Participation in Pulmonary Rehabilitation Following Hospitalization for COPD among Medicare Beneficiaries

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Abstract

Rationale: Current guidelines recommend pulmonary rehabilitation (PR) after hospitalization for a COPD exacerbation, but little is known about its adoption or factors associated with participation.

Objectives: To evaluate receipt of PR after a hospitalization for COPD exacerbation among Medicare beneficiaries and identify individual- and hospital-level predictors of PR receipt and adherence.

Methods: We identified individuals hospitalized for COPD during 2012 and recorded receipt, timing, and number of PR visits. We used generalized estimating equation models to identify factors associated with initiation of PR within 6 months of discharge and examined factors associated with number of PR sessions completed.

Results: Of 223,832 individuals hospitalized for COPD, 4,225 (1.9%) received PR within 6 months of their index hospitalization and 6,111 (2.7%) within 12 months. Median time from discharge until first PR session was 95 days (IQR 44 - 190) and median number of sessions completed was 16 (IQR 6-25). The strongest factor associated with initiating PR within 6 months was prior home oxygen use (OR: 1.49; 95% CI: 1.39 - 1.59). Individuals aged 75-84 and 85 and over (0R: 0.71; 95% CI: 0.66 – 0.76; OR: 0.25; 95% CI: 0.22 -0.29), those living over 10 miles from a PR facility (OR: 0.47; CI: 0.42 - 0.51) and those with lower SES (OR: 0.42; 95% CI 0.38 - 0.46) were less likely to receive PR.

Conclusions: Two years after Medicare began providing coverage for PR, participation rates following hospitalization were extremely low. This highlights the need for strategies to increase participation.

Chronic Obstructive Pulmonary Disease (COPD) is the fourth leading cause of death in the United States. Roughly 16 million people have a diagnosis of COPD and millions more are undiagnosed(1). The burden on the U.S. health care system is substantial: COPD is responsible for over 700,000 hospitalizations annually, and the total direct costs of COPD are estimated at $29.5 billion(2–4). Patients with COPD also face physical limitations that negatively impact their physical and mental health(5, 6).

Pulmonary Rehabilitation (PR) is a treatment program for patients living with COPD. PR is a patient-tailored intervention that includes exercise training and self-management education aimed at sustained behavior change to improve physical and psychological well-being(7). While the delivery of PR varies, PR typically takes place in a center-based setting, with individuals attending two or three sessions a week for a course of eight weeks or more(8). PR has been shown to reduce dyspnea, reduce fatigue, increase exercise tolerance, and improve quality of life(9). There is also evidence that PR reduces hospital readmissions(10). Current guidelines recommend that patients begin PR within three weeks after a hospitalization for COPD(7, 11, 12).

Despite these benefits, studies in the US and elsewhere suggest that PR is underutilized in the setting of stable COPD(13–15), but rates of receipt of PR after hospitalization for a COPD exacerbation are unknown. Many individuals with COPD are never referred to PR; of those referred a significant percentage do not make it to the first visit(15). Furthermore, of those who do attend, only a fraction complete the recommended number of sessions within 1 year(14, 16, 17). Following Medicare's policy change in 2010, which provided coverage for PR services and effectively opened up PR to millions of US Medicare beneficiaries, we sought to examine the

use of PR by elderly patients following a hospitalization for COPD.

Methods

Cohort

From the Centers for Medicare and Medicaid Services (CMS) we obtained beneficiary denominator and standard analytic files for every individual hospitalized in an acute care hospital in 2012, with a principal diagnosis of COPD or a principal diagnosis of acute respiratory failure combined with a secondary diagnosis of COPD with acute exacerbation. We defined the cohort in accordance with methods used by CMS (International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9) codes were used to define the cohort: a principal diagnosis of COPD, ICD-9-CM codes 490, 491.0, 491.1, 491.21, 491.22, 491.8, 491.9, 492.8, 493.20, 493.21, 493.22, or 496, or a principal diagnosis of acute respiratory failure or arrest 518.81, 518.82, 518.84, 786.09, or 799.1, when combined with a secondary diagnosis of COPD with acute exacerbation, 491.21, 491.22, 493.21, or 493.22)(18).

We included individuals 66 years or older, if they were continuously enrolled for 1 year in Medicare fee-for-service from their index admission, and had not received PR during the prior year. We excluded individuals aged 65 to ensure that all subjects in our cohort had at least one prior year of Medicare data to assess comorbidities and health care utilization. In order to limit the study to those individuals who would likely benefit and be eligible to participate in PR, we excluded those who were hospitalized for more than 30 days at their index hospitalization, died within 30 days of their index hospitalization, or were transferred to

another acute care facility, hospice, long-term-care facility, transferred to court or law enforcement, or discharged against medical advice.

PR Services Use

In order to identify patients who received PR and providers of PR we used healthcare common procedure coding system (HCPCS) codes (G0424 (COPD), and G0237, G0238, and G0239 (non-COPD)) from the Medicare outpatient file, which contains claims data from institutional outpatient providers (i.e. hospital outpatient-based facilities), and carrier file, which contains claims from non-institutional providers (i.e. physicians' offices). We matched the denominator file with these claims files to identify individuals who received at least one PR session within 6 months and 1 year after discharge from their index hospitalization. The providers associated with these PR claims were identified as PR providers. As with other medical procedures, the incentive to bill for services should lead to a high level of validity of this claims data as a means of measuring PR services received by this population(19). We included HCPCS codes for pulmonary rehabilitation, regardless of whether it was specifically ordered for COPD, in order to ensure that we ascertained all pulmonary rehabilitation received by COPD patients. We measured the number of days from the index hospitalization to the first PR session, and the number of sessions attended.

Predictors of PR Use and Covariates

At the individual level, we included measures of age, gender, race and ethnicity, and Medicaid eligibility (a proxy for lower-socio economic status) from the Medicare denominator file. In

order to investigate the contribution of comorbidity burden to participation in PR, we captured ICD-9 codes from physician office visits, hospital outpatient visits, and hospitalizations in the year prior to the index hospitalization. We used these diagnoses to compute a longitudinal Charlson comorbidity index (20–23) and divided subjects into groups of low, medium, and high comorbidity burden based on the weighted index. As an additional marker of disease severity, we identified (from the Medicare Durable Medical Equipment files) home oxygen use in the 90 days prior to hospitalization. We recorded treatment with noninvasive or invasive mechanical ventilation during the index hospitalization via ICD-9 procedure codes. Additionally, we determined whether the subject was a current smoker at the time of the index hospitalization using ICD-9 diagnoses.

We determined geographic accessibility of PR by calculating the distance from the centroid of each individual's zip code of residence to the nearest PR provider. We extracted hospital characteristics such as the geographic region, rural or urban location, teaching status, and size of the hospital (based on the number of beds) from the Medicare provider of service files.

Statistical Analysis

We calculated individual and hospital characteristics as frequencies and percentages for categorical variables and mean, standard deviation or median, inter-quartile range for continuous variables. Given the very large size of our study population, associations between receipt of PR within 6 months of index discharge and individual and hospital characteristics were assessed using absolute standardized differences, where differences greater than 10%

were considered meaningful(24, 25). In order to identify factors associated with receipt of PR within 6 months of index discharge, we developed a generalized estimating equations (GEE) model with logit link accounting for the natural clustering of individuals within hospitals. This model included demographics, distance to the nearest PR facility, comorbidity burden, current smoking status, ventilator support during the index admission, hospital admissions and oxygen use in the year prior to the index hospitalization, and hospital size, region, teaching status and rural or urban status.

We then restricted our cohort to individuals who had at least one PR session within a year of index discharge and modeled factors associated with the number of PR sessions attended. After visually examining the distribution of the number of sessions, we categorized individuals into three clinically meaningful groups, those completing 1 – 11, 12 – 23, and greater than or equal to 24 sessions. We fit the 3-level PR sessions variable as an ordinal outcome with individual characteristics including demographics, comorbidity burden, smoking status, markers of disease severity, and distance to nearest PR provider as independent variables.

All analyses were performed using SAS (version 9.4, SAS Institute Inc., Cary, NC) and STATA 15 (StataCorp. Inc., College Station, TX). Provider service locations were geo-coded using Texas A&M University Geoservices(26).

Results

Demographics

After exclusions, a total of 223,832 Medicare beneficiaries hospitalized for COPD in 2012 were included in our cohort (Figure 1). The median age was 77 years (IQR: 71-83 years), the majority were female (59.4%), white non-Hispanic (84.8%) and 27.9% were eligible for Medicaid. Half of the patients lived within 4.8 miles (IQR: 2.4-10.7 miles) of the nearest PR provider (Table 1).

Clinical Features and Outcomes

The majority of individuals, 87.3%, had a principal diagnosis of COPD, 12.7% had a principal diagnosis of acute respiratory failure with a secondary diagnosis of COPD. The three most common comorbidities were congestive heart failure (61.2%), diabetes (49.4%), and peripheral vascular disease (48.9%). In addition, 20.8% of individuals were current smokers. The median weighted Charlson comorbidity index was 4(IQR: 2-7). Nearly half (48.6%) of all subjects had been hospitalized during the prior year. More than one-third (35.3 %) received home oxygen in the 90 days prior to hospitalization. During the index admission, 5.7 % were treated with noninvasive ventilation and 3.3% with invasive mechanical ventilation (Table 1). The all-cause one-year readmission rate was 63.2% and the one-year mortality rate was 14.4%.

Receipt of PR

Receipt of PR following a hospitalization was rare. Fewer than 2 in 100 potentially eligible individuals hospitalized for COPD (1.9%) received any PR within 6 months after a hospitalization

(n=4,225). Examining cumulative enrollment rates over time, we found that 732 (0.3%) patients had received PR within 1 month of discharge, 3,321 (1.5%) within 3 months, and 6,111 (2.7%) within 12 months. The median number of days from the index hospitalization to the first instance of PR receipt was 95 days (IQR: 44 – 190 days). Individuals who received PR completed a median of 16 (IQR: 6-25) sessions over the course of a year (Figure 2).

Predictors of PR Receipt

Factors that were independently associated with PR receipt within 6 months included younger age, male, white, and higher SES (Table 2). Compared to individuals aged 66-74 years, those aged 75-84 years were 29% percent less likely to receive PR, and those 85 and older were 75% less likely. Men were 21% more likely than women to receive at least one PR session. Compared to white, non-Hispanic patients, African Americans were 30% less likely to receive PR and Hispanics were 40% less likely to receive PR. Those who were dual-eligible for Medicaid and Medicare, indicating lower socio-economic status, were 58% less likely to receive PR (Table 2).

Clinical factors, such as number of prior admissions and severity of comorbidity burden, were also important in predicting PR receipt. As the number of prior admissions increased, the probability of receiving PR declined. Compared to those with no prior admits, individuals with one, two, or three or more admissions in the prior year were 16%, 22%, and 39% less likely to receive PR. Individuals with a weighted Charlson score of 6 or higher were 34% less likely to participate in PR than those with a weighted index of 0-2. In contrast, those receiving home oxygen within 90 days prior to their hospitalization were 49% more likely to participate in PR

than those without. Notably, ventilatory support (noninvasive or invasive mechanical ventilation) during the index hospitalization had no association with PR receipt.

As we anticipated, those living in zip-codes closer to PR providers were more likely to receive PR, with a clear threshold difference at around 10 miles travel distance. Specifically, those living in zip-codes within 5-10 miles of the nearest PR provider were only 4 % less likely to receive PR than those within 5 miles of the nearest provider, however those who were over 10 miles were 53% less likely to receive PR. Individuals hospitalized in the North East, Midwest and West regions of the US were 21%, 65%, and 19% more likely than those in the South to receive PR.

PR Adherence

Among those who received one or more sessions of PR within one year (n= 6,111), over half completed 16 sessions and approximately 10% completed 35 sessions or more. We found that gender, and socio-economic status (i.e. Medicaid eligibility), and clinical factors continued to be associated with the intensity of PR attendance. On average, women, those of lower SES, and current smokers completed fewer sessions. Patients who had more prior admissions and higher comorbidity burden also completed fewer sessions (Table 3).

Discussion

In this national study of elderly Medicare beneficiaries hospitalized for COPD, we found an enormous gap between the recommendations found in professional society guidelines and

recent clinical practice(11). The vast majority of individuals who might benefit from PR never receive it: less than 2% received PR within 6 months of their index hospitalization. Furthermore, while rates were low overall, we found evidence that receipt of PR was even lower among those from disadvantaged patient populations. Individuals who are female, non-white, and dually eligible for Medicaid were less likely to receive PR after a hospitalization for COPD. Furthermore, among those who received any PR, those who were female or Medicaid eligible completed fewer PR sessions. At the zip-code level, distance to PR facility was a factor and living closer to a PR facility was associated with increased receipt of PR. Clinical factors helped explain PR receipt in predictable ways with younger, healthier individuals more likely to receive PR. In addition, those with more prior hospital admissions were less likely to attend PR, suggesting that we are missing an opportunity to improve the quality of life and, potentially, reduce readmissions for patients who are most impacted by their disease. Moreover, these findings underscore the need to make sure that PR is made accessible to all patients who could potentially benefit, including those who face multiple challenges, whether health related, social, or financial. Recent guidelines recommend PR post-hospitalization for patients with COPD exacerbation; our findings illustrate just how much progress will need to be made to close the gap we have documented.

This study builds upon prior work by Nishi and colleagues. They examined PR receipt among the 5% sample of Medicare beneficiaries with an inpatient or outpatient diagnosis of COPD, and found that rates of PR attendance ranged from 2.6% in 2003 to 3.7% in 2012(12). In contrast, our study examined PR attendance during the period following hospitalization for COPD exacerbation. The differences in our overall rates of PR utilization are also explained by

differences in our definition of PR receipt. Where Nishi and colleagues utilized both HCPCS and current procedural terminology codes, which can be overly broad (e.g. “therapeutic procedures, group”), we used HCPCS codes exclusively to accurately identify PR.

Studies in the UK have also found that there is much room for improvement in PR participation, however rates are much higher than in the U.S. (26, 27). Hakamy and colleagues conducted a study in the UK using data from the Health Information Network (THIN) primary care database and found that 9.8% of COPD patients received PR. As in our study, older individuals and those of lower SES were less likely to receive PR and also less likely to adhere to PR. In contrast to our study, they found that those with higher Charlson comorbidity were more likely to receive PR; in addition, they found no relationship between gender and PR receipt. They also included a measure of dyspnea and showed that worse dyspnea scores were associated with PR receipt. This finding, along with our finding that individuals on home oxygen are more likely to attend PR, suggests that increased dyspnea, either on its own or through increasing interaction with the health care system, may increase participation in PR. Individuals with increased dyspnea may be more willing to participate in PR, or they may be more likely to receive the necessary diagnostic tests and referrals. Furthermore, these findings suggest that low rates of PR are not unique to the US, but that differing rates of utilization by patient characteristics, such as gender, may be driven by systemic or cultural factors.

Our focus on the window of time following hospitalization is especially relevant given the recent addition of COPD to the list of conditions used in Medicare’s Hospital Readmission Reduction Program. This change, along with the growth of accountable care organizations, and bundled forms of payment have focused attention on identifying and implementing programs

to reduce the risk of readmissions and improve longer term outcomes for patients with COPD and other chronic conditions. Although there are limitations in current understanding of how to effectively prevent readmissions for COPD, beyond its many other benefits, PR is an intervention that has been identified as a promising strategy for preventing readmissions (9, 29). Our study shows that there is room for considerable growth in PR utilization and underscores the need to understand why PR utilization is so low.

Additionally, further study is needed to disentangle the effects of geographic variation in PR programs from the role of race and socio-economic status in explaining lower rates of PR among non-whites and those eligible for Medicaid. Prior studies have shown that COPD is more prevalent in rural areas of the US, as are Medicare hospitalizations for COPD and deaths, but more research is needed to understand the distribution of PR programs and whether there are gaps in accessibility (30). This is especially important because distance to PR facility was a strong negative predictor of PR receipt in this study and other studies have shown that distance to PR was negatively associated with adherence to PR (31). In addition, research outside the US has shown that patients from disadvantaged areas are less likely to complete PR, even though the benefits of PR are consistent across populations from different areas (32). Non-clinical factors, such as spatial accessibility and the nature of PR programs, may play a role in creating barriers to enrollment and adherence. Our study suggests that more needs to be done to identify and address these barriers, including efforts to increase access through home-based PR programs.

There is evidence that health care providers are referring patients at very low rates in the US and elsewhere(33). Given the nature of our dataset we were unable to determine

whether physicians fail to refer patients to PR , whether physicians refer patients PR at different rates based on non-clinical factors (e.g. gender or race), or whether patients choose not to enroll. A recent national survey of primary care physicians (PCP) found that while two thirds reported having PR available to their patients only 38% routinely referred their COPD patients to PR, suggesting that more needs to be done to encourage PCPs to recommend PR to patients that may benefit (34). Existing research suggests that one of the greatest barriers to PR referrals is a lack of knowledge of PR on the part of providers(33). For patients, existing research indicates that transportation, current smoking, depression, fear of making a change, and not feeling well enough are barriers to PR (14, 35, 36). Our analysis supports the findings that transportation, current smoking, and health status are barriers for patients; more research is needed to shed light on where in the health care system efforts to increase PR utilization should be targeted.

Our study has a number of strengths. Using a 100% census sample of US Medicare beneficiaries hospitalized for COPD, it is the first to examine participation in PR following a hospitalization. Unlike prior work, we were able to identify those individuals who were most likely to have moderate to severe COPD and therefore be eligible for PR. Furthermore, we captured PR performed in both hospital-based and office-based settings. Our dataset also allowed us to observe pre-hospitalization factors and thus control for the severity of disease, comorbidity burden, and home oxygen utilization.

While we attempted to limit our cohort to patients most likely to be eligible for PR by selecting only those who have been hospitalized for COPD exacerbations, we did not have results of spirometry, which, in addition to providing additional information on the severity of

the airway obstruction, are also used to determine actual eligibility. In addition, we were unable to assess whether or not individuals participated in PR more than 1 year prior to their index admission, thus our cohort might have included a small number of patients who had already completed PR and for whom Medicare reimbursement for PR was no longer available. The typical beneficiary is limited to 36 sessions of PR, with the potential to receive 72 sessions if their doctor documents a need for additional sessions, In addition, Medicare's limits on the number of sessions could influence referral rates if physicians are reluctant to refer patients to PR with the aim or preserving PR sessions for when the patients are more stable. This study is also limited in that we observed only elderly Medicare fee-for-service beneficiaries. While the majority of patients hospitalized for COPD in the US are Medicare beneficiaries(37), we cannot generalize to younger patients, where our findings suggest that PR receipt may be somewhat higher.

In conclusion, two years after Medicare began providing coverage for PR services, we found that the vast majority of individuals who might benefit from PR following a COPD hospitalization never receive these services, and that this is particularly true among those who are non-white, female, lower-SES, and those with multiple comorbidities and prior hospitalizations. In order to identify strategies to increase the receipt of PR and reduce disparities, more research is needed to understand the reasons that patients fail to receive PR and learn from hospitals that have been successful at enrolling COPD patients.

References

1. National Heart, Lung, and Blood Institute. What Is COPD? *Natl Heart Lung Blood Inst* 2017;at <https://www.nhlbi.nih.gov/health/health-topics/topics/copd/#>.
2. *The Morbidity & Mortality: Chart Book on Cardiovascular, Lung, and Blood Diseases*. National Institutes of Health National Heart, Lung, and Blood Institute; 2012. at <https://www.nhlbi.nih.gov/files/docs/research/2012_ChartBook_508.pdf>.
3. Wier LM, Elixhauser A, Pfuntner A, Au DH. Overview of Hospitalizations among Patients with COPD, 2008: Statistical Brief #106. *Healthc Cost Util Proj HCUP Stat Briefs* Rockville (MD): Agency for Health Care Policy and Research (US); 2011. at <http://www.ncbi.nlm.nih.gov/books/NBK53969/>.
4. *National Heart, Lung and Blood Institute. Morbidity and Mortality: 2009 Chartbook on Cardiovascular, Lung and Blood Diseases.* at <https://www.nhlbi.nih.gov/files/docs/factbook/FactBook2009.pdf>.
5. Benzo R. Satori: Awakening to Outcomes That Matter: The Impact of Social Support in Chronic Obstructive Pulmonary Disease. *Ann Am Thorac Soc* 2017;14:1385–1386.
6. Global Initiative for Chronic Obstructive Lung Disease (GOLD). Global Strategy for the Diagnosis, Management and Prevention of COPD. 2015;at <http://www.goldcopd.org/.>.
7. Spruit MA, Singh SJ, Garvey C, ZuWallack R, Nici L, Rochester C, Hill K, Holland AE, Lareau SC, Man WD-C, Pitta F, Sewell L, Raskin J, Bourbeau J, Crouch R, Franssen FME, Casaburi R, Vercoulen JH, Vogiatzis I, Gosselink R, Clini EM, Effing TW, Maltais F, van der Palen J, Troosters T, Janssen DJA, Collins E, Garcia-Aymerich J, Brooks D, *et al.* An official American Thoracic Society/European Respiratory Society statement: key concepts and advances in pulmonary rehabilitation. *Am J Respir Crit Care Med* 2013;188:e13-64.
8. McCarthy B, Casey D, Devane D, Murphy K, Murphy E, Lacasse Y. Pulmonary rehabilitation for chronic obstructive pulmonary disease. In: The Cochrane Collaboration, editor. *Cochrane Database Syst Rev* Chichester, UK: John Wiley & Sons, Ltd; 2015. doi:10.1002/14651858.CD003793.pub3.
9. Puhan MA, Gimeno-Santos E, Cates CJ, Troosters T. Pulmonary rehabilitation following exacerbations of chronic obstructive pulmonary disease. In: The Cochrane Collaboration, editor. *Cochrane Database Syst Rev* Chichester, UK: John Wiley & Sons, Ltd; 2016. doi:10.1002/14651858.CD005305.pub4.
10. Criner GJ, Bourbeau J, Diekemper RL, Ouellette DR, Goodridge D, Hernandez P, Curren K, Balter MS, Bhutani M, Camp PG, Celli BR, Dechman G, Dransfield MT, Fiel SB, Foreman MG, Hanania NA, Ireland BK, Marchetti N, Marciniuk DD, Mularski RA, Ornelas J, Road JD, Stickland MK. Prevention of Acute Exacerbations of COPD: American College of Chest Physicians and Canadian Thoracic Society Guideline. *Chest* 2015;147:894–942.
11. Wedzicha JA, Miravitlles M, Hurst JR, Calverley PMA, Albert RK, Anzueto A, Criner GJ, Papi A, Rabe KF, Rigau D, Sliwinski P, Tonia T, Vestbo J, Wilson KC, Krishnan JA. Management of

COPD exacerbations: a European Respiratory Society/American Thoracic Society guideline. *Eur Respir J* 2017;49:.

12. Nishi SPE, Zhang W, Kuo Y-F, Sharma G. Pulmonary Rehabilitation Utilization in Older Adults With Chronic Obstructive Pulmonary Disease, 2003 to 2012. *J Cardiopulm Rehabil Prev* 2016;36:375–382.
13. Johnston K, Grimmer-Somers K. Pulmonary Rehabilitation: Overwhelming Evidence but Lost in Translation? *Physiother Can* 2010;62:368–373.
14. Keating A, Lee A, Holland AE. What prevents people with chronic obstructive pulmonary disease from attending pulmonary rehabilitation? A systematic review. *Chron Respir Dis* 2011;8:89–99.
15. Jones SE, Green SA, Clark AL, Dickson MJ, Nolan A-M, Moloney C, Kon SSC, Kamal F, Godden J, Howe C, Bell D, Fleming S, Haselden BM, Man WD-C. Pulmonary rehabilitation following hospitalisation for acute exacerbation of COPD: referrals, uptake and adherence. *Thorax* 2014;69:181–182.
16. Fischer MJ, Scharloo M, Abbink JJ, van 't Hul AJ, van Ranst D, Rudolphus A, Weinman J, Rabe KF, Kaptein AA. Drop-out and attendance in pulmonary rehabilitation: the role of clinical and psychosocial variables. *Respir Med* 2009;103:1564–1571.
17. Hayton C, Clark A, Olive S, Browne P, Galey P, Knights E, Staunton L, Jones A, Coombes E, Wilson AM. Barriers to pulmonary rehabilitation: Characteristics that predict patient attendance and adherence. *Respir Med* 2013;107:401–407.
18. Dorsey K, Grady JN, Desai N, Lindenauer PK, Schwartz J, Bierlein M, Wang C, DeBuhr J, Bernheim S, Krumholz HM. *2016 Condition-Specific Measures Updates and Specifications Report Hospital-Level 30-Day Risk-Standardized Readmission Measures for Chronic Obstructive Pulmonary Disease (Version 5.0)*. Yale New Haven Health Services Corporation/Center for Outcomes Research & Evaluation (YNHHSC/CORE); . at <http://aann.org/uploads/Condition_Specific_Readmission_Measures.pdf>.
19. Warren JL, Harlan LC, Fahey A, Virnig BA, Freeman JL, Klabunde CN, Cooper GS, Knopf KB. Utility of the SEER-Medicare Data to Identify Chemotherapy Use. *Med Care* 2002;40:IV55–IV61.
20. Deyo RA, Cherkin DC, Ciol MA. Adapting a clinical comorbidity index for use with ICD-9-CM administrative databases. *J Clin Epidemiol* 1992;45:613–619.
21. Quan H, Parsons GA, Ghali WA. Validity of information on comorbidity derived rom ICD-9-CCM administrative data. *Med Care* 2002;40:675–685.
22. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. *J Chronic Dis* 1987;40:373–383.
23. Roos LL, Walld RK, Romano PS, Roberecki S. Short-term mortality after repair of hip fracture. Do Manitoba elderly do worse? *Med Care* 1996;34:310–326.

24. Austin PC. Balance diagnostics for comparing the distribution of baseline covariates between treatment groups in propensity-score matched samples. *Stat Med* 2009;28:3083–3107.

25. Yang D, Dalton JE. A unified approach to measuring the effect size between two groups using SAS®. 6.

26. Goldberg D. *Texas A&M University Geoservices*. 2018. at <http://geoservices.tamu.edu>.

27. Hakamy A, McKeever TM, Gibson JE, Bolton CE. The recording and characteristics of pulmonary rehabilitation in patients with COPD using The Health Information Network (THIN) primary care database. *NPJ Prim Care Respir Med* 2017;27:58.

28. Moore E, Newson R, Joshi M, Palmer T, Rothnie KJ, Singh S, Majeed A, Soljak M, Quint JK. Effects of Pulmonary Rehabilitation on Exacerbation Number and Severity in People With COPD: An Historical Cohort Study Using Electronic Health Records. *Chest* 2017;152:1188–1202.

29. Shah T, Press VG, Huisingh-Scheetz M, White SR. COPD Readmissions: Addressing COPD in the Era of Value-based Health Care. *Chest* 2016;150:916–926.

30. Croft JB, Wheaton AG, Liu Y, Fang X, Lu H, Matthews K, Cunningham T, Wang Y, Holt JB. Urban-Rural County and State Differences in Chronic Obstructive Pulmonary Disease — United States, 2015. *MMWR Morb Mortal Wkly Rep* 2018;67:205–211.

31. Fan VS, Giardino ND, Blough DK, Kaplan RM, Ramsey SD, Group the NR. Costs of Pulmonary Rehabilitation and Predictors of Adherence in the National Emphysema Treatment Trial. *COPD J Chronic Obstr Pulm Dis* 2008;5:105–116.

32. Steiner MC, Lowe D, Beckford K, Blakey J, Bolton CE, Elkin S, Man WD-C, Roberts CM, Sewell L, Walker P, Singh SJ. Socioeconomic deprivation and the outcome of pulmonary rehabilitation in England and Wales. *Thorax* 2017;72:530–537.

33. Milner et al. S. Rate of, and barriers and enablers to, pulmonary rehabilitation referral in COPD: A systematic scoping review. *Respir Med* 2018;at <https://www.ncbi.nlm.nih.gov/pubmed/29605192>.

34. *COPD: Tracking Perceptions of Individuals Affected, Their Caregivers, and the Physicians Who Diagnose and Treat Them*. Bethesda, MD: National Heart, Lung, and Blood Institute; 2017. at <https://www.nhlbi.nih.gov/health/educational/copd/health-care-professionals/COPD-Tracking-Perceptions-of-Individuals-Affected-Their-Caregivers-and-the-Physicians-Who-Diagnose-and-Treat-Them.pdf>.

35. Sohanpal R, Seale C, Taylor SJC. Learning to manage COPD: a qualitative study of reasons for attending and not attending a COPD-specific self-management programme. *Chron Respir Dis* 2012;9:163–174.

36. Meis JJM, Bosma CB, Spruit MA, Franssen FME, Janssen DJA, Teixeira PJ, Augustin IML, Wouters EFM, de Vries NK, Schols AMWJ, Kremers SPJ. A qualitative assessment of COPD patients' experiences of pulmonary rehabilitation and guidance by healthcare professionals. *Respir Med* 2014;108:500–510.

37. Patil SP, Krishnan JA, Lechtzin N, Diette GB. In-hospital mortality following acute exacerbations of chronic obstructive pulmonary disease. *Arch Intern Med* 2003;163:1180–1186.

Figure Legends

Figure 1: Flow chart showing study selection criteria. COPD, Chronic Obstructive Pulmonary Disease; ARF, Acute Respiratory Failure; PR, Pulmonary Rehabilitation

Figure 2: Participation in pulmonary rehabilitation in 1 year following index discharge

Table 1: Individual characteristics and associations with incidence of PR

Individual characteristic	Total	None/later start of PR	PR within 6 months of discharge	Absolute Standardized Differences (%)
	N	n(%)	n(%)	
	223832 (100)	**219607 (98.1)**	**4225 (1.9)**	
Demographics				
Age, Median (IQR), years	77 (71 - 83)	77 (71 - 83)	74 (70 - 79)	
Mean (SD), years	77.4 (7.6)	77.4 (7.6)	74.8 (6.1)	38.02
Gender				
Male	90824 (40.58)	88875 (40.5)	1949 (46.1)	11.44
Race/ethnicity				22.45
Non-Hispanic White	189889 (84.84)	186018 (84.7)	3871 (91.6)	
Black (OR African-American)	18850 (8.42)	18624 (8.5)	226 (5.3)	
Hispanic	9977 (4.46)	9903 (4.5)	74 (1.8)	
Other	5116 (2.29)	5062 (2.3)	54 (1.3)	
Distance to nearest PR, Median (IQR), miles	4.8 (2.4 - 10.7)	4.8 (2.4 - 10.8)	4.0 (2.1 - 7.4)	
Mean (SD), miles	8.8 (13.5)	8.8 (13.6)	5.5 (6.5)	30.82
Dual eligibility (Medicaid buy-in)	62500 (27.92)	61985 (28.2)	515 (12.2)	40.76
Current tobacco smoker	46580 (20.8)	45719 (20.8)	861 (20.4)	1.1
Principal Diagnosis				
COPD	195505 (87.3)	191866 (87.4)	3639 (86.1)	3.6
ARF	28327 (12.7)	27741 (12.6)	586 (13.9)	
Charlson Comorbidities				
Congestive Heart Failure	136881 (61.15)	134794 (61.4)	2087 (49.4)	24.28
Diabetes without complications	110631 (49.43)	108953 (49.6)	1678 (39.7)	20.01
Peripheral Vascular Disease	109432 (48.89)	107597 (49)	1835 (43.4)	11.18
Cerebrovascular Disease	87253 (38.98)	85930 (39.1)	1323 (31.3)	16.42
Renal Disease	77495 (34.62)	76373 (34.8)	1122 (26.6)	17.9
Myocardial Infarction	57164 (25.54)	56267 (25.6)	897 (21.2)	10.38
Cancer	51832 (23.16)	50728 (23.1)	1104 (26.1)	7.04
Diabetes with complications	44830 (20.03)	44277 (20.2)	553 (13.1)	19.08
Dementia	29453 (13.16)	29309 (13.3)	144 (3.4)	36.46
Mild Liver Disease	23940 (10.7)	23480 (10.7)	460 (10.9)	0.63
Connective Tissue Disease-Rheumatic Disease	20884 (9.33)	20527 (9.3)	357 (8.4)	3.15
Peptic Ulcer Disease	14462 (6.46)	14253 (6.5)	209 (4.9)	6.65
Weight Charlson Comorbidity Index				

Mean (SD)	4.6 (3.2)	4.6 (3.2)	3.8 (3)	26.97
Median (IQR)	4 (2 - 7)	4 (2 - 7)	3 (1 - 5)	
Prior hospitalization factors				
Prior year admissions				22.37
No admits	115068 (51.41)	112504 (51.2)	2564 (60.7)	
1 admit	52024 (23.24)	51118 (23.3)	906 (21.4)	
2 admits	26145 (11.68)	25738 (11.7)	407 (9.6)	
3 or more admits	30595 (13.67)	30247 (13.8)	348 (8.2)	
Home oxygen use				
in 90 days prior to index hospitalization	78973 (35.28)	77158 (35.1)	1815 (43)	16.09
Index hospitalization factors				
Non-invasive Ventilation	12763 (5.7)	12504 (5.7)	259 (6.1)	1.85
Invasive Mechanical Ventilation	7272 (3.25)	7133 (3.2)	139 (3.3)	0.24

PR, Pulmonary Rehabilitation; IQR, Inter-Quartile Range; SD, Standard Deviation; COPD, Chronic Obstructive Pulmonary Disease; ARF, Acute Respiratory Failure

Table 2: Predictors of receipt of PR

Factor	OR (95% CI)
Age group	
66 - 74 years	Referent
75 - 84 years	0.71 (0.66 - 0.76)
>= 85 years	0.25 (0.22 - 0.29)
Miles to nearest PR group	
<= 5 miles	Referent
> 5 and <= 10 miles	0.96 (0.89 - 1.04)
> 10 miles	0.47 (0.42 - 0.51)
Male	1.21 (1.13 - 1.28)
Race/Ethnicity	
White	Referent
Black or African-American	0.70 (0.61 - 0.81)
Hispanic	0.60 (0.47 - 0.76)
Other	0.70 (0.53 - 0.92)
Dual Eligibility (state Medicaid buy in)	0.42 (0.38 - 0.46)
Tertiles of Weighted Charlson Score	
min-max: 0-2	Referent
min-max: 3-5	0.85 (0.79 - 0.92)
min-max: 6-27	0.66 (0.61 - 0.72)
Prior admits	
No prior admits	Referent
1 admit	0.84 (0.77 - 0.90)
2 admits	0.78 (0.70 - 0.87)
3 or more admits	0.61 (0.54 - 0.68)
Home Oxygen use in 90 days prior to hospitalization	1.49 (1.39 - 1.59)
Non-invasive Ventilation	1.02 (0.90 - 1.17)
Invasive Mechanical Ventilation	0.98 (0.83 - 1.17)
Current Tobacco User	0.79 (0.73 - 0.86)
Hospital region	
Northeast	1.21 (1.07 - 1.37)
Midwest	1.65 (1.50 - 1.82)
South	Referent
West	1.19 (1.04 - 1.035)
Rural hospitals	1.02 (0.91 - 1.13)
Teaching hospitals	1.00 (0.91 - 1.10)
Hospital size	
<200 beds	Referent
201-400 beds	0.95 (0.86 - 1.06)
401 and higher beds	1.15 (1.01 - 1.30)

Table 3: Ordinal Regression showing factors predicting receipt of higher number of PR sessions

Individual factor	OR (95% CI)
Age group	
66 - 74 years	Referent
75 - 84 years	1.07 (0.97 - 1.18)
>= 85 years	0.91 (0.76 - 1.10)
Miles to nearest PR program	
<= 5 miles	Referent
> 5 and <= 10 miles	1.07 (0.95 - 1.19)
> 10 miles	0.92 (0.80 - 1.06)
Male	1.24 (1.13 - 1.37)
Race/Ethnicity	
White	Referent
Black or African-American	1.00 (0.81 - 1.23)
Hispanic	0.70 (0.48 - 1.02)
Other	0.75 (0.49 - 1.14)
Dual Eligibility (state Medicaid buy in)	0.48 (0.41 - 0.56)
Home Oxygen use in 90 days prior to hospitalization	0.93 (0.85 - 1.03)
Current Tobacco User	0.87 (0.77 - 0.98)
Prior admits	
No prior admits	Referent
1 admit	0.80 (0.71 - 0.90)
2 admits	0.77 (0.65 - 0.91)
3 or more admits	0.62 (0.52 - 0.75)
Tertiles of Weighted Charlson Score	
min-max: 0-2	Referent
min-max: 3-5	0.84 (0.75 - 0.93)
min-max: 6-27	0.72 (0.64 - 0.83)

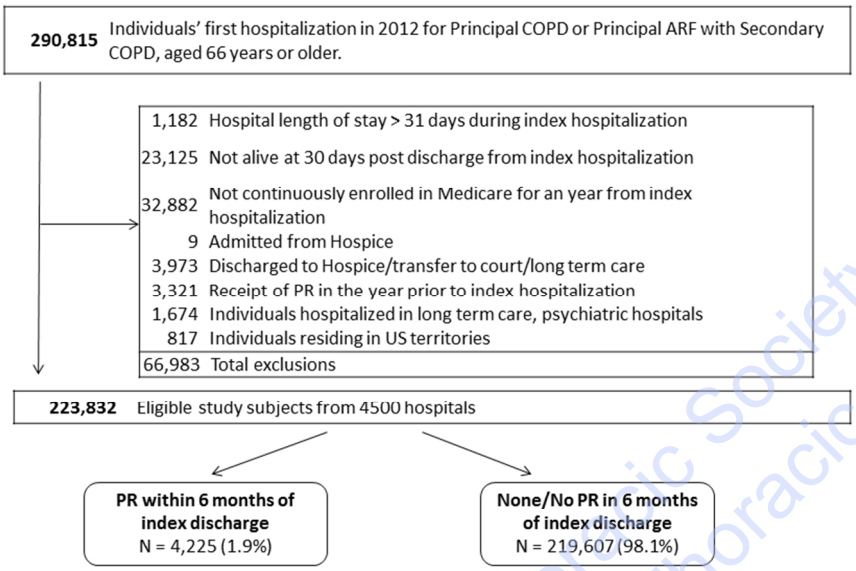

Figure 1: Flow chart showing study selection criteria

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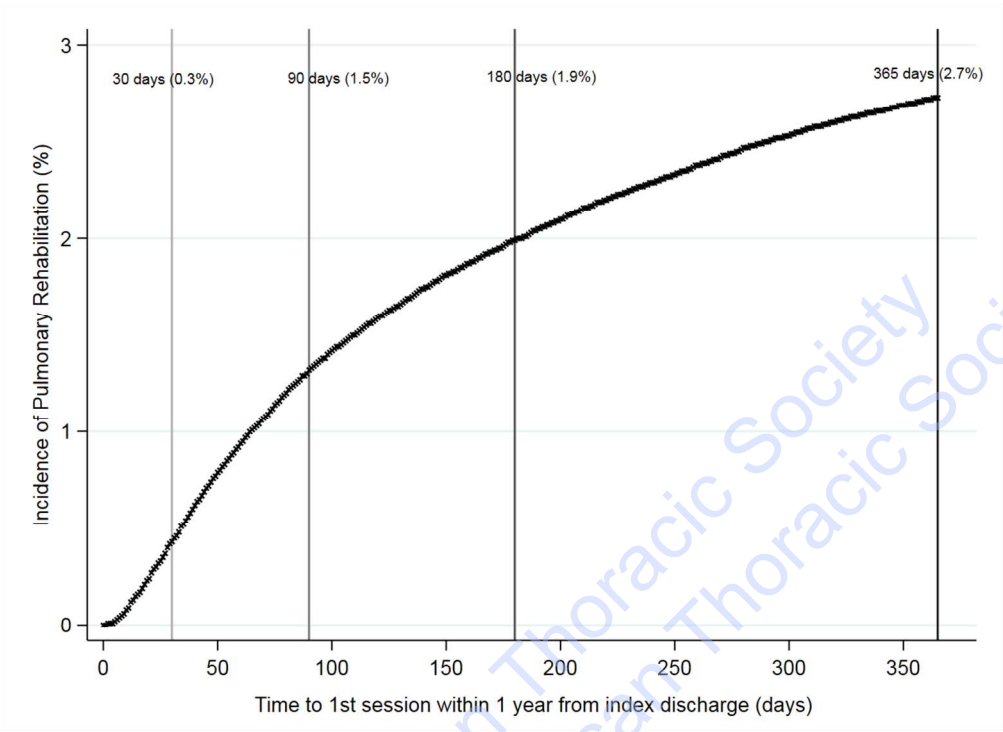

Figure 2: Participation in pulmonary rehabilitation in 1 year following index discharge

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