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## **Beta-blockers in Chronic Obstructive Pulmonary Disease: a Cohort Study from the TONADO Research Programme**

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# β-Blockers in COPD

## A Cohort Study From the TONADO Research Program



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**BACKGROUND:** Cardiovascular disease is a frequent comorbidity in patients with COPD. Many physicians, particularly pulmonologists, are reluctant to use β-adrenoceptor blocking agents (β-blockers) in patients with COPD, despite their proven effectiveness in preventing cardiovascular events.

**METHODS:** The large (5,162 patients) phase III TONADO 1 and 2 studies assessed lung function and patient-reported outcomes in patients with moderate to very severe COPD receiving long-acting bronchodilator treatment across 1 year. This post hoc analysis characterized lung-function changes, patient-reported outcomes, and safety in the subgroup of patients receiving β-blockers in the studies.

**RESULTS:** In total, 557 of 5,162 patients (11%) received β-blockers at baseline. Post-bronchodilator FEV<sub>1</sub> at baseline was higher in the β-blocker group (1.470 L) compared with that in the no β-blocker group (1.362 L). As expected, patients receiving β-blockers had a more frequent history of cardiovascular comorbidities and medications. Lung function improved from baseline in patients with or those without β-blocker treatment, and no relevant between-group differences were observed in trough FEV<sub>1</sub> or trough FVC at 24 or 52 weeks. No relevant differences were observed for St. George's Respiratory Questionnaire results and Transition Dyspnea Index in patients with β-blockers compared with those in patients without. Safety findings were comparable between groups.

**CONCLUSIONS:** Lung function, overall respiratory status, and safety of tiotropium/olodaterol were not influenced by baseline β-blocker treatment in patients with moderate to very severe COPD. Results from this large patient cohort support the cautious and appropriate use of β-blockers in patients with COPD and cardiovascular comorbidity.

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**KEY WORDS:** β-blockers; COPD; lung function; safety

FOR EDITORIAL COMMENT, SEE PAGE 1289

**ABBREVIATIONS:** AE = adverse event; GOLD = Global Initiative for Chronic Obstructive Lung Disease; SGRQ = St. George's Respiratory Questionnaire

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Cardiovascular disease is linked closely with COPD, mainly because of, but not limited to, the shared risk of smoking.<sup>1,2</sup> Cardiac failure is a leading cause of death in patients with COPD.<sup>3</sup> Physicians often are reluctant to use  $\beta$ -blockers in patients with COPD because of a fear that their use leads to deterioration in lung function<sup>2</sup> or that the effectiveness of COPD medications—specifically, inhaled  $\beta$ -agonists—may be reduced. This concern is reflected by their underuse, with limited prescription of  $\beta$ -blockers<sup>2,4</sup> and low daily dosage in patients with COPD.

As a drug class,  $\beta$ -agonists have the potential to be associated with cardiovascular adverse events (AEs) in obstructive lung disease.<sup>5-7</sup> Even though the risk-benefit profiles of  $\beta$ -agonists, including olodaterol,<sup>8</sup> are well established,<sup>6,9</sup> there is no strict guidance for their use in patients with very severe cardiovascular disorders who may benefit from  $\beta$ -blocker treatment. Consequently, it has been advised that  $\beta$ -agonists are to be used with caution in patients with pulmonary disease or severe cardiovascular disease and who are taking  $\beta$ -blockers.<sup>6,10</sup>

Both cardioselective and noncardioselective  $\beta$ -blockers have been reported to worsen pulmonary function in patients with concomitant heart failure and COPD,<sup>11,12</sup> and cardioselective  $\beta$ -blockers worsen dynamic hyperinflation during cycling exercise in patients with stable COPD.<sup>13</sup> There may be some reluctance among physicians to continue  $\beta$ -blockers during an episode of acute COPD exacerbation, perceiving the patients'

respiratory condition as more delicate.<sup>14</sup> In contrast, administrative database studies suggest that  $\beta$ -blocker use is associated with a 30% reduction in COPD exacerbation rate and even may reduce mortality in patients with COPD.<sup>15-17</sup> A large prospective follow-up study in the COPDGene cohort provided evidence that  $\beta$ -blockers have an acceptable safety profile in patients with Global Initiative for Chronic Obstructive Lung Disease (GOLD) II through IV COPD, including those with severe COPD using home oxygen, and are associated with fewer exacerbations in this population.<sup>18</sup> This issue is important because a large number of patients with COPD theoretically could benefit from  $\beta$ -blocker use, including patients with cardiac comorbidities such as heart failure, coronary artery disease, and hypertension.<sup>19</sup>

The TONADO studies established the efficacy and safety of once-daily maintenance treatment with the combination of tiotropium/olodaterol in patients with moderate to very severe COPD (GOLD II-IV).<sup>20</sup> Overall, approximately 10% of the 5,162 patients in the TONADO studies were receiving  $\beta$ -blockers, providing a unique opportunity to study their impact on lung function, quality of life, and AEs in a large cohort of patients across 1 year. This post hoc analysis was designed to compare lung function, quality of life, dyspnea, and frequency of COPD exacerbations in patients with COPD according to baseline  $\beta$ -blocker use in the TONADO studies.

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## Materials and Methods

### Study Design

The study design of the TONADO research program, which comprised multinational, replicate, phase III, multicenter, randomized, double-blind, active-controlled, five-arm, parallel-group studies (study 1237.5, NCT01431274; study 1237.6, NCT01431287) has been published previously.<sup>20</sup> Randomization details are summarized in e-Appendix 1. Data combined from all treatment arms were used for this cohort study. Baseline  $\beta$ -blocker use was a surrogate for use

throughout the study duration; patients who received  $\beta$ -blockers at baseline were allowed, and expected, to continue with this treatment for the duration of the 1-year study.

### Patients

Inclusion and exclusion criteria of the TONADO studies have been published previously<sup>20</sup> and are summarized in e-Appendix 1. Both studies were performed in accordance with the Declaration of Helsinki, the International Conference on Harmonisation's Harmonised Tripartite Guideline for Good Clinical Practice, and local regulations. Details of institutional review board approval are provided in e-Appendix 1.

### End Points and Assessments

The end points for lung function were trough FEV<sub>1</sub> response (change from baseline) and FVC response at 24 and 52 weeks. Patient-reported outcomes evaluated were St. George's Respiratory Questionnaire (SGRQ) total score and Transition Dyspnea Index score at 24 and 52 weeks.

Further safety end points were investigator-reported AEs (AEs, serious AEs, fatal AEs, AEs leading to discontinuation, and most frequent AEs according to system organ class) and frequency of COPD exacerbations. Moderate exacerbations were those requiring antibiotics or systemic steroids without hospitalization, and severe exacerbations were those requiring hospitalization.

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## Statistical Analysis

To compare patients with and those without  $\beta$ -blockers and to take into account potential confounding variables, we adapted the model used for treatment comparisons in the TONADO studies and adjusted it for additional variables. The adjusted means (SEs) for the efficacy comparisons were obtained from fitting a mixed-effects model for repeated measures, with further information provided in e-Appendix 1. Time to first exacerbation is presented for the first quartile (ie, the time at which 25% of patients reached this end

point) using Kaplan-Meier estimates of probability of COPD exacerbation across the 1-year study. Hazard ratios between patients with and those without  $\beta$ -blockers were estimated using a Cox proportional hazards model adjusting for the same additional variables as the mixed-effects model for repeated measures. Analyses of AEs were descriptive and not adjusted for potential confounding variables. All *P* values and comparisons presented are nominal because this is a post hoc analysis, and no adjustment for multiplicity has been performed.

## Results

In total, 5,163 patients (2,624 from study 1237.5 and 2,539 from study 1237.6) were randomly assigned to receive treatment; all patients were treated, except one in study 1237.6 (Fig 1). At study entry, 557 patients were treated with  $\beta$ -blockers, and 4,605 were not, with 468 (84.0%) and 3,900 (84.7%) patients, respectively, completing the studies. Cardioselective  $\beta$ -blockers were used by at least 80% of  $\beta$ -blocker users (e-Table 1).

Baseline patient characteristics between groups were generally well balanced (Table 1). Patients in the  $\beta$ -blocker group had less severe COPD and higher mean baseline postbronchodilator FEV<sub>1</sub>, which also was reflected in a higher number of patients with GOLD II

COPD and fewer patients with GOLD III or IV COPD than in the no  $\beta$ -blocker group. Change in prebronchodilator to postbronchodilator FEV<sub>1</sub> was consistent in patients with and those without  $\beta$ -blockers at 162 and 172 mL, indicating no influence of  $\beta$ -blockers on short-term bronchodilator reversibility. A similar proportion of patients in each group had received pulmonary medications before the study. More patients took lipid-modifying drugs and angiotensin-converting enzyme inhibitors in the  $\beta$ -blocker group than in the no  $\beta$ -blocker group. Most patients (99%) also took  $\beta$ -blockers during the study. More patients in the  $\beta$ -blocker group had a history of myocardial infarction, cerebrovascular accidents, and cardiac arrhythmia than did those in the no  $\beta$ -blocker group (Table 2).

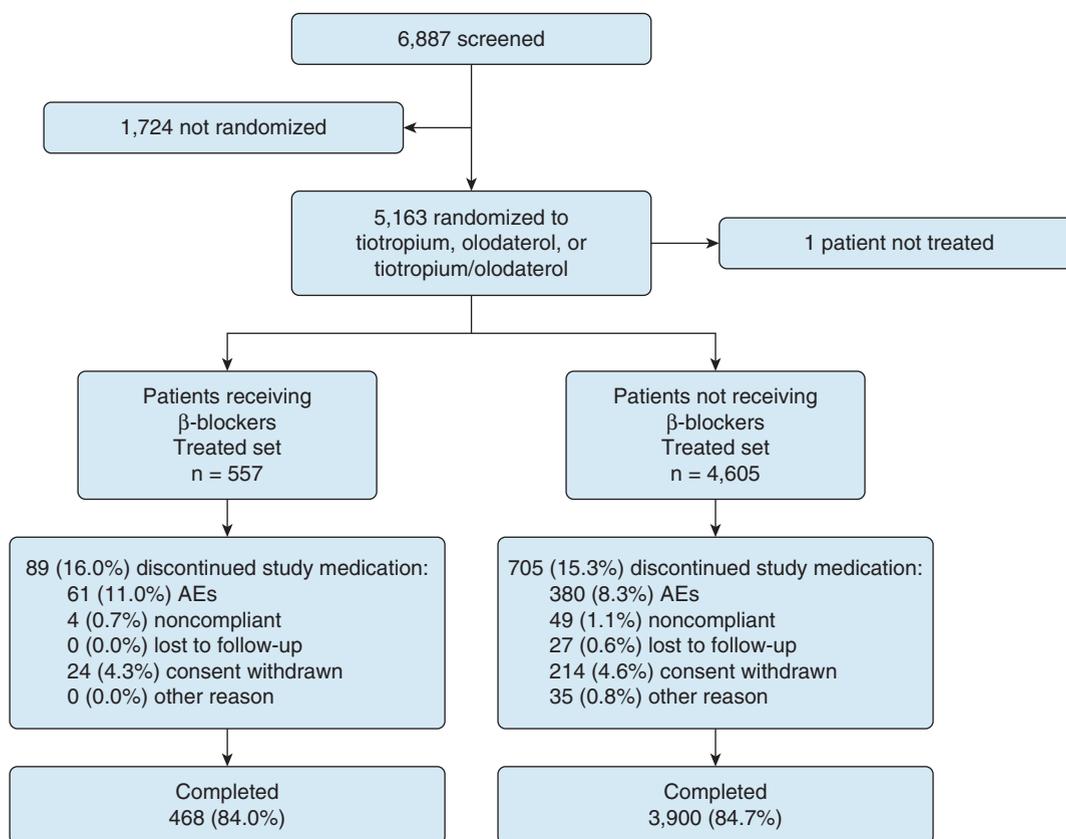


Figure 1 – Consolidated Standards of Reporting Trials diagram by baseline  $\beta$ -blocker, including discontinuations and causes, for combined studies. AE = adverse event.

**TABLE 1 ] Demographic and Baseline Patient Characteristics (Treated Population): Combined Data (N = 5,162)**

Characteristic	$\beta$ -Blocker (n = 557)	No $\beta$ -Blocker (n = 4,605)
Male, No. (%)	393 (70.6)	3,369 (73.2)
Age, mean (SD), y	65.0 (7.7)	63.9 (8.4)
Smoking status, No. (%)		
Exsmoker	359 (64.5)	2,895 (62.9)
Current smoker	198 (35.5)	1,710 (37.1)
BMI, mean (SD), kg/m <sup>2</sup>	28.5 (5.6)	25.5 (5.4)
Exacerbations in the y before study entry, No. (%)	220 (39.5)	1,976 (42.9) <sup>a</sup>
No. of exacerbations, mean	0.7	0.8
Prebronchodilator screening FEV <sub>1</sub> , mean (SD), L	1.308 (0.502)	1.190 (0.491)
Postbronchodilator screening FEV <sub>1</sub> , mean (SD), L	1.470 (0.504)	1.362 (0.510)
Change from prebronchodilator to postbronchodilator FEV <sub>1</sub> , mean (SD), L	0.162 (0.143)	0.172 (0.145)
FEV <sub>1</sub> /FVC, mean (SD), %	49 (11)	45 (12)
% predicted normal FEV <sub>1</sub> , mean (SD)	53 (14)	50 (15)
GOLD, No. (%) <sup>b</sup>		
I ( $\geq$ 80%)	0 (0.0)	3 (0.1)
II (50% to < 80%)	330 (59.2)	2,258 (49.0)
III (30% to < 50%)	191 (34.3)	1,798 (39.0)
IV (< 30%)	36 (6.5)	545 (11.8)
Baseline pulmonary medication, No. (%)		
SAMA <sup>c</sup>	89 (16.0)	576 (12.5)
LAMA <sup>d</sup>	217 (39.0)	1,623 (35.2)
SABA <sup>e</sup>	230 (41.3)	1,849 (40.2)
LABA <sup>f</sup>	276 (49.6)	2,117 (46.0)
ICS <sup>g</sup>	241 (43.3)	2,205 (47.9)
Xanthines <sup>h</sup>	52 (9.3)	464 (10.1)
Baseline cardiovascular medication, No. (%) <sup>i</sup>		
Lipid-modifying drugs	276 (49.6)	771 (16.7)
ACE inhibitors	163 (29.3)	556 (12.1)
ACE inhibitor combinations	39 (7.0)	125 (2.7)
Angiotensin II antagonist combinations	40 (7.2)	155 (3.4)
Angiotensin II antagonists	84 (15.1)	369 (8.0)
Cardiac glycosides	14 (2.5)	25 (0.5)
Cardiac stimulants excluding cardiac glycosides	3 (0.5)	22 (0.5)

ACE = angiotensin-converting enzyme; GOLD = Global Initiative for Chronic Obstructive Lung Disease; ICS = inhaled corticosteroid; LABA = long-acting  $\beta_2$ -agonist; LAMA = long-acting muscarinic antagonist; SABA = short-acting  $\beta$ -agonist; SAMA = short-acting muscarinic antagonist.

<sup>a</sup>Three patients had missing values.

<sup>b</sup>Based on postbronchodilator FEV<sub>1</sub> % predicted (in study 1237.6, one patient receiving tiotropium 2.5  $\mu$ g was not categorized).

<sup>c</sup>Ipratropium, ipratropium with fenoterol or ipratropium with salbutamol, and oxitropium.

<sup>d</sup>Tiotropium.

<sup>e</sup>Salbutamol, fenoterol, ipratropium with fenoterol, and ipratropium with salbutamol.

<sup>f</sup>Including salmeterol, formoterol, indacaterol, salmeterol with fluticasone, formoterol with budesonide, and formoterol with beclomethasone.

<sup>g</sup>Including beclomethasone, budesonide, ciclesonide, fluticasone, mometasone, salmeterol with fluticasone, formoterol with budesonide, formoterol with beclomethasone, and formoterol with mometasone.

<sup>h</sup>Including aminophylline and theophylline. Total number of patients includes only those with values for  $\beta$ -blocker use at baseline.

<sup>i</sup>Combination therapies are listed under each monotherapy drug class.

### Lung Function

Adjusted mean trough FEV<sub>1</sub> responses at 24 weeks were similar in both the  $\beta$ -blocker and no  $\beta$ -blocker groups,

with a between-group difference of 0.010 L (95% CI, -0.009 to 0.028) (Table 3). Similarly, the adjusted mean trough FVC responses were not modified

**TABLE 2 ]** Preexisting Disease Diagnoses by  $\beta$ -Blocker Use

Diagnosis, No. (%)	$\beta$ -Blocker (n = 557)	No $\beta$ -Blocker (n = 4,605)
<b>Cardiac disorders</b>	<b>289 (51.9)</b>	<b>818 (17.8)</b>
Coronary artery disease	99 (17.8)	190 (4.1)
Myocardial infarction	55 (9.9)	78 (1.7)
Angina pectoris	40 (7.2)	66 (1.4)
Myocardial ischemia	39 (7.0)	88 (1.9)
Cardiac arrhythmia	84 (15.1)	211 (4.6)
<b>Vascular disorders</b>	<b>487 (87.4)</b>	<b>1,994 (43.3)</b>
Hypertension	468 (84.0)	1,789 (38.8)
<b>Cerebrovascular accidents</b>	<b>41 (7.4)</b>	<b>126 (2.7)</b>
Transient ischemic attack	22 (3.9)	68 (1.5)
Stroke	22 (3.9)	66 (1.4)
Heart failure NYHA class III or IV	12 (2.2)	20 (0.4)
<b>Prostatic hyperplasia or bladder neck obstruction</b>	<b>56 (10.1)</b>	<b>409 (8.9)</b>
Renal or urinary tract diseases	43 (7.7)	225 (4.9)
<b>Narrow-angle glaucoma</b>	<b>7 (1.3)</b>	<b>16 (0.3)</b>
<b>Cancer</b>	<b>43 (7.7)</b>	<b>190 (4.1)</b>

NYHA = New York Heart Association.

significantly by  $\beta$ -blocker use, with a between-group difference of  $-0.010$  L (95% CI,  $-0.048$  to  $0.028$ ). At 52 weeks, the differences between the  $\beta$ -blocker and no  $\beta$ -blocker groups for trough FEV<sub>1</sub> and FVC responses were also similar ( $-0.005$  L and  $-0.008$  L, respectively).

### Symptom Benefit

There was no difference in baseline mean SGRQ total score between the  $\beta$ -blocker and no  $\beta$ -blocker groups.

**TABLE 3 ]** Adjusted Mean (SE) Trough FEV<sub>1</sub> and Trough FVC Responses (Change From Baseline) After 24 and 52 Weeks of Treatment by  $\beta$ -Blocker Use at Baseline (Full Analysis Set): Combined Data

Response	$\beta$ -Blocker (n = 557)	No $\beta$ -Blocker (n = 4,605)	Treatment Difference (95% CI), L
<b>24 wk</b>			
Trough FEV <sub>1</sub> response, adjusted mean (SE), L	0.080 (0.009)	0.070 (0.003)	0.010 ( $-0.009$ to $0.028$ )
Trough FVC response, adjusted mean (SE), L	0.140 (0.018)	0.150 (0.006)	$-0.010$ ( $-0.048$ to $0.028$ )
<b>52 wk</b>			
Trough FEV <sub>1</sub> response, adjusted mean (SE), L	0.044 (0.009)	0.049 (0.003)	$-0.005$ ( $-0.024$ to $0.014$ )
Trough FVC response, adjusted mean (SE), L	0.111 (0.018)	0.119 (0.006)	$-0.008$ ( $-0.047$ to $0.030$ )

Data obtained from fitting a mixed-effects model for repeated measures, including fixed effects of treatment, planned test day, treatment-by-test-day interaction, baseline, and baseline-by-test-day interaction; patient as a random effect; spatial power covariance structure for within-patient errors; and Kenward-Roger approximation of denominator degrees of freedom.

After 24 weeks, there was a greater, significant reduction (improvement) in adjusted mean SGRQ total score in the  $\beta$ -blocker group compared with that in the no  $\beta$ -blocker group (treatment difference,  $-1.39$ ; 95% CI,  $-2.581$  to  $-0.207$ ) (Table 4). This treatment difference decreased to  $-0.60$  (95% CI,  $-1.810$  to  $0.602$ ) at 52 weeks. Dyspnea improved from baseline after 24 and 52 weeks in both groups (Table 4). Only small, nonsignificant differences in improvement in Transition Dyspnea Index were observed in the  $\beta$ -blocker group compared with those in the no  $\beta$ -blocker group ( $-0.18$ ; 95% CI,  $-0.469$  to  $0.115$  and  $-0.13$ ; 95% CI,  $-0.424$  to  $0.170$  at 24 and 52 weeks, respectively).

### Safety

After 52 weeks of treatment, the proportion of patients with an AE was similar in both groups (Table 5), as was the proportion with specific AEs with an incidence  $> 2\%$ . Respiratory AEs, specifically COPD, occurred at a slightly higher frequency in the no  $\beta$ -blocker group. In the  $\beta$ -blocker group, 19.4% experienced a serious AE compared with 16.0% in the no  $\beta$ -blocker group. The most frequent class of serious AEs in the  $\beta$ -blocker group was respiratory, thoracic, and mediastinal disorders (5.4% compared with 7.2% in the no  $\beta$ -blocker group), followed by infections and infestations (3.6% compared with 2.8%), cardiac disorders (3.2% compared with 1.6%), and neoplasms (2.9% compared with 2.1%) (Table 5).

Incidence of fatal AEs was low across both groups: 2.0% in the  $\beta$ -blocker group and 1.4% in the no  $\beta$ -blocker group (Table 5). The most frequent class of fatal AEs in both groups was cardiac disorders (1.1% compared with 0.3% in the no  $\beta$ -blocker group). Incidence of major adverse cardiovascular events was low, with 2.7% in the  $\beta$ -blocker group and 2.0% in the no  $\beta$ -blocker group (data not shown).

**TABLE 4 ]** Adjusted Mean (SE) SGRQ Total Score and TDI Focal Score After 24 and 52 Weeks of Treatment by  $\beta$ -Blocker Use at Baseline (Full Analysis Set): Combined Data

Score	$\beta$ -Blocker (n = 557)	No $\beta$ -Blocker (n = 4,605)	Difference (95% CI), L
<b>Baseline</b>			
SGRQ total score, mean (SE)	43.58 (0.76)	43.60 (0.28)	...
BDI focal score, mean (SE)	6.40 (0.09)	6.55 (0.03)	...
<b>24 wk</b>			
SGRQ total score, adjusted mean (SE)	36.36 (0.57)	37.75 (0.19)	-1.39 (-2.581 to -0.207)
TDI focal score, adjusted mean (SE)	1.61 (0.14)	1.79 (0.05)	-0.18 (-0.469 to 0.115)
<b>52 wk</b>			
SGRQ total score, adjusted mean (SE)	37.29 (0.58)	37.90 (0.19)	-0.60 (-1.810 to 0.602)
TDI focal score, adjusted mean (SE)	1.57 (0.14)	1.70 (0.05)	-0.13 (-0.424 to 0.170)

BDI = Baseline Dyspnea Index; SGRQ = St. George's Respiratory Questionnaire; TDI = Transition Dyspnea Index.

Patients using  $\beta$ -blockers at study entry experienced fewer COPD exacerbations during the study than did patients not using  $\beta$ -blockers (150 [26.9%] and 1,420 [30.8%], respectively). Time to first COPD exacerbation was not significantly different between groups (271 vs 236 days for patients with and those without  $\beta$ -blocker use, respectively; adjusted hazard ratio, 0.878; 95% CI, 0.732-1.053;  $P = .1604$ ) (Fig 2). Moderate or severe exacerbations were experienced by 145 (26.0%) and 1,339 (29.1%) patients with and those without  $\beta$ -blocker use at study entry, respectively. There was no difference in time to first moderate or severe exacerbation between groups: 304 vs 261 days for patients with and those without  $\beta$ -blocker use at baseline, respectively (adjusted hazard ratio, 0.896; 95% CI, 0.745-1.079;  $P = .2471$ ).

#### Analysis of Safety by Indication for $\beta$ -Blockers

Approximately one-half of all patients in TONADO had an indication for  $\beta$ -blocker treatment according to their recorded cardiovascular disease at baseline: tachyarrhythmias, including supraventricular and ventricular tachyarrhythmias; ischemic heart disease, including myocardial infarction and noninfarction; any diagnosis of cardiac failure or heart failure New York Heart Association class III or IV; or hypertension. Within the  $\beta$ -blocker indication subgroup, the demographic characteristics relating to preexisting disease and concomitant medications of patients with and those without  $\beta$ -blocker treatment were more similar than in the total cohort. Age, sex, and smoking history were similar in the  $\beta$ -blocker and no  $\beta$ -blocker groups, and, as in the entire cohort, baseline FEV<sub>1</sub> was higher in patients receiving  $\beta$ -blockers than in those not receiving them (e-Table 2).

Within the  $\beta$ -blocker indication subgroup, cardiovascular events (e-Table 3) and major adverse cardiovascular events incidences were similar for patients who were receiving  $\beta$ -blocker treatment (2.7%) and those who were not (2.7%). The incidence of fatal AEs was low across both groups: 1.9% in the  $\beta$ -blocker group and 1.8% in the no  $\beta$ -blocker group. As in the total cohort, in the  $\beta$ -blocker indication subgroup the incidence of the majority of respiratory events was numerically lower in patients receiving  $\beta$ -blockers than in patients not receiving  $\beta$ -blockers (e-Table 3).

#### Discussion

The TONADO studies offered a unique opportunity to investigate the influence of  $\beta$ -blocker use on the safety and efficacy of long-acting bronchodilator treatment with tiotropium/olodaterol. To our knowledge, this study is also the first to investigate whether  $\beta$ -blocker use modifies clinical responses to long-acting bronchodilators by assessing well-defined and relevant patient-orientated end points such as dyspnea, quality of life, and exacerbation frequency. In the TONADO studies, in which lung function was improved significantly by use of long-acting bronchodilator treatment, lung-function measures were similar between patients receiving  $\beta$ -blocker treatment and those without. In the  $\beta$ -blocker group, however, mean postbronchodilator FEV<sub>1</sub> at baseline was higher, and there were more patients with GOLD II COPD and fewer patients with GOLD III or IV compared with those in the no  $\beta$ -blocker group. This result is consistent with that observed in the COPDGene cohort and may reflect a reluctance among physicians to use  $\beta$ -blockers in patients with more severe COPD.<sup>18</sup> Results of the

**TABLE 5 ]** Frequency of AEs, Serious AEs, and Fatal AEs After 52 Weeks of Treatment Occurring in > 2% of Patients by  $\beta$ -Blocker Use at Baseline (Treated Set): Combined Data

Variable, No. (%)	$\beta$ -Blocker	No $\beta$ -Blocker
Total No. of patients	557 (100)	4,605 (100)
All AEs	412 (74.0)	3,428 (74.4)
Serious AEs	108 (19.4)	738 (16.0)
Respiratory, thoracic, and mediastinal disorders	30 (5.4)	331 (7.2)
COPD	24 (4.3)	282 (6.1)
Cardiac disorders	18 (3.2)	75 (1.6)
Infections and infestations	20 (3.6)	131 (2.8)
Neoplasms benign, malignant, and unspecified	16 (2.9)	99 (2.1)
Vascular disorders	13 (2.3)	22 (0.5)
Fatal AEs	11 (2.0)	64 (1.4)
Specific AEs with an incidence > 2%		
Respiratory, thoracic, and mediastinal disorders	208 (37.3)	1,954 (42.4)
COPD exacerbation or worsening	158 (28.4)	1,537 (33.4)
Cough	21 (3.8)	184 (4.0)
Dyspnea	26 (4.7)	183 (4.0)
Infections and infestations	207 (37.2)	1,665 (36.2)
Nasopharyngitis	72 (12.9)	565 (12.3)
Urinary tract infection	23 (4.1)	83 (1.8)
Upper respiratory tract infection	24 (4.3)	273 (5.9)
Pneumonia	14 (2.5)	137 (3.0)
Bronchitis	16 (2.9)	122 (2.6)
Influenza	12 (2.2)	119 (2.6)
GI disorders	86 (15.4)	674 (14.6)
Diarrhea	16 (2.9)	120 (2.6)
Musculoskeletal and connective tissue disorders	91 (16.3)	580 (12.6)
Back pain	23 (4.1)	131 (2.8)
Arthralgia	13 (2.3)	59 (1.3)
Nervous system disorders	52 (9.3)	413 (9.0)
Headache	11 (2.0)	143 (3.1)
General disorders and administration site conditions	55 (9.9)	349 (7.6)
Chest pain	15 (2.7)	70 (1.5)
Edema peripheral	11 (2.0)	53 (1.2)
Vascular disorders	48 (8.6)	248 (5.4)
Hypertension	16 (2.9)	155 (3.4)
Cardiac disorders	48 (8.6)	232 (5.0)
Neoplasms benign, malignant, and unspecified	21 (3.8)	142 (3.1)

Percentages were calculated using the total number of patients in the  $\beta$ -blocker use groups at baseline divided by the treatment class as the denominator. AE = adverse event.

present analysis did not show any negative effects of  $\beta$ -blocker treatment, even in patients with severe COPD.

Our study adds to the current knowledge regarding the use of  $\beta$ -blockers in patients with COPD by showing that patient quality of life and dyspnea were not impacted negatively by  $\beta$ -blocker use. At 24 weeks,

SGRQ total score was also improved in both groups, with similar findings for dyspnea, measured by using the Transition Dyspnea Index. Overall, the AE profile was similar in both groups. Fewer patients in the  $\beta$ -blocker group had respiratory AEs, including fewer COPD events, than did those in the no  $\beta$ -blocker group. Patients receiving  $\beta$ -blockers with less severe

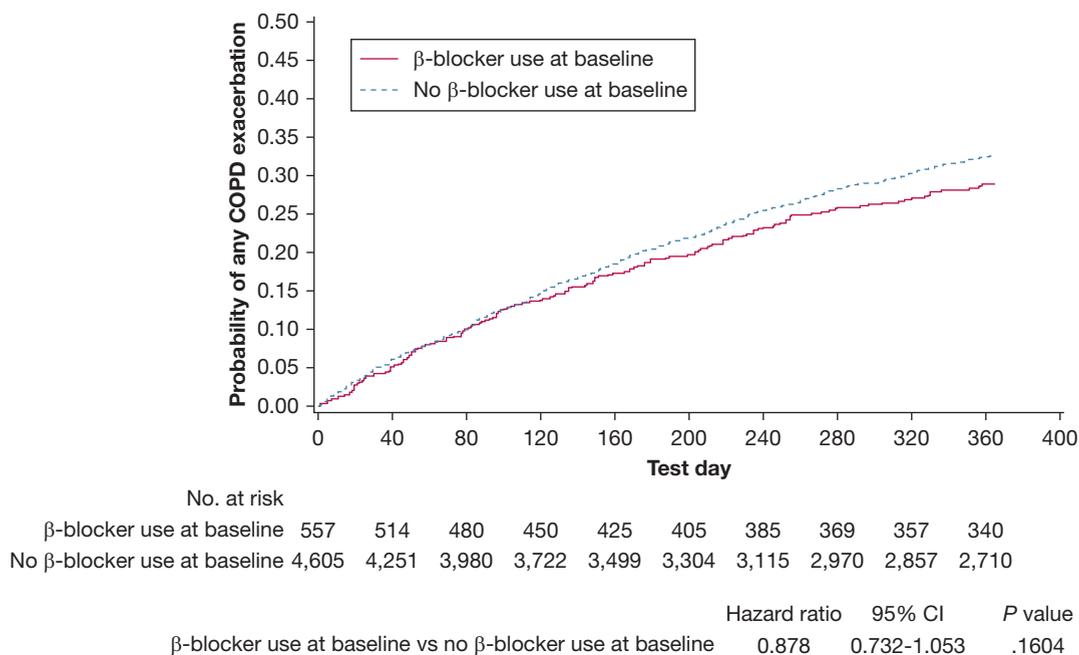


Figure 2 – Kaplan-Meier estimates of probability of COPD exacerbation across the 1-year study by  $\beta$ -blocker use at baseline (treated set), for combined data. Hazard ratio of time to first COPD exacerbation was calculated by using a Cox proportional hazards model adjusting for COPD treatment, sex, age, BMI, race (Asian vs non-Asian), Global Initiative for Chronic Obstructive Lung Disease stage, cardiac disorders, hypertension, angiotensin-converting enzyme inhibitors, angiotensin II antagonists, and lipid-modifying agents.

COPD at baseline may have contributed to this observation. As expected, cardiac disorder AEs had a higher frequency in the  $\beta$ -blocker group, likely because of more preexisting cardiac disease at baseline. Similarly, the overall number of patients with serious AEs was slightly higher in the  $\beta$ -blocker group, which may reflect the higher proportion of patients with general comorbidities in this group.

To explore this issue further, we performed a secondary analysis that was restricted to patients who had a clinical indication for the use of a  $\beta$ -blocker. Approximately one-half of patients in the TONADO studies had an existing indication for  $\beta$ -blockers, but only 20% of them received a  $\beta$ -blocker, another possible reflection of the tendency to avoid the use of  $\beta$ -blockers in patients with COPD. We found that the differences in cardiac disorder AEs and serious AEs between patients with  $\beta$ -blockers and those without became smaller compared with what was seen in the overall cohort. This finding would support the contention that the differences in AEs and serious AEs that were seen between those receiving  $\beta$ -blockers and those who were not were likely driven by individuals with better cardiovascular health in the no  $\beta$ -blocker group. In the subgroup of patients with a  $\beta$ -blocker indication, cardiovascular events and major adverse cardiovascular events incidences between patients who were receiving  $\beta$ -blocker treatment and

those who were not were similar. In this analysis,  $\beta$ -blockers were not protective against cardiovascular events in the indication subgroup. However, it is not known from the available data whether the severity of cardiovascular conditions between the patients receiving  $\beta$ -blockers and those not receiving  $\beta$ -blockers was the same. Also, we would not expect that hypertension, a relatively mild cardiovascular disease and the most frequent condition of the  $\beta$ -blocker indications in the present study would have led to cardiovascular events in the 1-year study follow-up.

Within the  $\beta$ -blocker indication subgroup, there was a numerical advantage for patients in the  $\beta$ -blocker treatment group in terms of respiratory events compared with patients not receiving  $\beta$ -blockers. This finding suggests that treatment with  $\beta$ -blockers does not increase respiratory events in patients with COPD, although this finding could be influenced by the better lung function at baseline in the group of patients receiving  $\beta$ -blockers.

The most frequent system organ class of serious AEs—respiratory, thoracic, and mediastinal disorders—was observed more frequently in the no  $\beta$ -blocker group (7.2% compared with 5.4%). Correcting for differences in baseline characteristics, the tendency to prolonged time to first COPD exacerbation in the  $\beta$ -blocker group

did not reach statistical significance. However, this trend is consistent with the results of a prospective follow-up of the COPDGene cohort, which included 3,464 individuals with COPD GOLD II through IV, although that analysis had a median follow-up of 2 years compared with 1 year in our study and reported delayed time to first exacerbation in patients treated with a  $\beta$ -blocker.<sup>18</sup>

Mortality was low and not substantially different between groups. We did not see a negative pulmonary consequence with respect to AEs for patients taking a  $\beta$ -blocker in this vulnerable population of patients with COPD.

A 2005 systematic review provided reassurance that the use of selective  $\beta$ -blockers is generally safe in stable COPD<sup>21</sup> and that their use should not be withheld routinely from patients with COPD. However, exposure to  $\beta$ -blockers in the included studies was short (2 days to 16 weeks), and diagnosing COPD via administrative databases is poorly validated and potentially unreliable.<sup>22,23</sup> A 2011 study suggested that  $\beta$ -blockers reduce mortality in patients admitted to the hospital with acute COPD exacerbations.<sup>24</sup> Another retrospective study of patients with ischemic heart disease, congestive heart failure, or hypertension who were hospitalized for an acute COPD exacerbation found no association between  $\beta$ -blocker use, in-hospital mortality, 30-day readmission, or initiation of mechanical ventilation.<sup>25</sup>

Similarly to patients in this study, the COPDGene cohort led to the conclusion that  $\beta$ -blockers were safe and associated with significantly reduced total and severe exacerbations, including in patients with severe oxygen-dependent disease.<sup>18</sup> This finding is in contrast to those of a 2013 study involving patients with COPD requiring oxygen, which concluded that  $\beta$ -blocker use may increase mortality in these individuals.<sup>26</sup> Nevertheless, most available evidence indicates that  $\beta$ -blockers are generally safe in patients with COPD,<sup>27</sup> with the possible exception of patients with GOLD IV receiving oxygen therapy. There are compelling reasons to use cardioselective  $\beta$ -blockers in patients with COPD who also have heart failure or have had myocardial infarction.<sup>2</sup> Guidance from the GOLD strategy document, which is based on many of these studies, suggests that the benefits of selective  $\beta$ -blocker use for ischemic heart disease, heart failure, atrial fibrillation, and hypertension are larger than the potential risks associated with treatment, even in patients with severe COPD.<sup>28</sup> Our data appear to support the

recommendation to continue the concomitant use of  $\beta$ -blockers in these patients.

Although counterintuitive at first glance, there is a strong pharmacologic rationale to support the safety and/or potential pulmonary benefits of  $\beta$ -blocker therapy in patients with COPD, particularly in the presence of a concomitant chronic heart disease.<sup>29</sup> Long-term adrenergic stimulation, related either to the presence of a chronic disease or to long-term use of  $\beta$ -agonists, is seen in COPD and eventually may down-regulate the expression of  $\beta$ -adrenergic receptors and attenuate the airway relaxation effects of  $\beta$ -agonists.<sup>29</sup> These adverse consequences of long-term adrenergic stimulation could be mitigated by the long-term use of  $\beta$ -blockers<sup>30</sup> through the reduction in sympathetic tone and the upregulation of  $\beta$ -adrenoceptors in the lungs.<sup>29,31</sup> Irrespective of the exact underlying pharmacologic mechanisms, a meta-analysis of 15 pooled cohort studies on the use of  $\beta$ -blockers in patients with COPD suggested that  $\beta$ -blockers may reduce the risk of overall mortality and exacerbation in those patients.<sup>32</sup>

This analysis was across 12 months, compared with previously reported, shorter-term data,<sup>21</sup> and was performed in patients who were well characterized with thorough clinical monitoring of relevant outcomes.  $\beta$ -Blocker use at baseline was a surrogate for use throughout the study; however, adherence to  $\beta$ -blockers was not monitored during the study. The analysis does not have the strength of a prospective randomized clinical trial, and the trial was not designed and randomized to test for the effect of  $\beta$ -blocker use on outcome measures. Therefore, baseline characteristics showed some differences (eg, in COPD severity and comorbidities), though analyses were controlled for these differences in patient characteristics. However, the large data set for this post hoc analysis from the TONADO studies with a close follow-up provides confidence regarding the surveillance of COPD exacerbations and AEs.

One limitation of these analyses is that patients with myocardial infarction, hospitalization for heart failure in the 12 months prior to screening, or unstable or life-threatening cardiac arrhythmias were excluded from the TONADO studies. However, the study included patients with clinically significant cardiac disease, including those with cerebrovascular accidents, heart failure, and a history of cardiac disorders according to the Medical Dictionary for Regulatory Activities system organ class

definition available at [www.meddra.org/](http://www.meddra.org/). Furthermore, the multicenter and international nature of the trial led to a broad study population, adding further confidence to the application of these findings to clinical practice. Some limitations could be circumvented by the ongoing clinical trial evaluating the efficacy of  $\beta$ -blockers to prevent COPD exacerbation; however, all patients with an indication for  $\beta$ -blocker treatment are excluded from participation in this trial.<sup>33</sup> Therefore, data about the safety of  $\beta$ -blockers in this population are unlikely to emerge from randomized studies. Although confounding by indication is a potential caveat to the validity of our results, all analyses (except safety analyses) were performed after adjusting for important baseline variables, including comorbid conditions. Therefore, we are confident that this analysis provides

important insights concerning the safety of  $\beta$ -blockers in patients with COPD and adds to the evidence base for their use in patients with COPD.

## Conclusions

Overall, there was no relevant effect of  $\beta$ -blocker use on lung function, SGRQ score, or dyspnea in patients with moderate to very severe COPD treated with tiotropium/olodaterol in the TONADO studies. No increase in respiratory AEs or exacerbations was observed in patients receiving tiotropium/olodaterol and  $\beta$ -blockers. Our findings are consistent with the guidance supporting the continuation of usual maintenance therapy in patients with COPD with  $\beta$ -blocker use when clinically indicated.

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