Chronic obstructive pulmonary disease risk assessment tools: is one better than the others?

Jennifer M. Wang, MeiLan K. Han and Wassim W. Labaki

Purpose of review
Risk assessment tools are essential in COPD care to help clinicians identify patients at higher risk of accelerated lung function decline, respiratory exacerbations, hospitalizations, and death.

Recent findings
Conventional methods of assessing risk have focused on spirometry, patient-reported symptoms, functional status, and a combination of these tools in composite indices. More recently, qualitatively and quantitatively assessed chest imaging findings, such as emphysema, large and small airways disease, and pulmonary vascular abnormalities have been associated with poor long-term outcomes in COPD patients. Although several blood and sputum biomarkers have been investigated for risk assessment in COPD, most still warrant further validation. Finally, novel remote digital monitoring technologies may be valuable to predict exacerbations but their large-scale performance, ease of implementation, and cost effectiveness remain to be determined.

Summary
Given the complex heterogeneity of COPD, any single metric is unlikely to fully capture the risk of poor long-term outcomes. Therefore, clinicians should review all available clinical data, including spirometry, symptom severity, functional status, chest imaging, and bloodwork, to guide personalized preventive care of COPD patients. The potential of machine learning tools and remote monitoring technologies to refine COPD risk assessment is promising but remains largely untapped pending further investigation.

Keywords
chronic obstructive pulmonary disease, long-term outcomes, risk assessment

INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is a heterogeneous condition characterized by different clinical phenotypes and highly variable disease courses [1▪]. In the context of this complex heterogeneity, risk assessment tools are very valuable to clinicians as they seek to identify patients at higher risk of accelerated lung function decline, exacerbations, hospitalizations, and death. Initial studies mainly focused on prognostic data obtained from spirometry as the forced expiratory volume in 1 s (FEV_1) remains an important predictor of mortality [2]. However, patient-reported symptoms within validated scoring systems, such as the St. George's Respiratory Questionnaire (SGRQ) [3] and the COPD assessment test (CAT) [4▪], as well as practical functional status assessments, such as the six-minute walk test (6MWT) [5] and the Sit-to-Stand test (STST) [6▪] have also been recognized as important for long-term prognosis. Furthermore, these metrics have been combined into a variety of composite indices [7▪▪] that provide comprehensive risk assessment in COPD. More novel risk assessment tools include chest imaging-based metrics, such as the presence and severity of emphysema, large airways disease, and small airways abnormalities [8,9]. Certain blood biomarkers, such as peripheral eosinophilia [10,11▪▪,12], are associated with long-term outcomes in COPD and may also help predict response to therapy. Finally, new technologies, such as remote digital monitoring devices and mobile applications can provide personalized patient care and detect early clinical decline [13▪▪,14▪]. A summary of these risk assessment tools is provided in Table 1.

Division of Pulmonary and Critical Care Medicine, University of Michigan, Ann Arbor, Michigan, USA

Correspondence to Wassim W. Labaki, MD, MS, 1500 E. Medical Center Drive, 3916 Taubman Center, Ann Arbor, MI 48109, USA. E-mail: wlabaki@med.umich.edu

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KEY POINTS

- COPD risk assessment tools include spirometry, patient-reported symptoms, history of exacerbations, functional assessments, composite indices as well as novel blood, sputum, and chest imaging biomarkers.
- No single metric can fully capture the risk of poor long-term outcomes (including accelerated lung function decline, exacerbation, hospitalization, and death), given the clinical heterogeneity of COPD.
- Combinations of metrics through validated composite indices typically provide best risk assessment in COPD; ongoing work on machine learning tools may help refine risk assessment even further.
- Remote digital monitoring technologies to detect early clinical deterioration are promising risk assessment tools but require further research with regards to their performance and implementation.

SPIROMETRY

Spirometry has long been used as a practical tool to diagnose and monitor the progression of a variety of obstructive lung diseases, including COPD. FEV_1 is inversely associated with risk of mortality [15▪] and acute COPD exacerbation [16]. Beyond baseline FEV_1, trajectories of lung function decline also carry important prognostic implications. For example, individuals who developed COPD through a normal maximally attained FEV_1 trajectory (normal lung function in early adulthood followed by accelerated lung function decline leading to airflow obstruction later in life) had an increased risk of respiratory and all-cause mortality compared with those who developed COPD via a low maximally attained FEV_1 trajectory [17▪▪]. However, there was no difference in incidence of severe exacerbations between these groups. Although spirometry remains an important prognostic tool, it does not always capture the clinical complexity of COPD and smoking-related lung disease. Recent evidence suggests that symptomatic current and former smokers with no or only mild airflow obstruction can also experience significant respiratory morbidity, hence the need for additional risk assessment strategies [18].

SYMPTOMS AND EXACERBATION HISTORY

The severity of chronic respiratory symptoms, as assessed by validated tools, such as the Modified Medical Research Council (mMRC) dyspnea scale [19] and CAT [20▪], is associated with long-term morbidity and mortality in COPD. Similarly, both the classic (presence of a productive cough for at least 3 months per year for 2 consecutive years) and SGRQ (productive cough that is near daily in frequency or occurring several days a week for 4 weeks) definitions of chronic bronchitis have been linked to an increased risk of COPD exacerbations [3]. However, only the SGRQ definition was associated with severe exacerbations requiring a visit to the emergency department or hospitalization. Even among ever-smokers without airflow obstruction, chronic bronchitis has been associated with accelerated lung function decline, higher hospitalization rates, and increased mortality [21▪,22].

A history of COPD exacerbations is the best predictor of future exacerbations, regardless of Global Initiative for Chronic Obstructive Lung Disease (GOLD) grade [23]. Repeat exacerbations lead to excess FEV_1 decline over time, especially in patients with GOLD 1 COPD [24]. Furthermore, in a study of the UK Clinical Practice Research Datalink, the number of COPD exacerbations during the baseline year was associated with increased subsequent mortality over a mean of 4.9 years following a dose–response relationship [25].

The GOLD 2017 ABCD classification based on symptom burden and exacerbation history [26] did not predict survival as well as the GOLD 2011 classification, which additionally incorporated FEV_1 [27]. The discriminative power of the 2011 and 2017 classifications for future exacerbations was nonetheless similar. It must be noted, however, that the main goal of these classifications is to guide clinical management strategies rather than predict long-term outcomes.

FUNCTIONAL ASSESSMENT

General assessments of functional status predict morbidity and mortality in several chronic diseases, including COPD. Distance ambulated during the 6MWT [5] as well as the performance time and repetition number of the STST [6▪] are associated with risk of hospitalization and mortality. Further, a recent study found that the short physical performance battery (SPPB), which incorporates gait speed, balance, and STST, identified patients at risk for exacerbations requiring hospitalization, with the sit-to-stand component correlating best with length of hospitalization [28▪]. More broadly, frailty, as measured by the frailty index or as defined by the Fried frailty phenotype, was associated with an increased risk of exacerbations, hospitalizations, and mortality in older patients with stable COPD [29▪,30▪]. Finally, anxiety and depression, as assessed by the Hospital Anxiety and Depression Scale, were found to be associated with higher 11-

Table 1. Summary of risk assessment tools in chronic obstructive pulmonary disease

Risk assessment tool	Outcomes	Key points	References
Spirometry			
FEV_1	Exacerbation, mortality	Baseline FEV_1 and low FEV_1 attained through accelerated lung function decline trajectory from normal peak in early adulthood predict mortality and exacerbation risk	[16,17▪▪]
Symptoms and exacerbation history			
mMRC	Mortality	Dyspnea is a strong predictor of 5-year survival	[19]
CAT	Exacerbation	CAT score is associated with frequency, severity, and duration of exacerbations	[20▪]
SGRQ	Exacerbation	SGRQ criteria of chronic bronchitis were similar if not better predictor of exacerbation risk compared with classically defined chronic bronchitis	[3]
GOLD 2017	Exacerbation, mortality	Similar predictive power as the GOLD 2011 criteria for exacerbations (including severe), but lower predictive power for mortality. Intended to guide clinical management strategies rather than predict long-term outcomes	[27]
Exacerbation history	Lung function decline, exacerbation, mortality	History of exacerbations placed patients at increased risk for declining FEV_1, future exacerbations, and death	[16,23–25]
Functional assessment			
6MWT	Hospitalization, mortality	6MWT distance can be used to predict hospitalizations and mortality in clinical trials. Walk distance under 350 m was the threshold	[5]
STST	Exacerbation, hospitalization	STST performance time and repetition number is correlated with exacerbations and hospitalizations	[6▪]
SPPB	Exacerbation, hospitalization	SPPB (gait speed, balance, and STST) identifies patients at risk for exacerbations and hospitalizations	[28▪]
Frailty	Exacerbation, hospitalization, mortality	Frailty was correlated to disease severity and lung function; in older patients, it was also associated with exacerbations, hospitalizations, and mortality	[29▪,30▪]
Anxiety and depression	Mortality	Anxiety and depression, as assessed by the HADS score, were associated with higher mortality in patients with COPD	[31▪]
Chest imaging			
Emphysema	Lung function decline, exacerbation, hospitalization, mortality, emphysema progression, lung cancer incidence	The presence, extent and subtype of emphysema can predict exacerbation risk, rate of lung function decline, hospitalization, and long-term mortality	[9,32▪,33▪,35▪,36▪]
Small airways disease	Lung function decline, exacerbation, emphysema progression	Functional small airways disease on PRM has been associated with increased exacerbation risk as well as 5-year FEV_1 decline and emphysema progression	[8,9]
Bronchiectasis	Hospitalization, mortality	COPD patients with bronchiectasis have increased risk of hospitalization and death compared with those without bronchiectasis. Airway wall thickness was not independently associated with mortality	[38▪]
Enlarged pulmonary artery	Exacerbation, mortality	A pulmonary artery:aorta diameter ratio greater than 1 is associated with increased risk of exacerbation and mortality	[39,40▪]
ILAs	Lung function decline, exacerbation, hospitalization	ILAs are predictive of risk of moderate–severe exacerbations, and progressing ILAs are associated with lung function decline	[41▪]
Biomarkers			
Blood eosinophil count	Lung function decline, exacerbation, hospitalization, mortality	High blood eosinophil count is associated with exacerbations, hospitalizations, and FEV_1 decline. A persistently high blood eosinophil count after initiation of inhaled corticosteroids in the stable state portends worse outcomes. Eosinopenia in the acute exacerbation state is associated with longer hospital stay and higher mortality	[10,11▪▪,12,42▪▪,43▪,44▪]
Neutrophil-to-lymphocyte ratio	Mortality	A high neutrophil-to-lymphocyte ratio is a strong predictor of mortality in patients hospitalized for a COPD exacerbation	[44▪,45▪]

Table 1 (*Continued*)

Risk assessment tool	Outcomes	Key points	References
Inflammatory markers	Exacerbation, mortality	Elevated fibrinogen has been associated with a higher risk of exacerbations and elevated CRP with a higher mortality rate	[46▪,48]
Airway mucins	Exacerbation, lung function decline	Concentrations of airway mucins, especially MUC5AC, are associated with increased exacerbation risk and lung function decline	[51▪▪,52]
Airway mycobiome	Severity, exacerbation, mortality	A specific airway mycobiome profile (characterized by dominance of Aspergillus, Curvularia and Penicillium) has been linked to a higher risk of exacerbations and mortality	[64▪▪]
Immunoglobulins	Exacerbation, hospitalization	Low serum IgG and free light chain levels have been associated with increased exacerbations and hospitalizations	[57▪,58▪]
Composite indices			
BODE index	Mortality	The BODE index is better than FEV_1 alone at predicting all-cause and respiratory related mortality	[65]
ADO index	Mortality	The ADO index was found to be a better predictor of all-cause and respiratory mortality than spirometry and the GOLD 2011 and 2017 ABCD classification	[66▪]
ACCEPT	Exacerbation, hospitalization	ACCEPT pools number of prior exacerbations, age, sex, BMI, smoking status, SGRQ score, postbronchodilator FEV_1, and use of inhalers and oxygen therapy to predict exacerbation risk	[67▪▪]
Respiratory disability score	Exacerbation, mortality	Impairment detected on four of seven questionnaires and tests assessing symptoms and functional status is independently associated with increased risk of exacerbation and death	[68▪]
DOSE index	Exacerbation, hospitalization, mortality	The DOSE index predicts risk of exacerbation, hospital admission and length of stay but it does not predict mortality as well as the BODE or ADO indices	[7▪▪,69]
Summit Lab score	Exacerbation, hospitalization	In patients with COPD and cardiovascular disease, the Summit Lab score was associated with exacerbation risk and length of hospital stay	[70▪]
Remote digital monitoring			
Electronic inhaler sensors	Exacerbation, hospitalization	Sensors attached to inhalers can detect increased inhaler usage (limited by patient adherence) to predict exacerbation and hospitalization	[13▪▪,74▪]
Mobile applications	Exacerbation, hospitalization	Limited studies show mobile applications can provide early signs of impending COPD exacerbation requiring hospitalization	[14▪]

6MWT, six-minute walk test; ACCEPT, Acute COPD Exacerbation Prediction Tool; ADO, Age, Dyspnea and Obstruction; BMI, body mass index; BODE, BMI, Airflow Obstruction, Dyspnea and Exercise Capacity; CAT, COPD assessment test; COPD, chronic obstructive pulmonary disease; CRP, C-reactive protein; DOSE, Dyspnea, Obstruction, Smoking and Exacerbation; FEV_1, forced expiratory volume in 1 s; GOLD, Global Initiative for Chronic Obstructive Lung Disease; HADS, Hospital Anxiety and Depression Scale; ILAs, interstitial lung abnormalities; mMRC, Modified Medical Research Council; PRM, Parametric Response Mapping; SGRQ, St. George's Respiratory Questionnaire; SPPB, short physical performance battery; STST, Sit-to-Stand test.

year mortality in patients with COPD [31▪], further emphasizing the importance of addressing these comorbidities as part of a comprehensive clinical management strategy.

CHEST IMAGING

Chest computed tomography (CT) scans are frequently ordered in patients with COPD to screen for lung cancer, rule out acute pulmonary emboli, and assess candidacy for lung transplantation and lung volume reduction interventions. Although the primary indication for these scans is not long-term prognostication, they provide a wealth of information with regards to risk assessment in COPD through qualitative and quantitative evaluations of emphysema, large and small airways disease, pulmonary vascular abnormalities, and interstitial lung abnormalities (ILAs).

The presence of emphysema on low-dose CT scans ordered for lung cancer screening has been associated with increased COPD hospitalizations [32▪]. Furthermore, the subtype of visual emphysema can be important for risk assessment as paraseptal and moderate-to-severe centrilobular emphysema have been most associated with subsequent emphysema progression [33▪]. In addition, visual emphysema scored on chest CT using the Fleischner Society classification system is associated with a higher risk of mortality following a dose–response relationship [34]. Similarly, quantitative emphysema defined as the percentage of lung volume with voxels less than -950 Hounsfield Units on noise-filtered low-dose CT scans has been independently associated with lung

cancer incidence, lung cancer mortality, and all-cause mortality [35▪]. The size distribution of low attenuation clusters on CT and the spatial heterogeneity of emphysema have also been shown to predict the risk of exacerbation, rate of lung function decline, and long-term mortality in COPD patients [36▪].

Parametric Response Mapping (PRM) is a chest imaging analytic technique that pairs inspiratory and expiratory images to distinguish between emphysema and nonemphysematous air trapping referred to as functional small airways disease. Functional small airways disease has been associated with 5-year FEV_1 decline [9], 5-year emphysema progression [37], and risk of consistent exacerbations, defined as at least one exacerbation every year for 3 years [8]. With regards to large airway disease, although airway wall thickness was not independently associated with mortality, bronchiectasis conferred a higher risk of hospitalization and mortality in patients with COPD [38▪]. From a pulmonary vascular standpoint, increased pulmonary artery diameter (defined as a pulmonary artery : aorta ratio >1) has been associated with higher mortality and incidence of severe exacerbations [39,40▪]. COPD patients with CT findings of ILAs, including reticular abnormalities, nodularity, ground glass opacities, traction bronchiectasis, honeycombing, nonemphysematous cysts or other evidence of architectural distortion, had an increased annual risk of moderate-to-severe COPD exacerbations [41▪]. Further, progression of these radiologic fibrotic changes was associated with a higher rate of annual decline in FEV_1 and forced vital capacity (FVC).

BIOMARKERS

One of the most well studied biomarkers in COPD has been peripheral eosinophilia. A high blood eosinophil count (EOS) has been associated with a higher risk of moderate and severe COPD exacerbations [10] and a faster decline in FEV_1 [11▪▪]. Importantly, change in blood EOS count after initiation of inhaled corticosteroid (ICS) therapy carries prognostic implications in patients with COPD. In a post hoc analysis of the Inhaled Steroids in Obstructive Lung Disease in Europe (ISOLDE) trial, patients with EOS suppression of at least 200 cells/μl following ICS initiation experienced slower FEV_1 decline and a lower incidence of COPD exacerbations over 3 years of follow-up, while those with EOS increase of at least 200 cells/μl following ICS initiation experienced opposite outcomes [42▪▪]. When measured in the setting of an acute COPD exacerbation requiring hospitalization, low EOS (<50 cells/μl) has been associated with concurrent infection, longer hospital stay, and lower 12-month survival [12], especially in conjunction with lymphopenia [43▪] and an elevated neutrophil-to-lymphocyte ratio [44▪,45▪].

Biomarkers reflecting various biochemical pathways of inflammation have been increasingly studied in COPD [46▪]. High fibrinogen levels, the only Food and Drug Administration-approved biomarker for COPD, have been associated with an increased risk of exacerbation [47▪]. Elevated C-reactive protein predicts mortality in COPD [48] and has been used to guide antibiotic prescribing during exacerbations to reduce unnecessary use [49]. Low levels of the soluble receptor for advanced glycation end products (sRAGE) have been linked to worsening lung function and increasing emphysema in COPD [50▪]. Concentrations of airway mucins, especially MUC5AC, have been proposed as biomarkers of chronic bronchitis and have been associated with a higher exacerbation risk and decreased lung function [51▪▪,52].

Associations between various other biomarkers and COPD outcomes have been recently reported. Low concentrations of interleukin-15, a pleiotropic cytokine that induces proliferation of natural killer cells, and high concentrations of interleukin-8, a cytokine targeting neutrophils, have been associated with an increased risk of exacerbations [8]. High levels of endotrophin and von Willebrand factor as well as other markers of epithelial repair, alveolar destruction, and endothelial dysfunction have been correlated with higher morbidity and mortality in COPD [53▪–56▪]. Low-serum IgG and free light chain levels have been linked to a higher risk of exacerbation and hospitalization, which suggests a potential role for intravenous immunoglobulin administration in COPD patients with recurrent exacerbations [57▪–59▪]. High red cell distribution width, a marker of oxidative stress, appears to have excellent accuracy for the identification of the frequent exacerbator phenotype in COPD [60▪]. Vitamin D deficiency has been associated with greater FEV_1 decline, although the drivers behind this association remain to be elucidated [61▪]. Low alanine amino-transferase levels (<11 IU) have been associated with poor survival following a COPD exacerbation requiring hospitalization [62▪], while higher bilirubin may be associated with better COPD outcomes [63▪]. A distinct airway mycobiome profile characterized by dominance of Aspergillus, Curvularia, and Penicillium has been associated with high mortality and frequent exacerbations [64▪▪]. Given the paucity of large-scale studies with reproducible data for these various biomarkers, this evidence remains preliminary and warrants further validation.

COMPOSITE INDICES

One of the most used composite indices in COPD is the body mass index (BMI), Airflow Obstruction, Dyspnea and Exercise Capacity (BODE) index, which incorporates BMI, FEV_1% predicted, dyspnea severity on the mMRC questionnaire, and distance walked on the 6MWT [65]. The original BODE index and its derivatives [7▪▪] better predict all-cause and respiratory-related mortality than FEV_1 alone [65]. Similarly, in a recent study of COPD patients recruited from primary and secondary care clinics in Central Sweden, the Age, Dyspnea and Obstruction (ADO) index better predicted all-cause and respiratory-related mortality than spirometry as well as both GOLD 2011 and 2017 ABCD classifications [66▪]. These results indicate that long-term mortality prediction in COPD is most accurate when respiratory parameters, such as lung function and dyspnea severity are combined with systemic factors, such as age, BMI, and exertional capacity.

Beyond mortality prognostication, several composite tools have been used to predict other important outcomes, such as exacerbations, hospitalizations, and lung function decline. The Acute COPD Exacerbation Prediction Tool (ACCEPT), which was derived from pooled data of three randomized controlled trials, included several clinical and demographic variables, such as number of prior exacerbations, age, sex, BMI, smoking status, SGRQ score, postbronchodilator FEV_1, and use of inhalers and oxygen therapy [67▪▪]. ACCEPT performed well at predicting both the rate and severity of COPD exacerbations when tested in the Evaluation of COPD Longitudinally to Identify Predictive Surrogate End-points (ECLIPSE) cohort. In an analysis of the Subpopulations and Intermediate Outcome Measures in COPD Study (SPIROMICS), a novel respiratory disability score based on detecting impairment on at least four of seven tests and questionnaires (mMRC, CAT, SGRQ, Short Form-12 (SF-12), Functional Assessment of Chronic Illness Therapy-Fatigue (FACIT-F), Veterans Specific Activity Questionnaire, and 6MWT) has been independently associated with future exacerbations and deaths [68▪]. The Dyspnea, Obstruction, Smoking and Exacerbation (DOSE) index was also shown to accurately predict the risk of exacerbation and hospital admission but it did not predict mortality as well as the BODE or ADO indices [69]. The Summit Lab Score, which integrates age, BMI, smoking history, FEV_1, heart rate, blood pressure, prior hospitalizations for COPD exacerbations, comorbidities (including myocardial infection, heart failure, and diabetes), and use of certain antithrombotic and antiarrhythmic medications, was associated with risk of exacerbations and length of hospital stay in COPD patients with cardiovascular disease [70▪]. More recently, machine learning algorithms have been applied to create a mortality prediction model for individuals with moderate-to-severe COPD from the ECLIPSE and Genetic Epidemiology of COPD (COPDGene) cohorts [71▪▪]. This model included quantitative CT imaging metrics and outperformed the BODE and ADO indices at predicting mortality at 7 years of follow-up.

In addition to the aforementioned tools used for prediction of long-term outcomes in patients with stable COPD, other composite indices have been developed for short-term prognostication in the setting of acute COPD exacerbations. For example, the Integrated Pulmonary Index (combining end-tidal carbon dioxide, respiratory rate, pulse rate, and oxygen saturation) and the Ottawa COPD Risk Score (using patient history, vital signs, imaging, lab work, and EKG) have helped emergency medicine physicians decide on disposition based on risk of severe short-term events within 30 days [72▪]. These are just some of many available COPD risk assessment composite indices and are summarized in Table 2. The widespread use of these indices ultimately depends on their practicality, cost, and performance in real-world settings.

REMOTE DIGITAL MONITORING

The newest frontier of COPD management involves the use of remote digital monitoring, electronic inhaler sensors, at-home spirometry devices, and mobile applications targeting early markers of clinical deterioration prior to a patient developing an exacerbation or presenting to the hospital. Remote monitoring devices can track parameters, such as heart rate, respiratory rate and pattern, sleep quality, physical activity, body temperature, oxygen saturation, and cough when connected to patients on clothing, via arm or wristbands, or directly to the torso or ear [13▪▪]. In patients with stable COPD, parameters must be consistently obtained over a week but the data collected have been shown to correlate with symptom burden and inhaler usage [73]. By detecting increased inhaler use, sensors attached to patients' inhalers have been used to predict exacerbations [13▪▪] and have been shown to reduce healthcare utilization [74▪] but this technology remains limited by patient adherence. Although practical, at-home spirometry still faces challenges around its accuracy and lack of infrastructure within health systems to support its broad rollout [13▪▪]. Further, several studies have examined whether phone or web-based applications can serve as risk assessment tools. For example, COPD-Predict™, a novel application that uses a decision tree model to provide early warning signs of an

Table 2. Some composite indices used for risk assessment in chronic obstructive pulmonary disease

Name	Components	Interpretation	References
BODE index	BMI, FEV_1, mMRC dyspnea scale, 6MWT distance	10-point scale; higher score indicates higher risk of death	[65]
ADO index	Age, mMRC dyspnea scale, FEV_1	14-point scale; higher score indicates a higher risk of death	[66▪]
ACCEPT	Exacerbation history, age, sex, BMI, smoking status, SGRQ score, FEV_1, inhaler use, oxygen therapy	Good predictor of rate and severity of future COPD exacerbations	[67▪▪]
Respiratory disability score	mMRC, CAT, SGRQ, SF-12, FACIT-F, Veterans Specific Activity Questionnaire and 6MWT	Impairment on four or more of the seven components define the presence of respiratory disability, which is an independent predictor of exacerbation and death	[68▪]
DOSE index	FEV_1, mMRC dyspnea scale, smoking status, exacerbation frequency	Eight-point scale; higher score indicates higher risk of exacerbation and death	[69]
Summit Lab score	Age, BMI, smoking history, FEV_1, heart rate, blood pressure, prior hospitalizations for COPD exacerbations, comorbidities, medications	Specifically for patients with COPD and cardiovascular disease; score range 1–32, with higher tertile predictive of exacerbations	[70▪]

6MWT, six-minute walk test; ACCEPT, Acute COPD Exacerbation Prediction Tool; ADO, Age, Dyspnea and Obstruction; BMI, body mass index; BODE, BMI, Airflow Obstruction, Dyspnea and Exercise Capacity; CAT, COPD assessment test; COPD, chronic obstructive pulmonary disease; DOSE, Dyspnea, Obstruction, Smoking and Exacerbation; FACIT-F, Functional Assessment of Chronic Illness Therapy-Fatigue; FEV_1, forced expiratory volume in 1 s; mMRC, Modified Medical Research Council; SF-12, Short Form-12; SGRQ, St. George's Respiratory Questionnaire; SPPB, short physical performance battery; STST, Sit-to-Stand test.

exacerbation based on changes in symptoms, FEV_1 and C-reactive protein levels, has been shown to predict exacerbations, including severe exacerbations requiring hospitalization, in a small cohort of patients [14▪]. Many health systems have not yet developed robust workflows to import these types of data into the electronic medical record nor have the associated reimbursement processes been fully established. Therefore, while remote digital monitoring technologies are promising tools to personalize preventive care in COPD, their performance, ease of implementation, and cost effectiveness still need to be further evaluated.

CONCLUSION

Risk assessment tools have been extensively studied in COPD and have traditionally included spirometry, patient-reported symptoms, history of exacerbations, functional status, and combinations of these metrics in composite indices. More recently, specific blood, sputum, and chest imaging biomarkers have emerged as independent predictors of long-term outcomes in patients with COPD. In our practice, we administer CAT and record exacerbation history for all COPD patients to guide inhaler therapy and assess future exacerbation risk. We calculate the BODE score to estimate mortality risk and help guide decisions regarding lung transplantation. We also use the extent of emphysema and small airways disease on chest CT to determine candidacy for surgical or bronchoscopic lung volume reduction. In the setting of the complex heterogeneity of COPD with regards to both disease manifestation and progression, all available clinical information should be integrated to provide the best risk assessment. However, this strategy could be challenging in real-world settings depending on data accessibility, time constraints, and type of practice. Therefore, machine learning risk assessment tools may be very valuable in this context and warrant further investigation. Remote digital monitoring technologies may also prove to be another important risk assessment asset at the disposal of both patients and clinicians but questions regarding their accuracy, ease of use, and cost effectiveness still need to be addressed.

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Conflicts of interest

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- ■ of special interest
- ■■ of outstanding interest

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