Hyfe

Cost-benefit analysis of at-home COPD monitoring

The Hyfe Team

Introduction

Chronic Obstructive Pulmonary Disease (COPD) [1] is a highly prevalent (>5% of the population in the US) and debilitating [2] respiratory condition that poses a substantial economic burden [3] on healthcare systems. COPD exacerbations [4] account for the lion's share of the nearly $50 billion [5] spent annually in the US on COPD-related healthcare costs. Acute exacerbations are particularly costly due to patients' frequent emergency room visits and hospitalizations (if hospitalized once for an acute COPD exacerbation, the likelihood of a subsequent hospitalization in the next 30 days is 25% [6] and in the next 8 weeks is 30% [7]). In the US, the total discounted direct medical costs related to COPD over the next 20 years are estimated to be $800 billion [8], with the total of 315 million of exacerbations associated with COPD.

COPD exacerbations can have profound implications on a patient's health. Following at least a moderate COPD exacerbation, patients (compared to stable disease patients) face a two-fold increased risk of myocardial infarction [9] within 5 days and a significantly elevated stroke risk for the first 49 days post-exacerbation. Survival rates post-severe COPD exacerbation requiring hospitalization based on a meta analysis reveal a weighted average case-fatality rate of 15.6% [10]. These examples emphasize the lasting impact of severe exacerbations, contributing to overall COPD mortality beyond the hospitalization period.

Effective therapies and interventions [11] exist to prevent COPD exacerbations. Pharmacological interventions [12] such as antimuscarinic agents have been shown to reduce the likelihood of acute exacerbations. Bronchodilators and anti-inflammatory agents [11] have also been shown to be effective. Ventilatory assistance - positive airway pressure machines and supplementary oxygen - have also been used to prevent or reduce the severity of an exacerbation, including in at-home settings.

A patient's COPD can worsen slowly and insidiously. Such slow changes can be difficult for a patient to notice. Alternatively, COPD exacerbations can come on very quickly [4]. Either way, patients often do not recognize the signs and symptoms of an imminent exacerbation until their state is so severe that they require emergency care. If the onset of exacerbations could be identified earlier, non-emergency and even domiciliary care could be administered, which would have significant and long-term positive effects on both patient wellbeing and costs.

Cough is one of the three cardinal symptoms of COPD, reported by more than 70% [13] of COPD patients. Persistent chronic cough in patients with COPD [14] has been linked with more severe disease and increased healthcare utilization. Additionally, more coughing (as reported by patients) is linked [15] as one of the most common signs of COPD exacerbation or flare up. Appropriate COPD management can alleviate symptoms, lower the frequency and severity of exacerbations [16], reduce hospitalizations and readmissions, enhance health status, improve exercise capacity and extend survival. Therefore addressing cough as a dynamic data point in COPD care might be beneficial for a patient's quality of life and the utilization of healthcare.

Cough monitoring [17] has been shown to predict 45% of acute COPD exacerbations with an average lead time of 3.4 days, and an extremely low false positive rate (approximately one for every 100 days of person-time). At-home cough monitoring is not only more predictive of exacerbations than survey-based methods, it also has the advantage of being more amenable to long-term domiciliary contexts than methods for the monitoring of other symptoms (such as pulse oximetry or self-report), as cough monitoring can run continuously in the background without requiring any patient involvement. Since the high carbon dioxide blood concentrations associated with the onset of an exacerbation have cognitive effects, cough monitoring has the additional advantage of maintaining predictive robustness even at times when the patient may not be able to register or communicate his or her symptoms. Crooks et al. [17] exclude mild exacerbations in their exacerbations alert study, emphasizing the need to optimize healthcare resources by focusing on severe cases in telemonitoring. However, we argue that in this era of precision medicine, the value of mild exacerbation alerts is for tailored patient care, and for decision making regarding which patients to upgrade for novel treatment for COPD (e.g., biologics).

Could cough monitoring be a cost-effective method for at-home preventive COPD care? To what extent do the savings incurred from averted COPD exacerbations outweigh the costs of the method, the uncertainty of the associated preventive interventions, and the costs of monitoring-generated false positives? This paper attempts to answer these questions and to provide an evidence-informed cost-effectiveness ratio from a private payer's perspective.

Methodology

Conceptual framework

The total cost, TC, associated with implementing a cough monitoring system is the sum of all of the individual costs, so that

$$\mathrm{TC} = \sum_i C_i \,, \tag{1}$$

where C_i represents the i^{th} individual's incurred costs, including device acquisition, maintenance, and personnel training. The benefits, B, derived from the system are represented as

$$\mathrm{B} = \sum_i P_i(\mathrm{Exacerbation}) \times P_i(\mathrm{Prevention}) \times \mathrm{CH}_i \,, \tag{2}$$

where, for the i^{th} individual, $P_i(\mathrm{Exacerbation})$ is the probability of detecting a COPD exacerbation through cough monitoring, $P_i(\mathrm{Prevention})$ is the probability of preventing a hospitalization after detecting an exacerbation, and CH_i is the cost of a hospitalization event. Finally, the net benefit, NB, can be calculated as the difference between the benefits and total cost:

$$\mathrm{NB} = B - \mathrm{TC} \,.$$

Scope of Analysis

For the purpose of this analysis, we narrowly examine only the financial costs of preventive and care services. This undervalues the utility of cough monitoring insofar as (a) the benefit of improved patient health is set to \$0, (b) no monetary amount is assigned to outcomes with no associated services (such as death), and (c) non-health savings (productivity, etc.) are intentionally excluded from analysis. Furthermore, indirect health outcomes associated with exacerbation prevention are also ignored. To the extent that the payer might capture some of the value associated with averted exacerbations (in the case of value-based care or employer-funded insurance, for example), the ICER should be modified positively so as to reflect this.

Assumptions

This analysis is grounded in Crooks et al.'s [17] research on the utility of home-based cough monitoring for the early identification of acute COPD exacerbations. Costs are examined using sensitivity analysis so as to identify the cost-benefit threshold in the unit of dollars per person-day of monitoring.

We assume an annual exacerbation-related direct cost expenditure of $13,000, based on an inflation-adjusted weighted average of emergency and inpatient costs from Dalal, et al [18]. Based on Bogart et al [19], we estimate the rate of exacerbations to be 1,016 per 1,000 person-years. These numbers might vary substantially depending on the age, health status, and location of patients, as some studies report [20] on average patients experience 0.5 to 3.5 exacerbations of COPD per year and 0.09 to 2.4 hospitalizations per year, depending on the severity of the disease. Given the Hyfe Cough Monitor's demonstrated high sensitivity and low false positive rates, we conservatively assume that the system will identify exacerbations with the same lead-time (3.4 days), sensitivity (45%) and false positive rate (1 in 100 person-days) as the Crooks et al. method. It is worth noting that cough monitoring in the study by Crooks et al. was restricted to the room where patients slept. The Hyfe Cough Monitor, on the other hand, provides cough insights through more consistent passive longitudinal monitoring at all hours. We assume that a predicted acute exacerbation will be prevented from hospitalization at a rate of at least 50%, and that the cost of the preventive intervention (such as oxygen therapy or administration of pharmacological agents) and associated supervision is $200. We estimate the cost of a false positive (telephone investigation) to be $40. For simplicity's sake, we assume a cohort of 10,000 patients and a fixed operating cost to the program of $500,000 (this would naturally be higher if not integrated into an existent remote patient monitoring platform). We assume a cough monitoring system license cost of $4.00 per patient per day, and a cough monitoring hardware cost of $100 per patient.

Results

Savings

The 10,000 patient cohort would experience approximately 10,160 exacerbations per year. Of these, 4,572 would be detected through cough monitoring at home. Fifty percent of these, or 2,286 exacerbations, which would have led to hospitalizations, would be prevented. The savings from these prevented exacerbations would total $29,718,000 annually.

Costs

Preventive interventions on the “true positive” predicted COPD exacerbations would cost the program $914,400 per year. There would be 36,500 “false positive” exacerbations (ie, cases where the system detected an imminent exacerbation incorrectly); the cost of investigating these would be $1,460,000. Combined with the $500,000 annual operating cost, the total cough monitoring system license cost of $14,600,000 and the total hardware costs of $1,000,000, the program's total cost for one year of monitoring would be $18,474,400

In other words, for an investment of $18,474,400, the program would return $29,718,000 (difference = $11,243,600), a 161% ROI.

Sensitivity Analysis

Detection Rate

The acute COPD exacerbation detection rate is estimated at 45%. Even at a much lower rate, the program would still be sufficiently sensitive to reach a > 1 benefit-cost ratio (i.e., profitability). The detection rate would have to be lower than 28% for the program to not reach a > 1 profit ratio, holding constant other variables (Fig. 1).

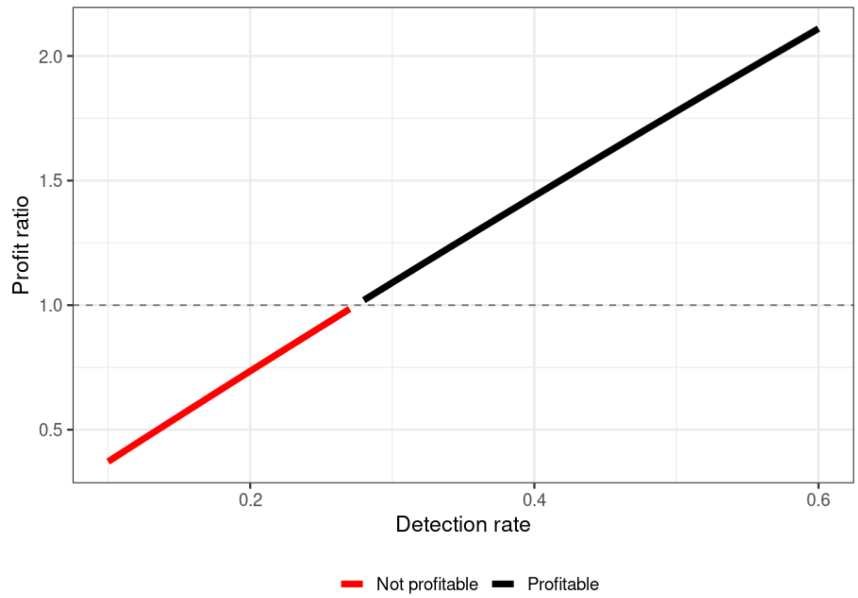

Fig 1. A profit ratio above 1 is achieved as long as the detection rate exceeds 28%.

Costs of Care

$13,000 per exacerbation is a reasonable estimate from the literature. However, for a program in which these savings might be only partially absorbed, one may find it valuable to vary the cost of care. Holding constant other variables, the program becomes profitable at a cost of care of as low as $8,500 (Fig. 2). This would be relevant, for example,if the proportion of emergency room treatment vs inpatient treatment increased.

Prevention Rate

The above assumes that 50% of exacerbations which are detected end up being prevented. This estimate is reasonable given the research literature. However, depending on the characteristics of a remote patient monitoring program, it may be useful to estimate the benefit-cost ratio at different prevention rates. For example, a high-touch program with the capacity for rapid response would expect a prevention rate of greater than 50%. Holding other variables constant, the program reaches a > 1 benefit-cost ratio (i.e., profitability) with a prevention rate of as little as 32% (Fig. 3).

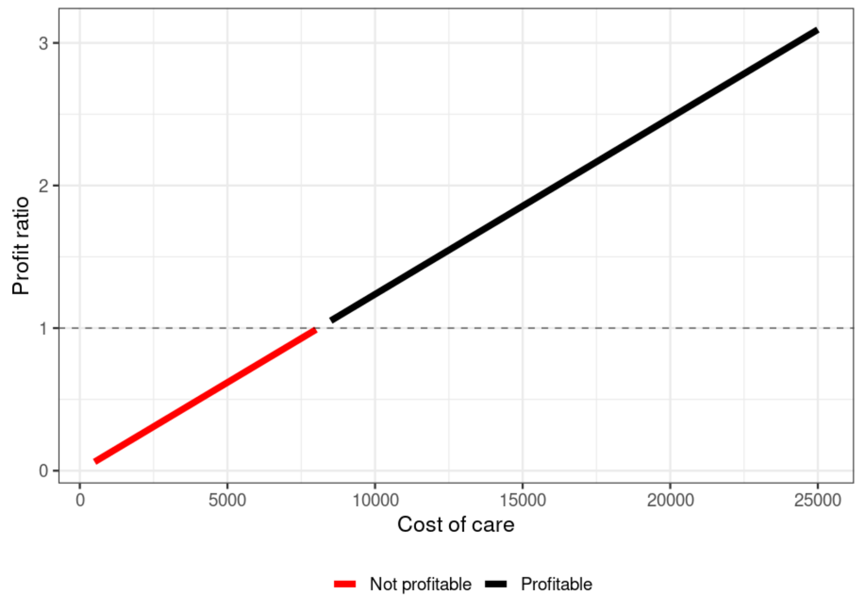

Fig 2. The program is profitable as long as the cost of care is $8,500 or higher.

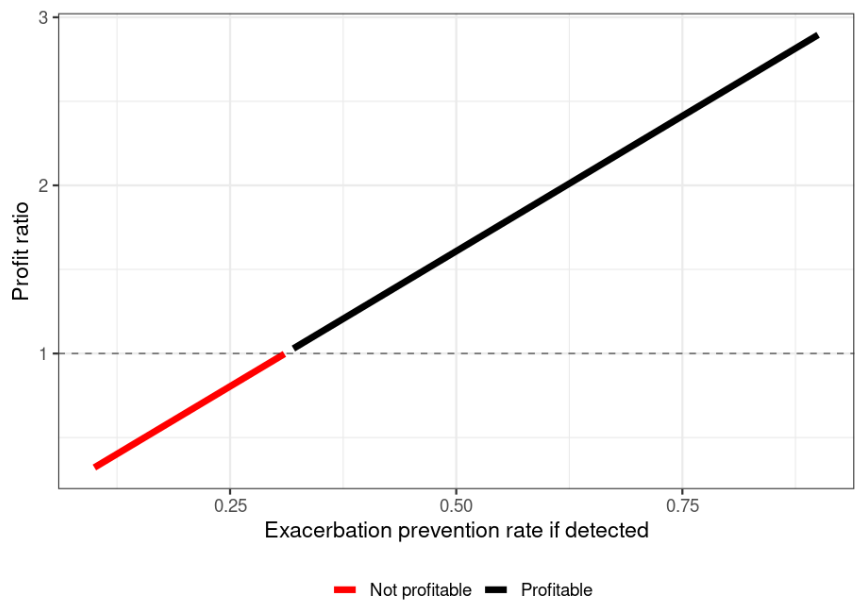

Fig 3. The program achieves a benefit-cost ratio above 1 for prevention rates of 32% and higher.

License Cost

This program assumes a cough monitoring license cost of $4.00 per patient per day. Since few vendors offer cough monitoring at scale, the reasonableness of this price is unknown. Holding constant other variables, the program remains profitable with a person-day license cost as high as $7.00 (Fig. 4).

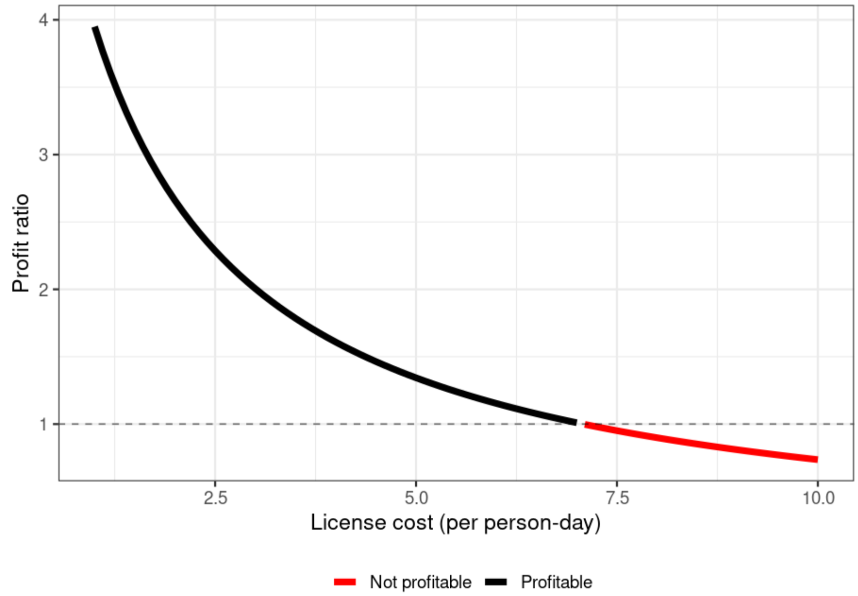

Fig 4. The program remains profitable as long as the license cost does not exceed $7.00.

Cost of Prevention

The above analysis assumes that an exacerbation, once detected, can be prevented 50% of the time. It also assumes that the cost of prevention is approximately $200. The cost of preventive therapy could vary widely based on program characteristics. Figure 5 shows the profit ratio as a function of the cost of preventive treatment after detecting a true positive (x-axis). Even at a cost of as much as $2,600, holding other variables constant, the program would be profitable.

Conclusions

At our assumed baseline parameters, for every dollar spent on the program, $1.61 is returned. Importantly, these returns are short-term and these figures exclude other likely sources of revenue and savings associated with the program (particularly in the case of value-based care, HMOs, employer-funded insurance programs, and/or penalties for hospital readmissions). In addition, these returns do not include out-year savings from averted health events downstream from emergency room visits and inpatient hospital stays for patients with advanced COPD.

Cough monitoring for COPD exacerbation prediction and prevention is extremely cost-effective and would result in prevented hospital admissions and readmissions.

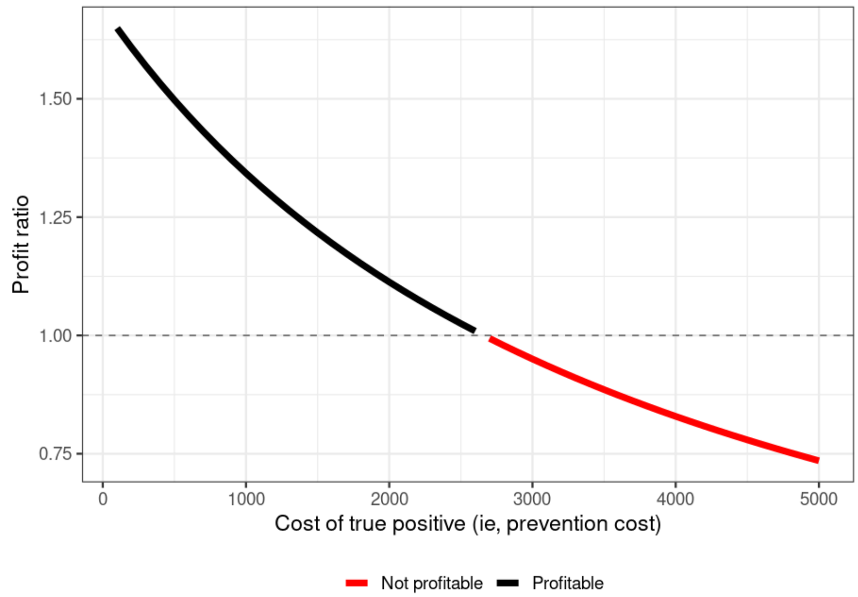

Fig 5. The program remains profitable as long as the cost of preventive treatment is below $2,600.

References

1. Centers for Disease Control and Prevention. (2023) Chronic obstructive pulmonary disease (COPD). [Online]. Available: https://www.cdc.gov/copd/data-and-statistics/state-estimates.html

2. National Heart, Lung, and Blood Institute. (2023) What is COPD?. [Online]. Available: https://www.nhlbi.nih.gov/health/copd

3. S. Chen, M. Kuhn, K. Prettner, Y. Feng Yun, T. Yang, T. Bärnighausen, D. Bloom, and C. Wang, The global economic burden of chronic obstructive pulmonary disease for 204 countries and territories in 2020-50: a health-augmented macroeconomic modelling study. The Lancet Global Health, vol. 11, pp. e1183–e1193, 07 2023.

4. American Thoracic Society. (2023) Exacerbation of COPD. [Online]. Available: https://www.thoracic.org/patients/patient-resources/resources/copd-exacerbation-ecopd.pdf

5. Centers for Disease Control and Prevention. (2023) COPD costs. [Online]. Available: https://www.cdc.gov/copd/ infographics/copd-costs.html

6. R. A. Mularski, M. A. McBurnie, P. K. Lindenauer, T. A. Lee, W. M. Vollmer, D. H. Au, S. S. Carson, and J. A. Krishnan, Comparative effectiveness research in chronic obstructive pulmonary disease. Journal of Comparative Effectiveness Research, vol. 1, no. 1, pp. 71–82, 2012. [Online]. Available: https://becarispublishing.com/doi/abs/10.2217/cer.11.10

7. J. A. Wedzicha and T. A. Seemungal, COPD exacerbations: defining their cause and prevention. Lancet, vol. 1, no. 370(9589), pp. 786–96, 2007. [Online]. Available: https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(07)61382-8/fulltext

8. Z. Zafari, S. L. an Michelle N Eakin, M. Bellanger, and R. M. Reed, Projecting long-term health and economic burden of copd in the united states. Chest, vol. 159, no. 4, pp. 1400–1410, 2021. [Online]. Available: https://journal.chestnet.org/article/S0012-3692(20)34848-0/fulltext
9. G. C. Donaldson, J. R. Hurst, C. J. Smith, and R. B. Hubbard, Increased risk of myocardial infarction and stroke following exacerbation of copd. Chest, vol. 137, no. 5, pp. 1091–1097, 2010. [Online]. Available: https://journal.chestnet.org/article/S0012-3692(10)60235-8/fulltext
10. M. Hoogendoorn, R. Hoogenveen, M. R. van Mölken, J. Vestbo, and T. Feenstra, Case fatality of copd exacerbations: a meta-analysis and statistical modelling approach. European Respiratory Journal, vol. 37, no. 3, pp. 508–515, 2011. [Online]. Available: https://erj.ersjournals.com/content/37/3/508
11. J. Vestbo and P. Lange, Prevention of COPD exacerbations: medications and other controversies. ERJ Open Research, vol. 1, no. 1, 2015. [Online]. Available: https://openres.ersjournals.com/content/1/1/00011-2015
12. J. A. Wedzicha, P. M. Calverley, R. K. Albert, A. Anzueto, G. J. Criner, J. R. Hurst, M. Miravitlles, A. Papi, K. F. Rabe, D. Rigau, P. Sliwinski, T. Tonia, J. Vestbo, K. C. Wilson, and J. A. Krishnan, Prevention of copd exacerbations: a european respiratory society/american thoracic society guideline. European Respiratory Journal, vol. 50, no. 3, 2017. [Online]. Available: https://erj.ersjournals.com/content/50/3/1602265
13. R. Choate, C. B. Pasquale, N. A. Parada, V. Prieto-Centurion, R. A. Mularski, and B. P. Yawn, The burden of cough and phlegm in people with copd: A copd patient-powered research network study. Chronic Obstructive Pulmonary Diseases, vol. 7, no. 1, pp. 49–59, 2020. [Online]. Available: https://erj.ersjournals.com/content/50/3/1602265
14. E. Landi, Y. Colak, P. Lange, L. C. Laursen, B. G. Nordestgaard, and M. Dahl, Chronic cough in individuals with copd a population-based cohort study. Chest, vol. 157, no. 6, pp. 1446–1454, 2020. [Online]. Available: https://journal.chestnet.org/article/S0012-3692(20)30130-6/fulltext
15. American Lung Association. (2023) Prevent copd exacerbations or flare ups. [Online]. Available: https://www.lung.org/lung-health-diseases/lung-disease-lookup/copd/living-with-copd/prevent-flare-ups
16. S. G. Bollmeier and A. P. Hartmann, Management of chronic obstructive pulmonary disease: A review focusing on exacerbations. American Journal of Health-System Pharmacy, vol. 77, no. 4, pp. 259–268, 01 2020. [Online]. Available: https://doi.org/10.1093/ajhp/zxz306
17. M. Crooks, A. den Brinker, S. Thackray-Nocera, R. Dinther, C. Wright, and A. Morice, Domiciliary cough monitoring for the prediction of copd exacerbations. Lung, vol. 199, pp. 131–137, 04 2021.
18. Dalal AA, Shah M, D'Souza AO, Rane P., Costs of COPD exacerbations in the emergency department and inpatient setting. Respir Med. 2011 Mar;105(3):454-60.
19. M. R. Bogart, S. D. Hopson, H.-C. Shih, R. H. Stanford, and A. D. Coutinho, COPD exacerbation costs in the impact study: a within-trial analysis. The American journal of managed care, vol. 26, no. 5, p. e150—e154, May 2020. [Online]. Available: https://doi.org/10.37765/ajmc.2020.43157

20. J. Bourbeau, Preventing hospitalization for COPD exacerbations. Seminars in Respiratory and Critical Care Medicine, vol. 3, no. 31, pp. 313–320, 2010. [Online]. Available: https://www.thieme-connect.com/products/ejournals/abstract/10.1055/s-0030-1254071