

Early View

Original article

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Predictors of Pulmonary Rehabilitation Completion in the UK

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Conflict of interest statement

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Notation of prior abstract publication/presentation

Unadjusted analyses from this work have previously been presented at the 2019 American Thoracic Society Conference in Dallas, TX, USA.

Take home message

Referring people with COPD to pulmonary rehabilitation (PR) in the earlier stages of disease, ensuring PR programmes follow best practice guidelines, and favouring cohort over rolling PR programmes could improve rates of PR completion.

Abbreviations

6MWT	Six-minute walk test
95% CI	95% confidence interval
BMI	body mass index
CAT	COPD Assessment Test
COPD	chronic obstructive pulmonary disease
CRQ	Chronic Respiratory Questionnaire
ESWT	Endurance shuttle walk test
FEV ₁	forced expiratory volume in one second
GOLD	Global Initiative for Chronic Obstructive Lung Disease
HQIP	Healthcare Quality Improvement Partnership
IMD	English Index of Multiple Deprivation
ISWT	Incremental shuttle walk test
MRC	Medical Research Council
NCAP	National COPD Audit Programme
OR	odds ratio
PR	pulmonary rehabilitation
RCT	randomised controlled trial
SES	socioeconomic status
SGRQ	St. George's Respiratory Questionnaire
UK	United Kingdom of Great Britain and Northern Ireland
WIMD	Welsh Index of Multiple Deprivation

Abstract

Aim

Determine characteristics of people with COPD associated with completion of pulmonary rehabilitation (PR).

Methods

Cross-sectional analysis of 7060 people with COPD enrolled in PR between 03/01/2017 and 31/03/2017. Data were from a UK national audit of COPD care. Factors associated with PR completion were determined using mixed-effects logistic regression with a random intercept for PR service. Factors chosen for assessment based on clinical judgement and data availability were: age, gender, country, SES, Body Mass Index (BMI), referral location, programme type, start within 90 days, smoking status, oxygen therapy, GOLD stage, MRC grade, any exercise test, and any health status questionnaire.

Results

4635 (66%) people with COPD completed a PR programme. People that were 60 years or older, resident in Wales, referred within 90 days, an ex- or never smoker, received an exercise test, or received a health status questionnaire had significantly greater odds of completing PR. People that were in the most deprived quintile, underweight or very severely obese, enrolled in a rolling rather than a cohort programme, had a higher GOLD stage, and had a higher MRC grade had significantly lower odds of completing PR.

Conclusion

People with COPD were more likely to complete PR when best-practice guidelines were followed. People with more severe COPD symptoms and those enrolled in rolling rather than cohort programmes were less likely to complete PR. Referring people with COPD in the earlier stages of disease, ensuring programmes follow best-practice guidelines, and favouring cohort over rolling programmes could improve rates of PR completion.

Background

Pulmonary rehabilitation (PR) has been shown to improve dyspnoea, fatigue, quality of life, and exercise capacity in individuals with COPD(1,2). The quality of evidence for these benefits has been declared such that no further randomised controlled trials (RCTs) comparing PR and usual care are required to demonstrate its benefits(1,3).

While the strength of evidence for the benefits of PR is high and the referral criteria are well defined(4,5), the proportion of people with COPD being referred to and completing PR remains low. In the UK, most PR referrals are from primary care(6,7), however, between 2004 and 2014 only 9% of eligible people with COPD in England were referred to PR from primary care(8). And in the English and Welsh PR audit it was found that only approximately 42% of those referred to PR completed a programme(6).

In the UK, PR programmes have a median session count of 12 (IQR: 12-14)(7) and are predominantly (98.2%) centre (community or acute unit) based, with 1.3% of programmes being home based, and the remaining 0.5% being delivered in both. 50% of programmes are rolling (patients start and end at different times) based and 48% are cohort based (all patients start and end at the same time)(7). 5% of programmes require patients to stop smoking before they can enrol(7).

Previous large studies of predictors of PR completion have either only presented unadjusted results(9), been limited to just one city(10–14), or used an RCT population(15) that are not representative of all potential PR referrals. We therefore aimed to use a national audit cohort to determine the characteristics of people with COPD associated with completion of PR. This would be the largest cohort assessed to date and allow us to discover individuals that require better targeting.

Material and methods

Database/population

To investigate patient factors associated with PR completion, we used data from the National COPD Audit Programme (NCAP) 2017 clinical audit of PR services in England and Wales, UK (E&W). The audit identified 195 PR services across E&W and invited them to participate in the audit which ran from 03/01/2017 to 31/03/2017. 184 (94%) chose to participate; reasons for non-participation were: lack of resources to complete data collection and entry, and no patients receiving initial assessment during the audit period. From these 184 PR services, 9427 patients were eligible to contribute to the audit (patients with a primary diagnosis of COPD who were assessed for or began PR during the audit period), 8769 patients were approached for consent, and 7896 (90% of approached) gave their consent to contribute to the audit. Patient data were entered into a bespoke web-tool created for the audit and data were stored in a secure data centre. PR services were allowed until 31/07/2017 to complete data entry. This was 3 months after the end of the study period to ensure that all patients were followed-up to completion. After data cleaning by the audit team, a dataset of 7,476 COPD patients who had been assessed for or began PR between 03/01/2017 and 31/03/2017 at one of 184 PR services in E&W was established. Full details of the audit and the methodology used to create the dataset can be found in the audit data report(7).

Variables

The outcome of the analysis – completion of PR – was defined as any enrolled patient that received a discharge assessment. 14 exposures (age, gender, country, SES, Body Mass Index (BMI), referral location, programme type, start within 90 days, smoking status, oxygen therapy, GOLD stage, MRC

grade, any exercise test, and any health status questionnaire) were used as potential predictors of PR completion. Exposures were chosen based on clinical judgement and data availability. People without age data and people aged under 35 years at initial appointment for PR were excluded as the accepted definition of COPD in the UK requires patients to be at least 35 years old(4). Additionally, people that did not enrol on a PR programme were excluded to remove unsuitability or lack of motivation as factors for non-completion.

SES was defined as quintile of either English Index of Multiple Deprivation (IMD) 2015 or Welsh Index of Multiple Deprivation (WIMD) 2014, derived using the patient's home post code (note that IMD and WIMD derivation was performed prior to our receipt of data so that potentially identifying information such as post code was not made available to us). IMD and WIMD are measures of deprivation that ranks the relative deprivation between small areas (or neighbourhoods) of England and Wales, respectively. Values for IMD and WIMD are derived by assessing how deprived an area is the domains of income, employment, education, health, crime, housing, environment, and access to services(16,17). Country of residence was defined based on the presence of either an IMD (England) or WIMD (Wales) value. Further variable definitions can be found in **Supplementary Methods**.

Statistical analysis

All data management and statistical analyses were performed using Stata 15 (StataCorp, College Station, TX, USA). Data were first summarised using means and proportions where appropriate. Age was discretised to produce a categorical variable as its relationship PR completion was non-linear. MRC grade 1 and 2 were combined as very few patients were grade 1. Where variables had no more than 5% missing data, complete-case analysis was used, otherwise additional missing data categories were added to preserve sample size. To account for clustering of patients at the PR service level, mixed-effects logistic regression (xtlogit command, re option) was used to investigate association between each of the 14 exposures and PR completion with a random intercept for PR service. Odds ratios with 95% confidence intervals were generated for each exposure.

After univariate analyses, minimally-adjusted models were created by adding the *a priori* confounders age, sex, and SES to the mixed-effects logistic regression models to produce adjusted odds ratios and 95% confidence intervals for each predictor. Finally, mutually-adjusted mixed-effects logistic regression models were created using all predictors. These represent our maximally adjusted models. Statistical significance of predictors in the mutually-adjusted model was determined using the likelihood ratio test with $p < 0.05$ regarded as significant. Multicollinearity of predictors in the mutually-adjusted models was assessed using the Stata 'collin' command. A variance inflation factor (VIF) of 10 was defined as indicating problematic multicollinearity. All variables in both models had VIFs well below 10 indicating multicollinearity was not an issue in the final models. Odds ratio graphs were generated using coefplot(18).

Sensitivity analyses were performed using complete-case analysis instead in the mutually-adjusted models, where the additional missing data categories were not included. Sensitivity analyses were also performed separately in English and Welsh patients to see the effect of combining IMD and WIMD quintiles.

Ethical approval

The Healthcare Quality Improvement Partnership (HQIP) is data controller for National Clinical Audit and Patient Outcomes Programme (NCAPOP) projects. An HQIP extended output scope form was completed for both audit data sets used in this analysis. Formal approval from the HQIP Data Access Request Group (DARG)(19) was not required as both datasets use de-identified pseudonymised data for a purpose deemed to be in line with primary audit data collection. Formal consent to use their

data to produce academic papers was collected from patients who contributed to the PR clinical audit dataset.

Results

Of the 7,476 patients included in the audit dataset, 413 (5.52%) were excluded due to not enrolling in a PR programme, 2 (0.03%) were excluded for not having any age data, and 1 (0.01%) was excluded for being under 35 years of age. Of the 7,060 patients that enrolled on a PR programme, 4635 (66%) completed PR (**Table 1** and **Supplementary Table S1**). People under the age of 60 had the lowest proportion (50.2%) of PR completion, and Welsh (76.6%) and the least deprived quintile of patients (75.6%) had the highest proportion of completion. Patients that completed PR attended an average of 92% of their scheduled sessions, whereas those that did not complete PR attended an average of 32% of their scheduled sessions.

Crude, minimally-adjusted, and mutually-adjusted odds ratios for completion of PR are shown in **Table 2**. In age, sex, and deprivation adjusted analysis (minimally-adjusted), patients that were more deprived, underweight, very severely obese, enrolled in a rolling rather than cohort programme, receiving oxygen at home, had a higher GOLD stage, or higher MRC grade had lower odds of completing PR, and patients that were 60 years or older, lived in Wales, started PR within 90 days of referral, ex-smokers, never smokers, and received any exercise test or health status questionnaire at initial assessment had higher odds of completing PR.

After mutual-adjustment of the predictor variables, significant predictors of PR completion were age ($p<0.0001$), country of residence ($p=0.0197$), deprivation ($p=0.0012$), BMI ($p=0.0028$), programme type ($p=0.0004$), starting PR within 90 days of referral ($p=0.0051$), smoking status ($p<0.0001$), GOLD stage ($p=0.0362$), MRC grade ($p<0.0001$), receipt of an exercise test at initial assessment ($p<0.0001$), and receipt of a health status questionnaire at initial assessment ($p<0.0001$) (**Table 2**). In the mutually-adjusted analysis patients that were 60 years or older, lived in Wales, started PR within 90 days of referral, ex-smokers, never smokers, received any exercise test, or received any health status questionnaire at initial assessment had higher odds of completing PR. Patients that were in the most deprived quintile, underweight, very severely obese, enrolled in a rolling rather than a cohort programme, had a higher GOLD stage, or had a higher MRC grade had lower odds of completing PR (**Figure 1** and **Table 2**).

Sensitivity analyses

Results of analyses using English deprivation data only were very similar to analyses using combined English and Welsh deprivation data. Analysis using Welsh deprivation data only was not possible due to the small sample size. Analysis using complete-case resulted in the predictor variables of programme type ($p=0.0562$), starting PR within 90 days of referral ($p=0.0559$), and GOLD stage ($p=0.3820$) no longer being statistically significant (**Supplementary Table S2**).

Discussion

Age, country of residence, deprivation, BMI, programme type, starting PR within 90 days of referral, smoking status, GOLD stage, MRC grade, receipt of an exercise test at initial assessment, and receipt of a health status questionnaire at initial assessment were all associated with completion of PR. Patients who were 60 years or older, resident in Wales, started PR within 90 days of referral, ex- or

never-smokers (relative to current smokers), completed an exercise test at initial assessment, and completed a health status questionnaire at initial assessment were more likely to complete PR. Patients who were in the most deprived quintile of IMD/WIMD, underweight or very severely obese (relative to a healthy weight), enrolled in a rolling programme (rather than a cohort programme), had a higher GOLD stage, and had a higher MRC grade were less likely to complete PR.

It is concerning that those for whom the service is specifically directed, i.e. MRC grades 3,4 and 5, are less likely to complete than those who are less symptomatic from their COPD. This may be because patients with more severe symptoms are more likely to be hospitalised or die before they can complete their PR programme. It may also indicate that we are not delivering the optimum format of PR for more symptomatic patients to facilitate completion and that we could perhaps deliver PR to patients with lower MRC grades so that they are able to complete PR before their symptoms progress to a level that makes completing PR more difficult. This group of patients are not routinely referred and fall outside the scope of practice identified in national guidance(4), with some services not commissioned to provide PR to patients with an MRC score less than 3. Increased likelihood of completion in patients that started PR within 90 days of referral or completed an exercise test or health status questionnaire at initial assessment seems to indicate that in services that adhere to national(20) and international(21) process guidance, there is an increased likelihood of completion.

Several previous studies have examined patient characteristics associated with PR completion. The most frequent association found is between smoking status and PR completion, either in the form of ex-smoking relative to current smoking(12,14,22–25) (like in this study), smoking pack-years(26), or time since smoking cessation(11). Previous authors(11,14,22–24) have suggested this could be due to the same lack of motivation preventing both smoking cessation and adherence to a PR programme. Qualitative studies(27,28) also list lack of motivation as a key reason for not attending PR. Gender(25) and referral location(10,14) were variables that have also been associated with PR completion in previous studies, but no such association was found in this study. Hakamy et al.(29) similarly to our study, found that patients that had a practice test before their exercise test were 17% more likely to complete PR.

One novel association with failure to complete PR in this study is enrolment on a rolling cohort programme. It is possible that patients have a greater sense of camaraderie in cohort programmes, supporting, encouraging, and motivating each other to keep going and complete the programme. Hogg et al.(10) examined this relationship but found no association between programme type and PR completion; however, it was only examined in unadjusted analysis. Alternatively, this finding could be due to the design of the audit programme. The audit ran for a period of 3 months and the participating PR services had until 4 months after the audit period to complete their data entry into the audit system. In contrast, Hogg et al.(10) ran their study for a period of 2 years meaning participants entering a rolling cohort programme towards the end of the study would have comprised a lower proportion of the analysed cohort.

Other associations with PR completion found in previous studies as well as this study have been: MRC grade(10,23,28), FEV₁ % predicted(11,14,15) (used as GOLD stage in this study), SES(9,10,30) and age(11,25). As in this study, higher age(11) has previously been linked with PR completion, but so has lower age(25). As Selzer et al.(11) suggest, work commitments could be a reason for higher age being associated with completion as younger patients may find it harder to allocate time for PR sessions. This is an issue raised by some patients in qualitative studies(27,31). It's also worth noting the non-linear association with age in this study: up to age 70-74 years patients become increasingly more likely to complete, but over 75 years of age likelihood of completion decreases (although there

is no significant difference between any of the ≥ 60 years age groups), a possible indication that completion is less likely in the oldest participants.

Strengths and Limitations

The strength of this study comes from its size and generalisability. It examines completion for 7060 patients enrolled in PR programmes covering nearly all of England and Wales and as national audit data, patients included in the study are representative of PR users.

This analysis is not without limitations though. IMD/WIMD are not perfect definitions of SES, as they only signify the deprivation of an area in which a person lives, not how deprived that person is. This is likely to bias results towards the null hypothesis for SES as the deprivation of a local population will appear more homogenous. Ethnicity would have been a desirable predictor to include in our analysis, however this was unavailable in the audit dataset and we suspect that the analysed cohort would be very homogenous with regard to ethnicity, limiting generalisability. Missing data were also an issue; in sensitivity analysis using complete case rather than including missing data in its own category (the main analysis), programme type, starting PR within 90 days of referral, and GOLD stage were not significantly associated with PR completion (unlike in the main analysis). The reason for this lack of association in complete-case analysis could be due to reduced power (the sample size more than halved), or it could be that the missing data categories have biased the results (equally, excluding missing data could bias results). The fact that the p-values were borderline significant for programme type and starting PR within 90 days does perhaps indicate that power was the issue in complete case analysis. As completion of PR was quite common (66% completed) odds ratios are unlikely to approximate risk ratios and may overestimate likelihood of completion. And finally, several significance tests were performed in this study, increasing the probability that some of our significant results are chance findings.

Conclusion

People with COPD were more likely to complete PR when best-practice guidelines were followed. People with more severe COPD symptoms, those that were likely to be less motivated, and people enrolled in a rolling rather than a cohort programme were less likely to complete PR. This has potential implications for the future design of PR programmes – earlier referral and cohort programmes may need to be prioritised. Useful further work would be to compare outcomes between cohort and rolling programmes. This would help inform whether swift programme entry or programme type should be prioritised.

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Guarantor

JKQ

Author contributions

PWS did the analysis and wrote the first draft of the manuscript. All other authors contributed to the design, interpretation, and subsequent drafts.

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Table 1. Characteristics of patients that enrolled in and completed, and patients that enrolled in but did not complete pulmonary rehabilitation. Proportions shown are row percentages.

	Did not complete PR (%) N = 2,425	Completed PR (%) N = 4,635
Age (years)		
35-59	509 (49.8%)	514 (50.2%)
60-64	369 (40.1%)	552 (59.9%)
65-69	469 (32.7%)	964 (67.3%)
70-74	465 (28.7%)	1,154 (71.3%)
75-80	353 (30.4%)	810 (69.7%)
≥80	260 (28.9%)	641 (71.1%)
Gender		
Male	1,210 (32.7%)	2,488 (67.3%)
Female	1,215 (36.1%)	2,147 (63.9%)
Country of residence	N = 2,408	N = 4,587
England	2,347 (34.9%)	4,387 (65.2%)
Wales	61 (23.4%)	200 (76.6%)
Quintile of English or Welsh Index of Multiple Deprivation	N = 2,408	N = 4,587
1 (most deprived)	815 (45.1%)	993 (54.9%)
2	517 (34.5%)	980 (65.5%)
3	447 (32.1%)	946 (67.9%)
4	372 (29.9%)	873 (70.1%)
5 (least deprived)	257 (24.4%)	795 (75.6%)
Quintile of 2015 English Index of Multiple Deprivation	N = 2,347	N = 4,387
1 (most deprived)	797 (45.5%)	953 (54.5%)
2	504 (35.0%)	936 (65.0%)
3	434 (32.5%)	900 (67.5%)
4	361 (30.3%)	829 (69.7%)
5 (least deprived)	251 (24.6%)	769 (75.4%)
Quintile of 2014 Welsh Index of Multiple Deprivation	N = 61	N = 200

1 (most deprived)	18 (31.0%)	40 (69.0%)
2	13 (22.8%)	44 (77.2%)
3	13 (22.0%)	46 (78.0%)
4	11 (20.0%)	44 (80.0%)
5 (least deprived)	6 (18.8%)	26 (81.3%)
BMI		
Underweight	108 (46.4%)	125 (53.7%)
Healthy	507 (33.1%)	1,026 (66.9%)
Overweight	469 (30.8%)	1,056 (69.3%)
Obese	484 (33.2%)	976 (66.9%)
Very severely obese	102 (41.6%)	143 (58.4%)
No data	755 (36.6%)	1,309 (63.4%)
Location of referral to PR		
	N = 2,342	N = 4,513
Community	1,535 (32.8%)	3,140 (67.2%)
Hospital	807 (37.0%)	1,373 (63.0%)
Programme type		
	N = 2,333	N = 4,547
Cohort	782 (28.3%)	1,984 (71.7%)
Rolling	1,551 (37.7%)	2,563 (62.3%)
Referral to start of PR within 90 days		
	N = 2,373	N = 4,591
	1420 (33.7%)	2,792 (66.3%)
Smoking status		
	N = 2,352	N = 4,504
Current smoker	742 (49.4%)	759 (50.6%)
Ex-smoker	1,493 (30.4%)	3,425 (69.6%)
Never smoked	117 (26.8%)	320 (73.2%)
Patient receiving oxygen therapy at home at the time of initial assessment		
	N = 2,398	N = 4,605
	179 (36.8%)	308 (63.2%)
GOLD Stage		
1	151 (28.5%)	378 (71.5%)
2	660 (32.5%)	1,368 (67.5%)

	3	440 (32.5%)	912 (67.5%)
	4	141 (36.1%)	250 (63.9%)
	No data	1,033 (37.4%)	1,727 (62.6%)
MRC Grade			
	1 or 2	293 (25.6%)	852 (74.4%)
	3	830 (32.6%)	1,714 (67.4%)
	4	821 (37.6%)	1,360 (62.4%)
	5	255 (46.4%)	295 (53.6%)
	No data	226 (35.3%)	414 (64.7%)
Any of ISWT, ESWT, or 6MWT		2,185 (32.8%)	4,478 (67.2%)
		N = 2,421	N = 4,627
Any of SGRQ, CRQ, or CAT		2,018 (31.9%)	4,310 (68.1%)

PR = pulmonary rehabilitation, BMI = body mass index, GOLD = Global Initiative for Chronic Obstructive Lung Disease, MRC = Medical Research Council, ISWT = Incremental Shuttle Walk Test, ESWT = Endurance Shuttle Walk Test, 6MWT = 6 Minute Walk Test, SGRQ = St. Georges Respiratory Questionnaire, CRQ = Chronic Respiratory Questionnaire, CAT = COPD Assessment Test.

Table 2. Odds ratios for completion of pulmonary rehabilitation in patients that enrolled in a PR programme by patient characteristics. Minimally-adjusted for age, sex, and deprivation. Mutually-adjusted for all variables shown.

		Crude			Minimally-adjusted			Mutually-adjusted			
		Odds Ratio (95% CI)			Odds Ratio (95% CI)			Odds Ratio (95% CI)			p-value*
Age (years)											<0.0001
	35-59	1			1			1			
	60-64	1.49	(1.23	- 1.79)	1.43	(1.18	- 1.73)	1.36	(1.11	- 1.68)	
	65-69	1.97	(1.65	- 2.34)	1.85	(1.55	- 2.20)	1.62	(1.33	- 1.97)	
	70-74	2.42	(2.04	- 2.87)	2.25	(1.89	- 2.67)	1.86	(1.54	- 2.26)	
	75-80	2.16	(1.80	- 2.59)	1.98	(1.64	- 2.38)	1.64	(1.33	- 2.02)	
	≥80	2.33	(1.91	- 2.84)	2.09	(1.71	- 2.56)	1.70	(1.35	- 2.14)	
Gender											0.2985
	Male	1			1			1			
	Female	0.87	(0.79	- 0.97)	0.91	(0.82	- 1.00)	0.94	(0.84	- 1.06)	
Country of residence											0.0197
	England	1			1			1			
	Wales	1.62	(0.99	- 2.65)	1.71	(1.08	- 2.71)	1.83	(1.10	- 3.03)	
Quintile of English or Welsh Index of Multiple Deprivation											0.0012
	1 (most deprived)	0.47	(0.39	- 0.57)	0.55	(0.45	- 0.66)	0.66	(0.53	- 0.81)	
	2	0.69	(0.57	- 0.84)	0.76	(0.62	- 0.92)	0.83	(0.68	- 1.03)	
	3	0.73	(0.60	- 0.88)	0.78	(0.65	- 0.95)	0.83	(0.68	- 1.02)	
	4	0.80	(0.66	- 0.96)	0.81	(0.66	- 0.98)	0.87	(0.70	- 1.07)	
	5 (least deprived)	1			1			1			
BMI											0.0028
	Underweight	0.54	(0.41	- 0.73)	0.57	(0.43	- 0.77)	0.61	(0.45	- 0.85)	
	Healthy	1.00			1.00			1.00			
	Overweight	1.08	(0.92	- 1.26)	1.02	(0.86	- 1.19)	0.96	(0.81	- 1.15)	
	Obese	0.97	(0.82	- 1.13)	0.92	(0.79	- 1.09)	0.88	(0.74	- 1.05)	
	Very severely obese	0.69	(0.52	- 0.92)	0.73	(0.54	- 0.97)	0.70	(0.50	- 0.96)	
	No data	0.74	(0.62	- 0.88)	0.72	(0.60	- 0.86)	0.76	(0.63	- 0.92)	
Location of referral to PR											0.2702
	Community	1			1			1			

Hospital	0.89	(0.79 - 1.01)	0.90	(0.80 - 1.02)	0.93	(0.81 - 1.06)	
Programme type							0.0004
Cohort	1		1		1		
Rolling	0.62	(0.51 - 0.75)	0.66	(0.55 - 0.78)	0.70	(0.57 - 0.85)	
Referral to start of PR within 90 days	1.21	(1.07 - 1.36)	1.19	(1.05 - 1.34)	1.21	(1.06 - 1.38)	0.0051
Smoking status							<0.0001
Current smoker	1		1		1		
Ex-smoker	2.20	(1.95 - 2.49)	1.87	(1.64 - 2.13)	1.92	(1.66 - 2.21)	
Never smoked	2.62	(2.05 - 3.34)	2.13	(1.65 - 2.74)	2.15	(1.63 - 2.82)	
Patient receiving oxygen therapy at home at the time of initial assessment	0.84	(0.69 - 1.02)	0.80	(0.65 - 0.98)	0.87	(0.69 - 1.09)	0.2231
GOLD Stage							0.0362
1	1		1		1		
2	0.81	(0.65 - 1.01)	0.79	(0.63 - 0.98)	0.75	(0.59 - 0.96)	
3	0.79	(0.63 - 1.00)	0.76	(0.60 - 0.96)	0.73	(0.56 - 0.94)	
4	0.66	(0.49 - 0.88)	0.67	(0.50 - 0.90)	0.73	(0.52 - 1.02)	
No data	0.68	(0.55 - 0.85)	0.65	(0.52 - 0.82)	0.67	(0.52 - 0.86)	
MRC Grade							<0.0001
1 or 2	1		1		1		
3	0.69	(0.58 - 0.81)	0.71	(0.60 - 0.84)	0.73	(0.61 - 0.88)	
4	0.54	(0.46 - 0.64)	0.57	(0.48 - 0.68)	0.60	(0.50 - 0.73)	
5	0.37	(0.30 - 0.47)	0.40	(0.32 - 0.51)	0.45	(0.34 - 0.58)	
No data	0.54	(0.41 - 0.71)	0.57	(0.44 - 0.75)	0.71	(0.52 - 0.96)	
Any of ISWT, ESWT, or 6MWT	4.92	(3.75 - 6.44)	4.85	(3.69 - 6.37)	3.43	(2.55 - 4.63)	<0.0001
Any of SGRQ, CRQ, or CAT	3.93	(3.17 - 4.89)	3.74	(3.00 - 4.67)	2.97	(2.33 - 3.79)	<0.0001

*Likelihood ratio test

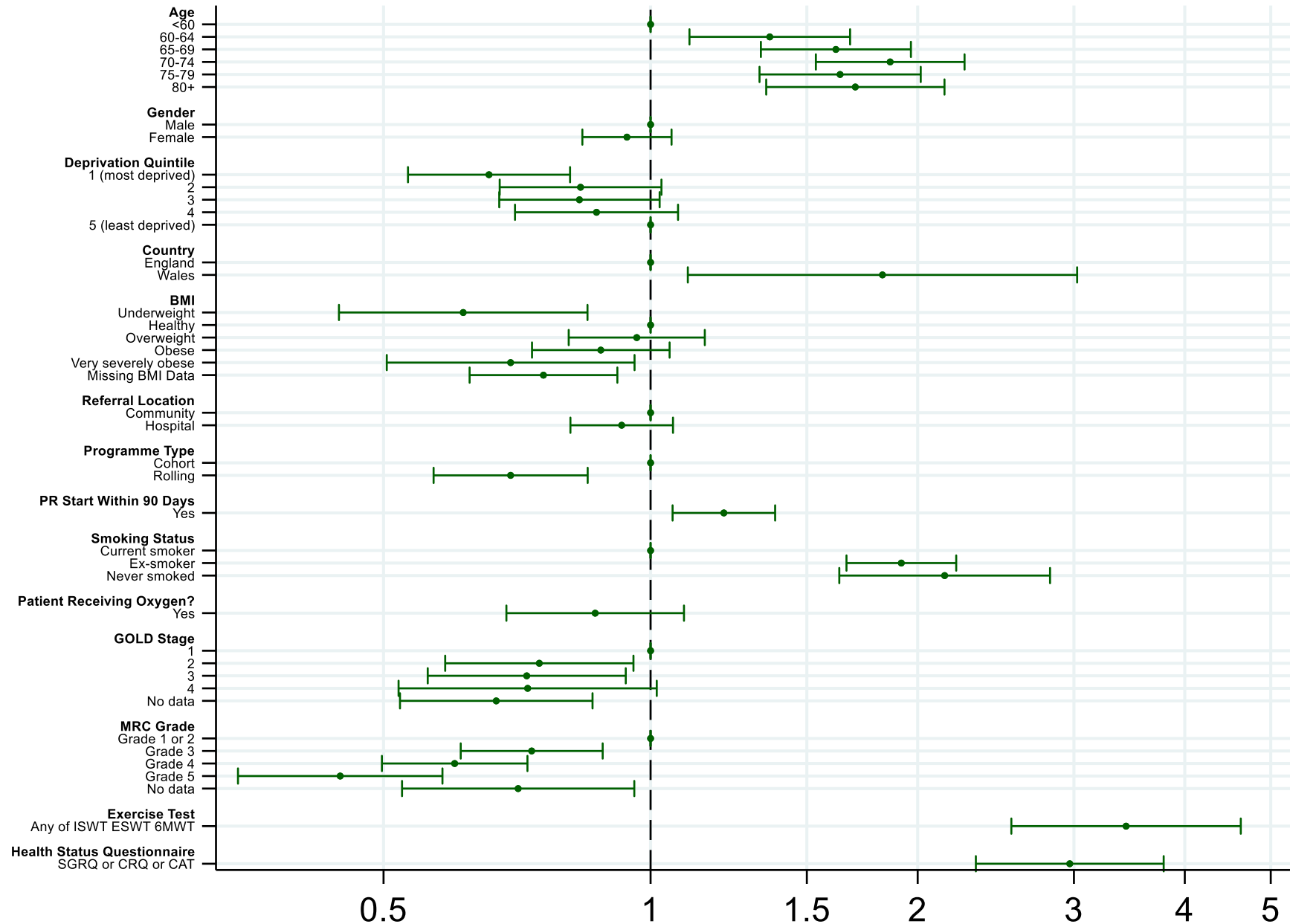
CI = confidence interval, BMI = body mass index, PR = pulmonary rehabilitation, GOLD = Global Initiative for Chronic Obstructive Lung Disease, MRC = Medical Research Council, ISWT = Incremental Shuttle Walk Test, ESWT = Endurance Shuttle Walk Test, 6MWT = 6 Minute Walk Test, SGRQ = St. Georges Respiratory Questionnaire, CRQ = Chronic Respiratory Questionnaire, CAT = COPD Assessment Test.

Figure legends

Figure 1

Plot showing mutually-adjusted odds and 95% confidence intervals for completion of pulmonary rehabilitation (PR) in patients that enrolled in a PR programme by patient characteristics. BMI = body mass index, GOLD = Global Initiative for Chronic Obstructive Lung Disease, MRC = Medical Research Council, ISWT = Incremental Shuttle Walk Test, ESWT = Endurance Shuttle Walk Test, 6MWT = 6 Minute Walk Test, SGRQ = St. Georges Respiratory Questionnaire, CRQ = Chronic Respiratory Questionnaire, CAT = COPD Assessment Test.

Figure 1. Plot showing mutually-adjusted odds and 95% confidence intervals for completion of pulmonary rehabilitation (PR) in patients that enrolled in a PR programme by patient characteristics.



Supplementary Methods

Variables

The outcome of the analysis – completion of PR – was defined as any enrolled patient that received a discharge assessment. 14 exposures (**Table 3**) were used as potential predictors of PR completion. Patients without age data, patients aged under 35 years at initial appointment for PR, and patients that did not enrol on a PR programme were excluded. Additionally, patients that did not enrol were excluded to remove unsuitability or lack of motivation as factors for non-completion.

SES was defined as quintile of either English Index of Multiple Deprivation (IMD) 2015 or WIMD 2014, derived using the patient's home post code. IMD and WIMD are measures of deprivation that ranks the relative deprivation between small areas (or neighbourhoods) of England and Wales, respectively. Values for IMD and WIMD are derived by assessing how deprived an area is the domains of income, employment, education, health, crime, housing, environment, and access to services(1,2). Country of residence was defined based on the presence of either an IMD (England) or WIMD (Wales) value.

Body mass index (BMI) was calculated using most recent available height and weight data and patients were categorised as: underweight ($<18.5 \text{ kg/m}^2$), healthy ($18.5 \leq \text{kg/m}^2 < 25$), overweight ($25 \leq \text{kg/m}^2 < 30$), obese ($30 \leq \text{kg/m}^2 < 40$), and very severely obese ($>40 \text{ kg/m}^2$).

Location of referral to PR was defined as 'community' if the patient was referred from community specialist respiratory services or their GP, or 'hospital' if the patient was referred by a hospital consultant, hospital specialist COPD team, or following a hospital admission for AECOPD.

Programme type was defined as 'rolling' if the patient was able to join the programme at any time, or 'cohort' if all patients started and finished the programme at the same time. PR start within 90 days of referral was considered met if the length of time between a PR programme receiving a referral letter and the patient's offered start date was 90 days or fewer. Patient smoking status was defined by habit in the 4 weeks prior to assessment: current smoker (in the 4 weeks prior), ex-smoker (ever), or never smoker. Oxygen therapy at home was defined as the patient receiving any sort of oxygen therapy (as needed, ambulatory, or long-term oxygen therapy) at home at the time of assessment.

Global Initiative for Chronic Obstructive Lung Disease (GOLD) stage was calculated using most recent available FEV₁ % predicted data and split as stage 1 (FEV₁ % predicted $< 80\%$), stage 2 (50-80%), stage 3 (30-50%), and stage 4 ($<30\%$). Medical Research Council (MRC) grade was calculated at assessment. Receipt of an exercise test at initial assessment was defined as a record for Incremental shuttle walk test (ISWT)(3), Endurance shuttle walk test (ESWT)(4), or Six-minute walk test (6MWT)(5) at initial assessment. Receipt of a health status questionnaire at initial assessment was defined as a record for St. George's Respiratory Questionnaire (SGRQ)(6), Chronic Respiratory Questionnaire (CRQ)(7), or COPD Assessment Test (CAT)(8) at initial assessment.

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Supplementary Tables

Supplementary Table S1. Characteristics of COPD patients that enrolled in a PR programme.

		Frequency (%)	
		N = 7,060	
Age (years)			
	35-59	1,023	(14.5%)
	60-64	921	(13.1%)
	65-69	1,433	(20.3%)
	70-74	1,619	(22.9%)
	75-80	1,163	(16.5%)
	≥80	901	(12.8%)
Gender			
	Male	3,698	52.38
	Female	3,362	47.62
Country of residence			
	England	6,734	(95.4%)
	Wales	261	(3.7%)
	No data	65	(0.9%)
Quintile of English or Welsh Index of Multiple Deprivation			
	1 (most deprived)	1,808	(25.6%)
	2	1,497	(21.2%)
	3	1,393	(19.7%)
	4	1,245	(17.6%)
	5 (least deprived)	1,052	(14.9%)
	No data	65	(0.9%)
Quintile of 2015 English Index of Multiple Deprivation			
	1 (most deprived)	1,750	(24.8%)
	2	1,440	(20.4%)
	3	1,334	(18.9%)
	4	1,190	(16.9%)
	5 (least deprived)	1,020	(14.5%)
	No data	326	(4.6%)

Quintile of 2014 Welsh Index of Multiple Deprivation		
1 (most deprived)	58	(0.8%)
2	57	(0.8%)
3	59	(0.8%)
4	55	(0.8%)
5 (least deprived)	32	(0.5%)
No data	6,799	(96.3%)
BMI		
Underweight	233	(3.3%)
Healthy	1,533	(21.7%)
Overweight	1,525	(21.6%)
Obese	1,460	(20.7%)
Very severely obese	245	(3.5%)
No data	2,064	(29.2%)
Location of referral to PR		
Community	4,675	(66.2%)
Hospital	2,180	(30.9%)
No data	205	(2.9%)
Programme type		
Cohort	2,766	(39.2%)
Rolling	4,114	(58.3%)
No data	180	(2.6%)
Referral to start of PR within 90 days		
>90 days	2,752	(39.0%)
≤90 days	4,212	(59.7%)
No data	96	(1.4%)
Smoking status		
Current smoker	1,501	(21.3%)
Ex-smoker	4,918	(69.7%)
Never smoked	437	(6.2%)
No data	204	(2.9%)

Patient receiving oxygen therapy at home at the time of initial assessment			
	No	6,516	(92.3%)
	Yes	487	(6.9%)
	No data	57	(0.8%)
GOLD Stage			
	1	529	(7.5%)
	2	2,028	(28.7%)
	3	1,352	(19.2%)
	4	391	(5.5%)
	No data	2,760	(39.1%)
MRC Grade			
	1 or 2	1,145	(16.2%)
	3	2,544	(36.0%)
	4	2,181	(30.9%)
	5	550	(7.8%)
	No data	640	(9.1%)
Any of ISWT, ESWT, or 6MWT			
	No	397	(5.6%)
	Yes	6,663	(94.4%)
Any of SGRQ, CRQ, or CAT			
	No	720	(10.2%)
	Yes	6,328	(89.6%)
	No data	12	(0.2%)
Received a discharge assessment (completed PR)			
	No	2,425	(34.4%)
	Yes	4,635	(65.7%)

PR = pulmonary rehabilitation, BMI = body mass index, GOLD = Global Initiative for Chronic Obstructive Lung Disease, MRC = Medical Research Council, ISWT = Incremental Shuttle Walk Test, ESWT = Endurance Shuttle Walk Test, 6MWT = 6 Minute Walk Test, SGRQ = St. Georges Respiratory Questionnaire, CRQ = Chronic Respiratory Questionnaire, CAT = COPD Assessment Test.

Supplementary Table S2. Mutually-adjusted odds ratios for completion of pulmonary rehabilitation in patients that enrolled in a PR programme by patient characteristics *using complete-case analysis*. Adjusted for all variables shown. N=2,938.

		Mutually-adjusted	
		Odds Ratio (95% CI)	p-value*
Age (years)	35-59	1	<0.0001
	60-64	1.58 (1.16 - 2.14)	
	65-69	1.55 (1.17 - 2.05)	
	70-74	1.99 (1.50 - 2.65)	
	75-79	1.90 (1.39 - 2.60)	
	80+	2.09 (1.47 - 2.97)	
Gender	Male	1	0.8018
	Female	0.98 (0.82 - 1.16)	
Country of residence	England	1	0.0061
	Wales	2.12 (1.24 - 3.61)	
Quintile of English or Welsh Index of Multiple Deprivation	1 (most deprived)	0.55 (0.40 - 0.74)	0.0021
	2	0.73 (0.53 - 0.99)	
	3	0.79 (0.58 - 1.07)	
	4	0.79 (0.57 - 1.09)	
	5 (least deprived)	1	
BMI	Underweight	0.64 (0.42 - 0.97)	0.0410
	Healthy	1.00	
	Overweight	0.89 (0.71 - 1.12)	
	Obese	0.79 (0.63 - 0.99)	
	Very severely obese	0.62 (0.41 - 0.93)	
Location of referral to PR	Community	1	0.2486
	Hospital	0.89 (0.73 - 1.08)	

Programme type				0.0562
Cohort	1			
Rolling	0.79	(0.61 - 1.01)		
Referral to start of PR within 90 days	1.21	(1.00 - 1.48)		0.0559
Smoking status				<0.0001
Current smoker	1			
Ex-smoker	2.07	(1.68 - 2.56)		
Never smoked	2.67	(1.74 - 4.11)		
Patient receiving oxygen therapy at home at the time of initial assessment	0.81	(0.58 - 1.15)		0.2515
GOLD Stage				0.3820
1	1			
2	0.78	(0.59 - 1.04)		
3	0.80	(0.59 - 1.08)		
4	0.78	(0.52 - 1.16)		
MRC Grade				<0.0001
1 or 2	1			
3	0.64	(0.49 - 0.84)		
4	0.54	(0.41 - 0.71)		
5	0.39	(0.27 - 0.58)		
Any of ISWT, ESWT, or 6MWT	2.54	(1.60 - 4.01)		0.0001
Any of SGRQ, CRQ, or CAT	2.96	(2.01 - 4.36)		<0.0001

*Likelihood ratio test

CI = confidence interval, BMI = body mass index, PR = pulmonary rehabilitation, GOLD = Global Initiative for Chronic Obstructive Lung Disease, MRC = Medical Research Council, ISWT = Incremental Shuttle Walk Test, ESWT = Endurance Shuttle Walk Test, 6MWT = 6 Minute Walk Test, SGRQ = St.

Georges Respiratory Questionnaire, CRQ = Chronic Respiratory Questionnaire, CAT = COPD Assessment Test.