reticulation and/or honeycombing. The interobserver agreement in the detection of ILA was fair to substantial and has previously been published in more detail.⁽²²⁾ Statistical analyses were performed on a combined ILA variable, classifying participants as having ILA if at least one observer noted a finding of ILA.

Registries

Registry data for all participants were obtained from the Danish national health registries covering the entire population. Data on public and private hospital admissions, outpatient clinic visits, emergency department visits and the diagnoses for these contacts were obtained from the Danish National Patient Register. Data on visits to a primary care provider were obtained from the Danish National Health Insurance Service Register. Data on medicine use were obtained from the Danish Prescription Database. Patients were followed up until May 5, 2016.

Data analysis

Analysis of baseline characteristics was performed with an unpaired t-test or Fisher's exact test for continuous and categorical variables, respectively.

Analysis of the association between ILA and the development of disease was based on all registered diagnoses (the primary discharge diagnosis and contributing or underlying diagnoses) for hospital admissions, outpatient clinic visits or emergency department visits. The ICD10-codes used to define the specific diseases and disease groups are listed in the supplementary material. We used Cox regression analysis to handle the censoring that was introduced by the known increased mortality of participants with ILA.(13)

Analysis of the association between ILA and hospital admission rates was exclusively based on the primary discharge diagnosis of hospital admissions to avoid overestimating chronic diseases that would often be listed as contributing diagnoses. Because of the possibility of repeated admissions with the same diagnosis, we used recurrent event Cox regression analysis using an Andersen-Gill model with death included as a censoring event. To adjust for within-subject correlation, the model included a count of previous admissions as a covariate.

The multivariate Cox regression models were adjusted for age, sex, BMI and pack-years. An extended model which also included baseline measurements of FEV₁ was also used for the analysis of disease development. For the analyses of development of disease and hospital admission rates the proportional hazards assumptions of the Cox models were violated by pack-years and body mass index (BMI), which consequently were included as stratifying variables in the models, allowing for varying hazard functions. Cumulative event curves of expected hospital admissions are based on a marginal model of a recurrent event Cox proportional hazards model with gap times (patients were not at risk for admission while hospitalised), and a terminal event (death) model.(23) To control the false discovery rate that could result from multiple comparisons, we applied the Benjamini-Hochberg procedure to all p-values.

The associations between ILA and primary care visits or prescription medicine use were determined by negative binomial regression analysis, using observation time as offset to adjust for a shortened observation time caused by the increased mortality of participants with ILA.(13) The models were adjusted for age, sex, BMI and pack-years. The ATC codes used to classify prescription medicine are listed in the supplementary material.

Two-sided p-values below 0.05 were considered significant. Missing data were handled by listwise deletion without imputation of data. All statistical analyses were performed with the statistical software R (version 3.5.1).

Results

The 332 (16.7%) participants of the Danish Lung Cancer Screening Trial with ILA were older, had lower FEV₁ % predicted and FVC % predicted, and had more frequently airway obstruction (FEV₁/FVC < 0.7) at the time of their CT scan, compared with participants without ILA (Table 1).

Table 1
Baseline characteristics of participants with or without a baseline CT finding of ILA.

	ILA (n = 332)	No ILA (n = 1658)	p-value
Age mean (SD), years	59.7 (5.0)	57.6 (4.7)	< 0.001
Female, n (%)	136 (41%)	742 (45%)	0.20
BMI, mean (SD)	24.9 (4.0)	25.3 (3.8)	0.06
Current/former smokers, n (%)	256/76 (77%/23%)	1243/415 (74%/26%)	0.41
Pack-years, mean (SD)	37.5 (13.4)	36.18 (13.4)	0.10
FEV ₁ l, mean (SD)	2.75 (0.76)	2.91 (0.75)	< 0.001
FEV ₁ % predicted, mean (SD)	87.9 (18.6)	92.4 (16.3)	< 0.001
FVC l, mean (SD)	4.03(1.0)	4.13 (0.99)	0.10
FVC % predicted, mean (SD)	99.5 (17.7)	101.7 (15.3)	0.04
FEV ₁ /FVC < 0.7, n (%)	178 (54%)	693 (42%)	0.001
Follow-up time median, years (IQR)	11.22 (10.77–11.75)	11.29 (11.03–11.75)	< 0.001
ILA: interstitial lung abnormalities, SD: standard deviation, BMI: body mass index, FEV1: forced expiratory volume in one second, FVC: forced vital capacity			

ILA and specific diagnoses

In multivariate Cox proportional hazards analysis, participants with ILA were more likely to be diagnosed with one of several respiratory, malignant or cardiovascular diseases, compared with those without ILA (Table 2, Fig. 1). Respiratory diseases were most markedly increased, including COPD, pneumonia, pleural empyema or lung abscess, ILD and respiratory failure (Table 2). Moreover, we found an increase in gastrointestinal disease, which was driven by an increase in functional intestinal disorders (Table 2, Fig. 1). In an extended multivariate Cox proportional hazards model, also including the baseline

measurement of FEV₁ as a covariate, COPD was no longer associated with ILA, while the other diagnoses remained unchanged (see supplementary material).

Table 2

Specific diagnoses prompting hospital admissions, outpatient clinic visits or emergency department visits.

Diagnosis	ILA (%)	No ILA (%)	HR	95% CI	Adjusted p-value
Respiratory	116 (34.9)	361 (21.8)	1.6	1.3–2.0	< 0.001
COPD	55 (16.6)	159 (9.6)	1.7	1.2–2.3	0.01
Pneumonia	56 (16.9)	126 (7.6)	2.0	1.4–2.7	< 0.001
Asthma	4 (1.2)	47 (2.8)	0.4	0.2–1.2	0.15
Pleural empyema or lung abscess	5 (1.5)	3 (0.2)	6.6	1.5–28.8	0.03
Interstitial lung disease	8 (2.4)	8 (0.5)	4.9	1.8–13.3	0.008
Respiratory failure	25 (7.5)	61 (3.7)	1.8	1.1–3.0	0.03
Malignant neoplasm	93 (28.0)	317 (19.1)	1.4	1.1–1.8	0.02
Lung cancer	39 (11.7)	71 (4.3)	2.7	1.8–4.0	< 0.001
Non-pulmonary cancer	67 (20.2)	266 (16.0)	1.2	0.9–1.6	0.30
Cardiovascular	157 (47.3)	652 (39.3)	1.2	1.0–1.5	0.09
Heart failure	19 (5.7)	47 (2.8)	1.7	1.0–3.0	0.19
Pulmonary embolism	8 (2.4)	22 (1.3)	1.9	0.8–4.3	0.17

Number of participants with ILA compared with participants without ILA for receiving one of several specific diagnoses of interest at a hospital admission, outpatient clinic visits or emergency department visit. Cox regression analysis is adjusted for age, sex, BMI and pack-years. P-values are adjusted for multiple comparisons by the Benjamini-Hochberg method. ILA: interstitial lung abnormalities, HR: hazard ratio, COPD: chronic obstructive pulmonary disease, GORD: gastro-oesophageal reflux disease

Diagnosis	ILA (%)	No ILA (%)	HR	95% CI	Adjusted p-value
Atrial fibrillation/atrial flutter	27 (8.1)	95 (5.7)	1.3	0.8–2.0	0.34
Ischemic heart disease	50 (15.1)	174 (10.5)	1.4	1.0–2.0	0.07
Cerebral infarction	18 (5.4)	59 (3.6)	1.4	0.8–2.3	0.34
Peripheral vascular disease	21 (6.3)	50 (3.0)	2.0	1.2–3.4	0.04
Gastrointestinal	125 (37.7)	489 (29.5)	1.3	1.1–1.6	0.02
GORD, gastritis or ulcer disease	25 (7.5)	95 (5.7)	1.3	0.8–2.1	0.30
Functional intestinal disorders	28(8.4)	66(4.0)	2.2	1.4–3.4	0.006
Musculoskeletal system and connective tissue	140 (42.2)	739 (44.6)	1.0	0.8–1.2	0.89
Inflammatory polyarthropathies	8 (2.4)	57 (3.4)	0.7	0.3–1.5	0.40
Number of participants with ILA compared with participants without ILA for receiving one of several specific diagnoses of interest at a hospital admission, outpatient clinic visits or emergency department visit. Cox regression analysis is adjusted for age, sex, BMI and pack-years. P-values are adjusted for multiple comparisons by the Benjamini-Hochberg method. ILA: interstitial lung abnormalities, HR: hazard ratio, COPD: chronic obstructive pulmonary disease, GORD: gastro-oesophageal reflux disease					

ILA and hospital admission rates

Participants with ILA had a higher crude mean admission rate during follow-up compared with participants without ILA (39 vs. 23 admissions per 100 person-years at risk) (Fig. 2). In a multivariate recurrent event Cox proportional hazards analysis, participants with ILA had a significantly higher hazard rate for hospital admission during short-term (1 year) follow-up (HR: 1.8, 95% CI: 1.3–2.6, $p = 0.002$) and long-term (12 years) follow-up (HR: 1.4, 95% CI: 1.2–1.7, $p < 0.001$) (Fig. 3).

After stratifying hospital admissions by discharge diagnoses, we found a significant increase in admissions due to respiratory and malignant diseases in participants with ILA (Table 3, Figs. 2 and 3). Most notably, admissions for pneumonia and lung cancer were more frequent (Table 2). Hospital

admissions for COPD were not associated with ILA when only considering the primary discharge diagnosis (Table 3). However, when expanding the analysis to include all discharge diagnoses (primary diagnosis and contributing diagnoses), participants with ILA had more frequent hospital admissions also with COPD (HR: 2.1, 95% CI: 1.3–3.3, $p = 0.003$). Hospital admissions with cardiovascular disease were increased in the unadjusted model (Fig. 3) but not in the multivariate model (Table 3). However, admission for pulmonary embolism and peripheral vascular disease were consistently increased in participants with ILA (Table 3).

The hazard rate of emergency department visits was similar in participants with or without ILA (HR: 1.3, 95% CI: 0.8–2.0, $p = 0.36$).

Table 3

Disease specific hospital admissions and emergency-department (ED) visits in participants with or without ILA.

Disease group	HR	95% CI	Adjusted p-value
Respiratory disease	2.1	1.4–3.1	0.001
COPD	2.5	0.9–6.8	0.10
Pneumonia	2.1	1.5–3.0	0.001
Asthma	0.8	0.1–7.7	0.90
Pleural empyema or lung abscess	0.3	0.0–32.6	0.90
Interstitial lung disease	1.8	0.3–12.5	0.82
Malignant neoplasm	1.6	1.2–2.1	0.001
Lung cancer	2.8	1.7–4.5	0.001
Non-pulmonary cancer	1.3	0.9–1.9	0.15
Cardiovascular disease	1.4	1.0–1.8	0.10
Heart failure	2.2	1.3–4.1	0.09
Pulmonary embolism	4.9	1.6–14.7	0.01
Atrial fibrillation/atrial flutter	1.3	0.5–3.3	0.82
Ischemic heart disease	1.1	0.8–1.6	0.90
Cerebral infarction	1.5	0.8–2.7	0.43
Peripheral vascular disease	5.0	2.5–9.9	0.001
Gastrointestinal disease	1.1	0.8–1.6	0.87
GORD, gastritis or ulcer disease	0.9	0.3–2.2	0.90
Functional intestinal disorders	1.1	0.4–3.0	0.90

Adjusted hazard ratios for disease specific hospital admissions and emergency-department (ED) visits in participants with ILA compared with participants without ILA. Cox regression analysis is adjusted for age, sex, BMI and pack-years. P-values are corrected multiple comparisons by the Benjamini-Hochberg method. ILA: interstitial lung abnormalities, HR: hazard ratio, GORD: gastro-oesophageal reflux disease

Disease group	HR	95% CI	Adjusted p-value
Diseases of the musculoskeletal system and connective tissue	1.1	0.8–1.4	0.90
Inflammatory polyarthropathies	1.5	0.9–2.4	0.95
Adjusted hazard ratios for disease specific hospital admissions and emergency-department (ED) visits in participants with ILA compared with participants without ILA. Cox regression analysis is adjusted for age, sex, BMI and pack-years. P-values are corrected multiple comparisons by the Benjamini-Hochberg method. ILA: interstitial lung abnormalities, HR: hazard ratio, GORD: gastro-oesophageal reflux disease			

ILA and primary care visits

The rate of visits to a primary care provider during follow-up was slightly increased in participants with ILA compared with participants without ILA (4.51 vs. 4.05 visits per person year at risk, $p = 0.01$). However, this difference was no longer significant in the multivariate model (see supplementary material).

ILA and medicine use

Participants with ILA had a higher overall rate of collected drug prescriptions during follow-up (median 3.1 vs. 2.5 prescriptions per person year at risk, $p = 0.009$). After adjusting for potential confounders in multivariate negative binomial regression analysis, there remained an increased use of several medications, including inhalation therapy ($p = 0.009$), antibiotic therapy ($p = 0.002$) and loop diuretics ($p = 0.008$) (Table 4).

Table 4

Proportion of participants with at least one prescription for the listed classes of medicine.

Medication	ILA	No ILA	p-value
Inhalation therapy	72 (22%)	316 (19%)	0.009
Antibiotic therapy	277 (83%)	1337 (81%)	0.002
Prednisolone	27 (8%)	130 (8%)	0.63
Proton pump inhibitors	111 (33%)	482 (29%)	0.07
Antithrombotic therapy	98 (30%)	361 (22%)	0.35
Antihypertensive therapy	77 (23%)	348 (21%)	0.09
Loop diuretics	27 (8%)	79 (5%)	0.008
Lipid lowering therapy	108 (33%)	517 (31%)	0.64
Antidiabetic therapy	75 (23%)	335 (20%)	0.86
P-values based on negative binomial regression of the number of prescriptions, adjusted for age, sex, BMI and pack-years. ILA: interstitial lung abnormalities			

Discussion

In this 12-year long follow-up study of the Danish Lung Cancer Screening Trial population we show an increased disease specific morbidity and healthcare utilisation in participants with ILA. This includes a more frequent diagnosis of several respiratory diseases, such as ILD, pulmonary infections, lung cancer and respiratory failure, a higher hospital admission rate, and higher use of several therapies for these diseases.

ILA and specific diagnoses

A higher proportion of participants with ILA received a hospital diagnosis of a respiratory disease or lung cancer in the 12 years following the radiologic finding. Our results add to previous reports of increased lung cancer related mortality and to a lesser extent respiratory mortality in individuals with ILA. (7,13,24) However, the present study adds to the understanding of ILA by describing an increased frequency of several more specific respiratory diagnoses, such as ILD, pneumonia, pleural empyema and respiratory failure, after adjusting for age, sex, BMI and smoking status. It is not clear how the presence of ILA predisposes to the increased morbidity, but these rather unspecific radiological findings possibly reflect inflammatory, premalignant or pulmonary vascular changes. ILA could also be the result of previous exposure to dust, gasses, infections or pneumotoxic medications, in a population already predisposed to respiratory diseases.

The association between ILA and the development of clinical ILD highlights the potential for an earlier diagnosis by recognizing ILA in a lung cancer screening setting.(25) It adds to previous findings of increased incidence of ILD in individuals with areas of increased lung attenuation.(24) In IPF, radiological findings can be visible many years before clinical disease, making screening by CT in conjunction with lung cancer screening an attractive option.(10,25) Considering that IPF is more common in smokers and older people, who also are the candidate population for lung cancer screening, it is possible that some cases of subclinical IPF could be detected as incidental findings from the CT scans in a lung cancer screening program.(25,26)

The marked increase in pulmonary infections in participants with ILA was confirmed by an increased use of antibiotics. This association could have several explanations. Firstly, patients with ILA were older and more frequently active smokers, and thus more susceptible to pneumonia.(27) Secondly, the higher frequency of COPD, a disease associated with pulmonary infections and exacerbations, in participants with ILA would lead to an expected increase in these infections.

In line with the general increase in respiratory disease, a hospital diagnosis of respiratory failure was twice as frequent in participants with ILA compared with those without ILA. A previous study has shown that critically ill patients with sepsis, who had ILA on chest CT scans taken within one week prior to ICU admission were more likely to develop acute respiratory distress syndrome.(28) We supplement these findings with longitudinal follow-up showing that a finding of ILA also increases the long-term risk of developing respiratory failure.

ILA and hospital admission rates

Participants with ILA had a higher rate of hospital admissions during both short-term and long-term follow-up. Hospital admission rates are measures of morbidity that are highly relevant to both patients and healthcare systems, and are a recommended outcome for clinical trials of IPF alongside mortality. (29,30) Our results thus highlight the clinical and economical importance of ILA as incidental findings. (13)

The most pronounced increase in hospital admissions for participants with ILA was found for respiratory and malignant causes, which corresponds with our finding of an increased incidence of these diseases in participants with ILA. The increased rate of hospital admissions with pulmonary embolism and peripheral vascular disease in participants with ILA was more surprising. Venous thromboembolic disease is associated with several ILDs, including lung fibrosis, sarcoidosis and IPF.(31–34) To our knowledge, we present for the first time an increase in pulmonary embolism morbidity also in individuals with ILA. The higher prevalence of malignancy, which is a known risk factor for thromboembolic disease, in participants with ILA could be a possible explanation. Alternatively, ILA and thromboembolic disease could share common, and possibly unknown, risk factors.

Limitations

There is a lack of standardization of ILA across different studies which makes comparisons difficult.(35) In contrast to other reports, we did not code any findings as 'indeterminate' or 'equivocal' but limited the analysis to a dichotomous variable of 'ILA' or 'No ILA'. This potentially weakened our conclusions by including less severe findings in the 'exposed' group. However, any cut-offs between different grades of severity would be arbitrary and not easily transferred to clinical practice, which could make them difficult to interpret. In addition, we relied on qualitative descriptors of ILA rather than quantitative measures. This reduces the repeatability of our findings due to the known interobserver variability of radiologic findings even among experienced radiologists.(36) However, our approach is similar to the use of imaging in clinical practice and research.(2,4,7)

The data on the specific contact diagnoses were only available for secondary care contacts (hospital admissions, outpatient clinic visits and emergency department visits). This could lead to potentially underestimating the prevalence of a certain diagnosis (i.e. COPD or pneumonia) for participants treated exclusively in primary care. However, for many diagnoses of interest, such as lung cancer and ILD, participants would be expected to be diagnosed in secondary care.

Conclusions

Individuals with ILA have an increased morbidity related to several respiratory diseases, including ILD, pulmonary infections, lung cancer and respiratory failure. These findings can help to explain the increased mortality in this population and should be taken into account in their healthcare plans.

Abbreviations

ILA
interstitial lung abnormalities
ILD
interstitial lung disease
IPF
idiopathic pulmonary fibrosis
CT
computed tomography
COPD
chronic obstructive pulmonary disease
DLCST
Danish lung cancer screening trial
BMI
body mass index
FEV₁
forced expiratory volume in one second
FVC

forced vital capacity

Declarations

Ethics approval and consent to participate

The DLCST was approved by the Ethics Committee of Copenhagen County. Approval of data management in the trial was obtained from the Danish Data Protection Agency. All participants provided written informed consent and the study was conducted according to the principles of the Declaration of Helsinki. This follow-up study was approved by the Danish Data Protection Agency (HGH-2016-017).

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available in an anonymized form from the corresponding author on reasonable request.

Competing interests

Dr. Hoyer reports grants from Roche a/s, grants from Skibsreder Per Henriksen, R. og Hustrus Fond, grants from P.A. Messerschmidt og Hustrus Fond outside the submitted work. Dr. Hohwü Thomsen has nothing to disclose. Dr. Winkler Wille has nothing to disclose. Dr. Wilcke has nothing to disclose. Dr. Dirksen has nothing to disclose. Dr. Holst Pedersen has nothing to disclose. Dr. Ashraf has nothing to disclose. Dr. Saghir has nothing to disclose. Dr. Shaker reports personal fees from Roche and personal fees from Boehringer Ingelheim, outside the submitted work.

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Authors' contributions

NH, TW and SS conceived the idea of this follow-up study. LHT and MMWW read the CT scans. AD, JHP, HA, ZS, LHT and MMWW performed the original screening study. NH collected and analysed the registry

data. NH created the first draft of the manuscript. All authors read and approved the final manuscript.

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Authors' information (optional)

Not applicable.

References

1. Doyle TJ, Hunninghake GM, Rosas IO. Subclinical interstitial lung disease: why you should care. *Am J Respir Crit Care Med*. 2012 Jun 1;185(11):1147–53.
2. Sverzellati N, Guerci L, Randi G, Calabrò E, La Vecchia C, Marchianò A, et al. Interstitial lung diseases in a lung cancer screening trial. *Eur Respir J*. 2011 Aug;38(2):392–400.
3. Mackintosh JA, Marshall HM, Slaughter R, Reddy T, Yang IA, Bowman R V, et al. Interstitial Lung Abnormalities in the Queensland Lung Cancer Screening Study: Prevalence and Progression Over Two Years of Surveillance. *Intern Med J*. 2018;1.
4. Tsushima K, Sone S, Yoshikawa S, Yokoyama T, Suzuki T, Kubo K. The radiological patterns of interstitial change at an early phase: Over a 4-year follow-up. *Respir Med*. 2010;104(11):1712–21.
5. Lederer DJ, Enright PL, Kawut SM, Hoffman EA, Hunninghake G, Van Beek EJR, et al. Cigarette smoking is associated with subclinical parenchymal lung disease: the Multi-Ethnic Study of Atherosclerosis (MESA)-lung study. *Am J Respir Crit Care Med*. 2009 Sep 1;180(5):407–14.
6. Washko GR, Hunninghake GM, Fernandez IE, Nishino M, Okajima Y, Yamashiro T, et al. Lung volumes and emphysema in smokers with interstitial lung abnormalities. *N Engl J Med*. 2011 Mar 10;364(10):897–906.
7. Putman RK, Hatabu H, Araki T, Gudmundsson G, Gao W, Nishino M, et al. Association Between Interstitial Lung Abnormalities and All-Cause Mortality. *JAMA*. 2016 Feb 16;315(7):672–81.
8. Jin GY, Lynch D, Chawla A, Garg K, Tammemagi MC, Sahin H, et al. Interstitial lung abnormalities in a CT lung cancer screening population: prevalence and progression rate. *Radiology*. 2013;268(2):563–71.
9. Raghu G, Collard HR, Egan JJ, Martinez FJ, Behr J, Brown KK, et al. An Official ATS/ERS/JRS/ALAT Statement: Idiopathic pulmonary fibrosis: Evidence-based guidelines for diagnosis and management. *Am J Respir Crit Care Med*. 2011;183(6):788–824.

10. Rosas IO, Ren P, Avila N a., Chow CK, Franks TJ, Travis WD, et al. Early interstitial lung disease in familial pulmonary fibrosis. *Am J Respir Crit Care Med.* 2007;176(7):698–705.
11. Doyle TJ, Washko GR, Fernandez IE, Nishino M, Okajima Y, Yamashiro T, et al. Interstitial lung abnormalities and reduced exercise capacity. *Am J Respir Crit Care Med.* 2012 Apr 1;185(7):756–62.
12. Araki T, Putman RK, Hatabu H, Gao W, Dupuis J, Latourelle JC, et al. Development and Progression of Interstitial Lung Abnormalities in the Framingham Heart Study. *Am J Respir Crit Care Med.* 2016;194(12):1514–22.
13. Hoyer N, Wille MMW, Thomsen LH, Wilcke T, Dirksen A, Pedersen JH, et al. Interstitial lung abnormalities are associated with increased mortality in smokers. *Respir Med.* 2018 Mar 1;136:77–82.
14. Coultas DB, Zumwalt RE, Black WC, Sobonya RE. The epidemiology of interstitial lung diseases. *Am J Respir Crit Care Med.* 1994 Oct;150(4):967–72.
15. Ley B, Collard HR. Epidemiology of idiopathic pulmonary fibrosis. *Clin Epidemiol.* 2013 Nov 25;5:483–92.
16. Hunninghake GM. Interstitial lung abnormalities: erecting fences in the path towards advanced pulmonary fibrosis. *Thorax.* 2019;thoraxjnl-2018-212446.
17. Vaidya S, Hibbert CL, Kinter E, Boes S. Identification of Key Cost Generating Events for Idiopathic Pulmonary Fibrosis: A Systematic Review. *Lung.* 2016 Nov 19;
18. Raimundo K, Chang E, Broder MS, Alexander K, Zazzali J, Swigris JJ. Clinical and economic burden of idiopathic pulmonary fibrosis: a retrospective cohort study. *BMC Pulm Med.* 2016 Jan 5;16:2.
19. Wu N, Yu YF, Chuang C-C, Wang R, Benjamin NN, Coultas DB. Healthcare Resource Utilization among Patients Diagnosed with Idiopathic Pulmonary Fibrosis in the United States. *J Med Econ.* 2014;6998(April 2016):1–26.
20. Wille MMW, Dirksen A, Ashraf H, Saghir Z, Bach KS, Brodersen J, et al. Results of the Randomized Danish Lung Cancer Screening Trial with Focus on High-Risk Profiling. *Am J Respir Crit Care Med.* 2016 Mar 1;193(5):542–51.
21. Pellegrino R, Viegi G, Brusasco V, Crapo RO, Burgos F, Casaburi R, et al. Interpretative strategies for lung function tests. 2005;26(5):948–68.
22. Wille MMW, Thomsen LH, Dirksen A, Petersen J, Pedersen JH, Shaker SB. Emphysema progression is visually detectable in low-dose CT in continuous but not in former smokers. *Eur Radiol.* 2014 Nov;24(11):2692–9.
23. Ghosh D, Lin DY. Marginal Regression Models for Recurrent and Terminal Events. *Stat Sin.* 2002;12:663–88.
24. Podolanczuk AJ, Oelsner EC, Barr RG, Bernstein EJ, Hoffman EA, Easthausen IJ, et al. High-Attenuation Areas on Chest Computed Tomography and Clinical Respiratory Outcomes in Community-Dwelling Adults. *Am J Respir Crit Care Med.* 2017;196(11):1434–42.

25. Cottin V, Richeldi L. Neglected evidence in idiopathic pulmonary fibrosis and the importance of early diagnosis and treatment. *Eur Respir Rev.* 2014;23(131):106–10.
26. Raghu G, Freudenberger TD, Yang S, Curtis JR, Spada C, Hayes J, et al. High prevalence of abnormal acid gastro-oesophageal reflux in idiopathic pulmonary fibrosis. *Eur Respir J.* 2006 Jan;27(1):136–42.
27. Torres A, Peetermans WE, Viegi G, Blasi F. Risk factors for community-acquired pneumonia in adults in Europe: A literature review. *Thorax.* 2013;68(11):1057–65.
28. Putman RK, Hunninghake GM, Dieffenbach PB, Barragan-Bradford D, Serhan K, Adams U, et al. Interstitial Lung Abnormalities Are Associated with Acute Respiratory Distress Syndrome. *Am J Respir Crit Care Med.* 2017;195(1):138–41.
29. Nathan SD, Meyer KC. IPF clinical trial design and endpoints. *Curr Opin Pulm Med.* 2014 Sep;20(5):463–71.
30. Raghu G, Collard HR, Anstrom KJ, Flaherty KR, Fleming TR, King TE, et al. Idiopathic pulmonary fibrosis: clinically meaningful primary endpoints in phase 3 clinical trials. *Am J Respir Crit Care Med.* 2012 May 15;185(10):1044–8.
31. Sprunger DB, Olson AL, Huie TJ, Fernandez-Perez ER, Fischer A, Solomon JJ, et al. Pulmonary fibrosis is associated with an elevated risk of thromboembolic disease. *Eur Respir J.* 2012;39(1):125–32.
32. Ungprasert P, Crowson CS, Matteson EL. Association of Sarcoidosis With Increased Risk of VTE: A Population-Based Study, 1976 to 2013. *Chest.* 2017 Feb;151(2):425–30.
33. Sode BF, Dahl M, Nielsen SF, Nordestgaard BG. Venous thromboembolism and risk of idiopathic interstitial pneumonia: A nationwide study. *Am J Respir Crit Care Med.* 2010;181(10):1085–92.
34. Hubbard RB, Smith C, Le Jeune I, Gribbin J, Fogarty AW. The association between idiopathic pulmonary fibrosis and vascular disease: A population-based study. *Am J Respir Crit Care Med.* 2008;178(12):1257–61.
35. Wells AU, Kokosi MA. Subclinical interstitial lung abnormalities: Toward the early detection of idiopathic pulmonary fibrosis? *Am J Respir Crit Care Med.* 2016;194(12):1445–6.
36. Walsh SLF, Wells AU, Desai SR, Poletti V, Piciocchi S, Dubini A, et al. Multicentre evaluation of multidisciplinary team meeting agreement on diagnosis in diffuse parenchymal lung disease: a case-cohort study. *Lancet Respir Med.* 2016 May 11;2600(16):1–9.

Figures

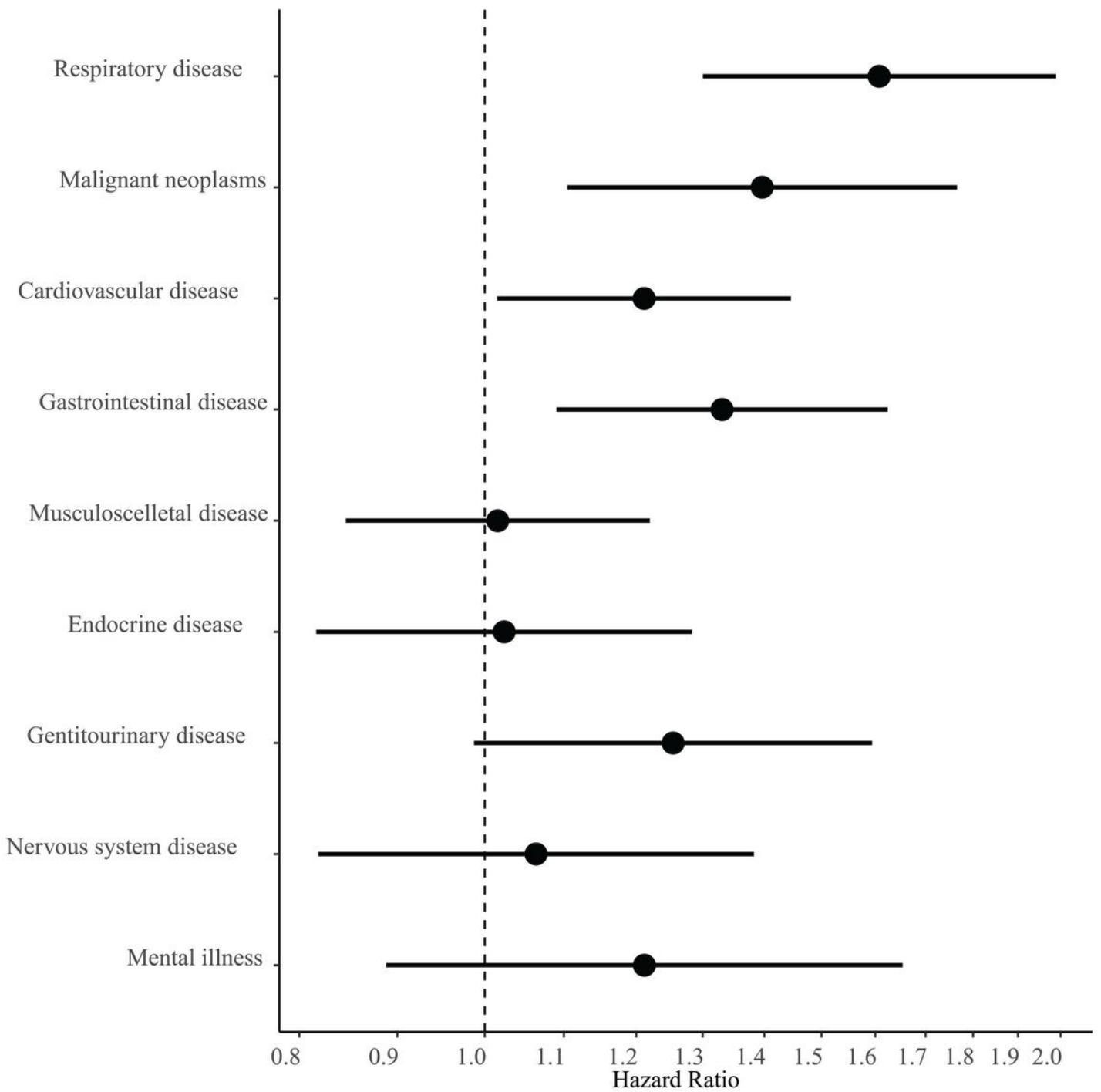


Figure 1

Hazard ratio for participants with ILA compared with those without ILA for developing a disease within a specific diagnostic group. The multivariate Cox regression analysis is adjusted for age, sex, BMI and pack-years. Error bars represent 95% confidence intervals.

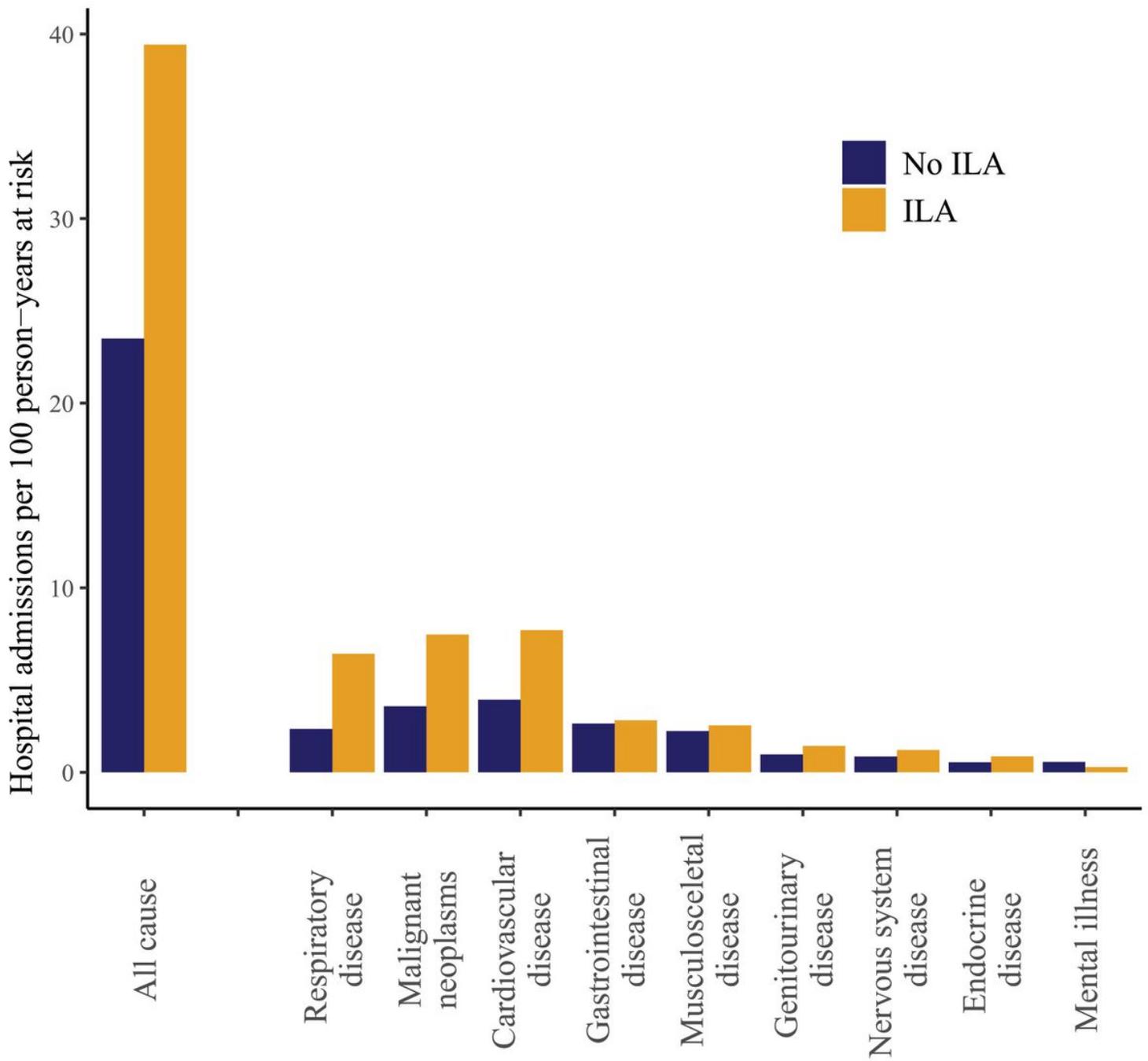


Figure 2

Unadjusted hospital admission rates in participants with ILA and those without ILA. ILA: interstitial lung abnormalities.

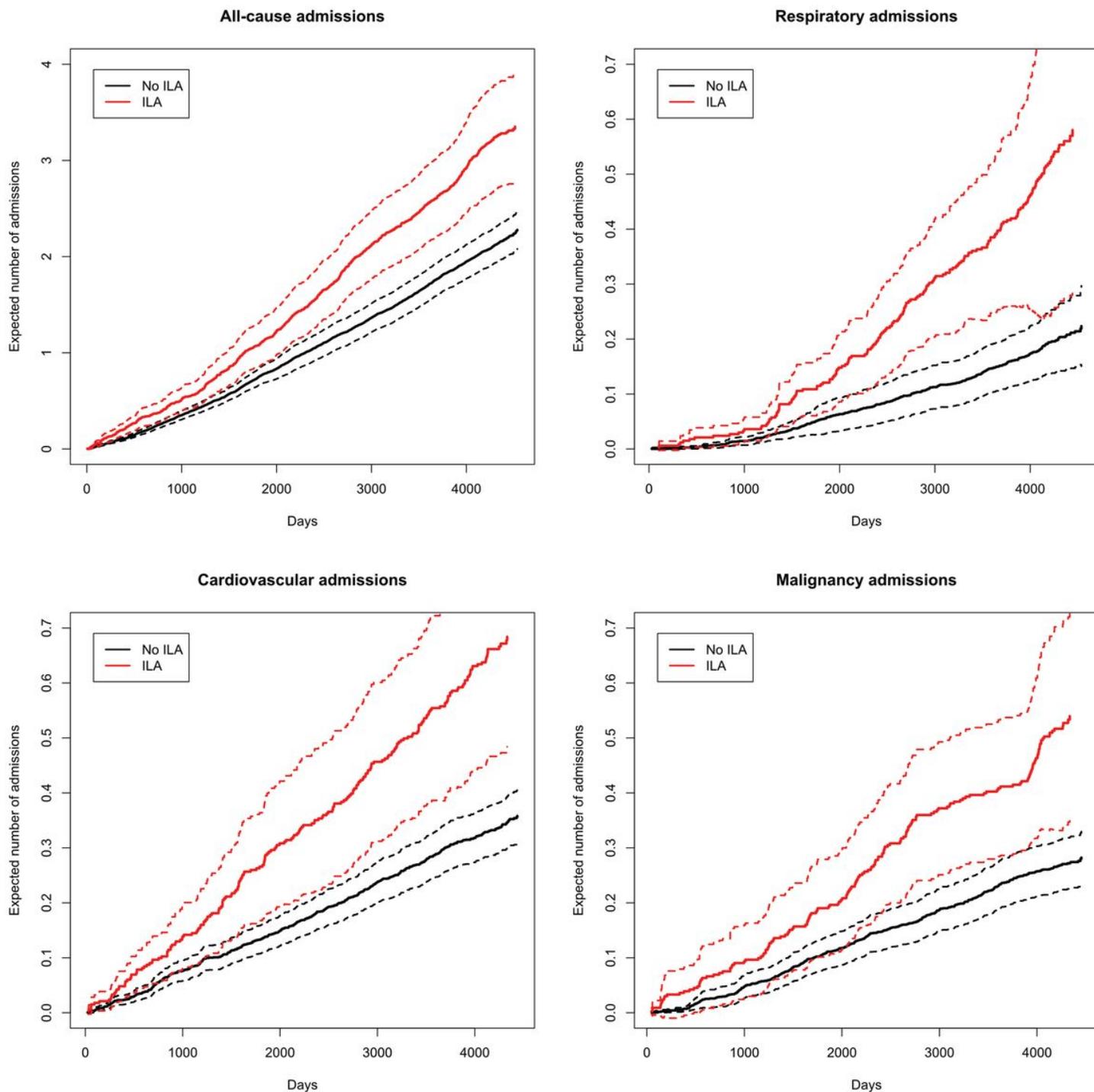


Figure 3

Expected number of hospital admissions in participants with ILA and without ILA respectively based on a marginal Cox proportional hazards model of a recurrent event model (hospital admissions) with gap times and a terminal event model (death). Dashed lines indicate standard errors. Note the different scales for all-cause hospital admissions and specific admissions, respectively.