Benralizumab for the Prevention of COPD Exacerbations

DOI: 10.1056/NEJMoa1905248

Citation for published version (APA):

Published in:
New England Journal Of Medicine

Citing this paper
Please note that where the full-text provided on Manchester Research Explorer is the Author Accepted Manuscript or Proof version this may differ from the final Published version. If citing, it is advised that you check and use the publisher's definitive version.

General rights
Copyright and moral rights for the publications made accessible in the Research Explorer are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

Takedown policy
If you believe that this document breaches copyright please refer to the University of Manchester's Takedown Procedures [http://man.ac.uk/04Y6B0] or contact uml.scholarlycommunications@manchester.ac.uk providing relevant details, so we can investigate your claim.
Benralizumab for the Prevention of COPD Exacerbations


ABSTRACT

BACKGROUND
The efficacy and safety of benralizumab, an interleukin-5 receptor alpha–directed cytolytic monoclonal antibody, for the prevention of exacerbations in patients with moderate to very severe chronic obstructive pulmonary disease (COPD) are not known.

METHODS
In the GALATHEA and TERRANOVA trials, we enrolled patients with COPD (at a ratio of approximately 2:1 on the basis of eosinophil count [≥220 per cubic millimeter vs. <220 per cubic millimeter]) who had frequent exacerbations despite receiving guideline-based inhaled treatment. Patients were randomly assigned to receive benralizumab (30 or 100 mg in GALATHEA; 10, 30, or 100 mg in TERRANOVA) every 8 weeks (every 4 weeks for the first three doses) or placebo. The primary end point was the treatment effect of benralizumab, measured as the annualized COPD exacerbation rate ratio (benralizumab vs. placebo) at week 56 in patients with baseline blood eosinophil counts of 220 per cubic millimeter or greater. Safety was also assessed.

RESULTS
In GALATHEA, the estimates of the annualized exacerbation rate were 1.19 per year (95% confidence interval [CI], 1.04 to 1.36) in the 30-mg benralizumab group, 1.03 per year (95% CI, 0.90 to 1.19) in the 100-mg benralizumab group, and 1.24 per year (95% CI, 1.08 to 1.42) in the placebo group; the rate ratio as compared with placebo was 0.96 for 30 mg of benralizumab (P=0.65) and 0.83 for 100 mg of benralizumab (P=0.05). In TERRANOVA, the estimates of the annualized exacerbation rate for 10 mg, 30 mg, and 100 mg of benralizumab and for placebo were 0.99 per year (95% CI, 0.87 to 1.13), 1.21 per year (95% CI, 1.08 to 1.37), 1.09 per year (95% CI, 0.96 to 1.23), and 1.17 per year (95% CI, 1.04 to 1.32), respectively; the corresponding rate ratios were 0.85 (P=0.06), 1.04 (P=0.66), and 0.93 (P=0.40). At 56 weeks, none of the annualized COPD exacerbation rate ratios for any dose of benralizumab as compared with placebo reached significance in either trial. Types and frequencies of adverse events were similar with benralizumab and placebo.

CONCLUSIONS
Add-on benralizumab was not associated with a lower annualized rate of COPD exacerbations than placebo among patients with moderate to very severe COPD, a history of frequent moderate or severe exacerbations, and blood eosinophil counts of 220 per cubic millimeter or greater (Funded by AstraZeneca [GALATHEA and TERRANOVA] and Kyowa Hakko Kirin [GALATHEA]; GALATHEA and TERRANOVA ClinicalTrials.gov numbers, NCT02138916 and NCT02155660.)
Chronic obstructive pulmonary disease (COPD) is characterized by persistent respiratory symptoms and airflow limitation. Patients may have episodes of increased respiratory symptoms (exacerbations) that are moderate (leading to enhanced treatment) or severe (leading to hospitalization). Exacerbations negatively affect patients’ health status and prognosis and have high societal and economic costs, and the prevention of exacerbations is a major therapeutic goal for patients with COPD.

Despite receiving dual or triple inhaled combination therapy (two or three of the following types of agents: inhaled glucocorticoids, long-acting β₂-agonists [LABAs], and long-acting muscarinic antagonists [LAMAs]), patients with COPD may continue to have exacerbations. As many as 40% of patients with stable COPD may have eosinophilic inflammation, which is associated with an increased risk of exacerbations as well as glucocorticoid responsiveness. Some studies have shown that elevated blood eosinophil counts are associated with an increased risk of exacerbations and that inhaled glucocorticoids are efficacious in preventing exacerbations in this population. Targeted treatments to deplete blood eosinophils may also reduce the risk of COPD exacerbations.

Benralizumab is an interleukin-5 receptor alpha–directed cytolytic monoclonal antibody that induces direct, rapid, and substantial eosinophil depletion by means of antibody-dependent cellular cytotoxic activity. In a phase 2 trial, benralizumab was not associated with a lower annual rate of COPD exacerbations than placebo in the per-protocol population of patients with COPD. However, a nonsignificant difference in the exacerbation rate, favoring benralizumab, was found for patients with baseline blood eosinophil counts that were 200 per cubic millimeter or greater.

GALATHEA (Benralizumab Efficacy in Moderate to Very Severe Chronic Obstructive Pulmonary Disease with Exacerbation History) and TERRANOVA (Efficacy and Safety of Benralizumab in Moderate to Very Severe Chronic Obstructive Pulmonary Disease with Exacerbation History) were complementary phase 3 trials designed to evaluate the efficacy (measured as the effect on the annualized exacerbation rate) and safety of benralizumab for patients with moderate to very severe COPD, eosinophilic inflammation (blood eosinophil counts ≥220 per cubic millimeter), and an increased risk of exacerbations.

### METHODS

#### TRIAL DESIGN AND OVERSIGHT

GALATHEA and TERRANOVA were phase 3, randomized, double-blind, placebo-controlled, parallel-group trials. Each trial included an enrollment visit, a 3-week screening period, and a 56-week randomized treatment period (Fig. 1).

Independent ethics committees of the trial centers or central institutional review boards approved the trial protocols, available with the full text of this article at NEJM.org. The trials were conducted in accordance with the principles of the Declaration of Helsinki; all patients provided written informed consent. The trials were designed by AstraZeneca and the academic investigators. Trial data were collected by clinical investigators and were analyzed by AstraZeneca employees. All the authors had access to the data and reviewed and approved the manuscript for submission. The first and second authors and the sponsor-employed authors vouch for the accuracy and completeness of the data and for the fidelity of the trials to the protocols. Writing and editing assistance, including preparation of a draft manuscript under direction and guidance of the authors, was funded by AstraZeneca.

Eligible patients were stratified according to country and blood eosinophil count at enrollment (≥300 per cubic millimeter or <300 per cubic millimeter). Recruitment was capped centrally according to baseline blood eosinophil count (<220 per cubic millimeter, 220 to 299 per cubic millimeter, or ≥300 per cubic millimeter) to maintain predefined cohort sizes and an approximate 2:1 ratio of patients with eosinophil counts of 220 per cubic millimeter or greater (primary analysis population) to patients with counts of less than 220 per cubic millimeter. An eosinophil threshold of 220 per cubic millimeter was selected on the basis of the phase 2 trial of benralizumab in patients with COPD, in which modeling of annual exacerbations according to baseline blood eosinophil count indicated that patients with eosinophil counts above a similar threshold were more likely to have a response to benralizumab. The doses selected were 30 mg, the approved dose for asthma treatment; 100 mg, to inform the safety margin; and
10 mg (in TERRANOVA), to evaluate the dose–
efficacy relationship.

At randomization, eligible patients were as-
signed in a 1:1:1 ratio (GALATHEA) or 1:1:1:1 ratio
(TERRANOVA) to receive placebo or benralizum-
ab (30 mg or 100 mg in GALATHEA; 10 mg, 30 mg,
or 100 mg in TERRANOVA). The trial agent was
administered by subcutaneous injection every
4 weeks for the first three doses, then every
8 weeks thereafter. Patients' use of maintenance
and rescue medication was recorded daily in an
electronic diary; changes in maintenance thera-
py were permitted only if considered medically
necessary by the investigator. The eligibility cri-
tera for randomization included at least 70%
adherence to the prescribed inhaled maintenance
therapy during the run-in period (based on data
from the electronic diary).

PATIENTS
The trials included patients who were 40 to 85
years of age and had moderate to very severe COPD
(i.e., had a postbronchodilator ratio of the forced
expiratory volume in 1 second [FEV1] to the forced
vital capacity of <0.70 at screening and a postbron-
chodilator FEV1 of >20% and ≤65% of the predicted
normal value)1, were current smokers or ex-smok-
ers (lifetime smoking exposure, ≥10 pack-years),
had COPD symptoms (modified Medical Research
Council dyspnea scale score of ≥1 at screening;
scores range from 0 [dyspnea only with strenuous
exercise] to 4 [too dyspneic to leave the house];
minimal clinically important difference, 1 point),
and had a documented history of at least two
moderate COPD exacerbations leading to oral
glucocorticoid treatment, antibiotic treatment, or
both or at least one COPD exacerbation leading to
hospitalization within the year before enroll-
ment despite treatment with dual therapy (an in-
haled glucocorticoid and a LABA or a LABA and
a LAMA) or triple therapy (an inhaled glucocor-
ticoid, a LABA, and a LAMA) throughout that
year. Patients were excluded from the trial if they
had a primary diagnosis of asthma that was con-
considered by the local investigator to contribute to their current respiratory symptoms (an earlier history of asthma [e.g., in childhood or adolescence] was permitted). The full list of eligibility criteria is provided in the trial protocols.

**END POINTS**

The primary population for all analyses was made up of patients with baseline blood eosinophil counts of at least 220 per cubic millimeter. The primary end point in both trials was the treatment effect of benralizumab, measured as the annualized COPD exacerbation rate ratio (benralizumab vs. placebo) at week 56, with sensitivity analysis of the annualized severe COPD exacerbation rate. Key secondary end points were the change from baseline in prebronchodilator FEV₁ and in St. George’s Respiratory Questionnaire (SGRQ) total score (scores are based on a 50-item questionnaire and range from 0 to 100, with higher scores indicating worse symptoms; a minimal clinically important difference is a decrease of 4 points). Safety end points included types and frequencies of adverse events.

A COPD exacerbation was defined as a symptomatic worsening of COPD for at least 3 days resulting in any of the following outcomes: the use of systemic glucocorticoids, the use of antibiotics, or hospitalization or COPD-related death (see Section 3.2 in the Supplementary Appendix, available at NEJM.org). Severe exacerbations were those resulting in hospitalization or death. Respiratory symptoms were recorded daily in an electronic diary. Patients completed the SGRQ during center visits. Additional assessments that were used but are not reported are described in Section 4 in the Supplementary Appendix. Safety data were collected at center visits along with spirometry data; the reading of spirometry results was centralized. In GALATHEA, 9% of patients were included in an induced-sputum substudy (see Section 3.7 in the Supplementary Appendix).

**STATISTICAL ANALYSIS**

We calculated that 348 patients with baseline blood eosinophil counts of at least 220 per cubic millimeter in each treatment group (overall total patients in GALATHEA, 1044; in TERRANOVA, 1392) would be required to provide 90% power for the detection of a 30% lower annualized exacerbation rate in the 30-mg or 100-mg benralizumab group than in the placebo group. For this calculation, we assumed a two-sided 4% alpha level (to reserve an alpha level of 1% for the testing of key secondary end points), an annual rate in the placebo group of 0.93 events per patient (1.0 event per patient over 56 weeks), and a negative binomial shape parameter of 0.4.

Exacerbation rates were compared between the benralizumab groups and the placebo group with the use of a negative binomial model for patients in the primary analysis population (baseline blood eosinophil count, ≥220 per cubic millimeter). The model response variable was the number of exacerbations over the 56-week treatment period. The model included covariates of treatment group, eosinophil-count stratum (220 to 299 per cubic millimeter or ≥300 per cubic millimeter), region, background therapy (an inhaled glucocorticoid plus a LABA, a LABA plus a LAMA, or all three types of agents), and number of exacerbations in the previous year. Adjustment for multiple testing, to maintain the overall type I error rate, was performed with the use of the Hochberg procedure. In TERRANOVA, the 10-mg benralizumab group was not adjusted for multiple testing.

Changes from baseline in the prebronchodilator FEV₁ and SGRQ score were key secondary end points (evaluated in patients with blood eosinophil counts of ≥220 per cubic millimeter). Analysis of secondary end points was not adjusted for multiple testing in TERRANOVA. The change from baseline in prebronchodilator FEV₁ at week 56 was compared between each benralizumab dose group and the placebo group with a repeated-measures analysis. The change from baseline in SGRQ total score at week 56 was analyzed separately with a similar model. Safety measures were analyzed by means of count summaries according to trial period.

We performed prespecified subgroup analyses according to the number of previous exacerbations, evaluated in patients with blood eosinophil counts of 220 per cubic millimeter or greater. The results among patients with baseline blood eosinophil counts of less than 220 per cubic millimeter were used to evaluate the effect of benralizumab on the annualized exacerbation rate according to the baseline blood eosinophil count. The trials were not designed or powered to assess efficacy within these subgroups; these analyses are therefore considered exploratory. Further details of the statistical analysis are provided in Section 5 in the Supplementary Appendix.
RESULTS

TRIAL POPULATIONS

The characteristics of the patients in the two trials were similar in the primary analysis populations (1120 patients in GALATHEA and 1545 patients in TERRANOVA had baseline blood eosinophil counts of ≥220 per cubic millimeter) and in the overall study populations (1656 in GALATHEA and 2254 in TERRANOVA) (Table 1, and Tables S1 and S2 in the Supplementary Appendix). The most common trial-specific reason for exclusion was previous closure of enrollment to the prespecified eosinophil-count stratum of less than 220 per cubic millimeter. In the primary analysis population in both trials, most patients were white men, and the mean age was 65 years. The percentages of patients with current (nonprimary diagnosis) or past asthma were low (current asthma, 5.4% in GALATHEA and 3.3% in TERRANOVA; past asthma, 8.3% in GALATHEA and 6.1% in TERRANOVA; the groups were not mutually exclusive) (Table 1). At baseline, most patients (approximately 93% in both trials) were classified as being in Global Initiative for COPD (GOLD) group D, and 69.6% of the patients in GALATHEA and 58.6% of the patients in TERRANOVA were receiving triple therapy with an inhaled glucocorticoid, a LABA, and a LAMA; 9.0% and 7.2%, respectively, were receiving dual therapy with a LABA and a LAMA. More than 29% of patients (overall and across all treatment groups) had had at least one exacerbation resulting in hospitalization in the year before enrollment, and more than 25% had had more than two moderate or severe exacerbations in the previous year. The percentages of patients overall who changed background maintenance therapy during the treatment and post-treatment periods were less than 5% and less than 1%, respectively.

The reported results are for the primary analysis population. In GALATHEA and TERRANOVA, 84.1% and 84.3% of patients, respectively, completed treatment. The primary reasons for treatment discontinuation were adverse events and patient decision (Figs. S1 and S2 in the Supplementary Appendix).

PRIMARY END POINTS

In GALATHEA, the annualized COPD exacerbation rate ratios (benralizumab vs. placebo) at week 56 did not reach significance. The estimates of the annualized exacerbation rate were 1.19 per year (95% confidence interval [CI], 1.04 to 1.36) in the 30-mg benralizumab group, 1.03 per year (95% CI, 0.90 to 1.19) in the 100-mg benralizumab group, and 1.24 per year (95% CI, 1.08 to 1.42) in the placebo group. The rate ratios were 0.96 for 30 mg of benralizumab (P=0.65) and 0.83 for 100 mg of benralizumab (P=0.05) (Table 2 and Fig. 2).

In TERRANOVA, the annualized COPD exacerbation rate ratios (benralizumab vs. placebo) at week 56 also did not reach significance. The estimates of the annualized exacerbation rate were 0.99 per year (95% CI, 0.87 to 1.13) in the 10-mg benralizumab group, 1.21 per year (95% CI, 1.08 to 1.37) in the 30-mg benralizumab group, 1.09 per year (95% CI, 0.96 to 1.23) in the 100-mg benralizumab group, and 1.17 per year (95% CI, 1.04 to 1.32) in the placebo group. The rate ratios were 0.85 (P=0.06), 1.04 (P=0.66), and 0.93 (P=0.40), respectively (Table 2).

There was no consistent dose effect of benralizumab on the annualized exacerbation rate. The time to first exacerbation for each group is shown in Figure S3 in the Supplementary Appendix. In GALATHEA, the annualized rate of severe exacerbations (sensitivity analysis) was 0.25 per year (95% CI, 0.19 to 0.33) in the 30-mg benralizumab group, 0.12 per year (95% CI, 0.08 to 0.17) in the 100-mg benralizumab group, and 0.21 per year (95% CI, 0.15 to 0.28) in the placebo group; the rate ratio was 1.20 in the 30-mg benralizumab group and 0.57 in the 100-mg benralizumab group (Table 2 and Fig. 2). In TERRANOVA, the annualized rates of severe exacerbations in the 10-mg, 30-mg, and 100-mg benralizumab groups were 0.18 per year (95% CI, 0.14 to 0.25), 0.22 per year (95% CI, 0.17 to 0.28), and 0.17 per year (95% CI, 0.13 to 0.22), respectively, and the annualized rate in the placebo group was 0.25 per year (95% CI, 0.19 to 0.32). The rate ratios were 0.75, 0.88, and 0.68, respectively (Table 2 and Fig. 2).

KEY SECONDARY END POINTS

In GALATHEA, the difference (benralizumab vs. placebo) in the mean change from baseline in prebronchodilator FEV₁ was 7 ml (95% CI, −35 to 48) in the 30-mg benralizumab group and 21 ml (95% CI, −21 to 62) in the 100-mg benralizumab group (Table S3 and Fig. S4 in the Supplementary Appendix).

The New England Journal of Medicine
Downloaded from nejm.org at UNIV OF MANCHESTER JOHN RYLANDS LIB on May 28, 2019. For personal use only. No other uses without permission. Copyright © 2019 Massachusetts Medical Society. All rights reserved.
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>GALATHEA</th>
<th>TERRANOVA</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Benralizumab, 30 mg (N = 382)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Benralizumab, 100 mg (N = 379)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Placebo (N = 359)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total (N = 1120)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Benralizumab, 10 mg (N = 377)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Benralizumab, 30 mg (N = 394)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Benralizumab, 100 mg (N = 386)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Placebo (N = 388)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total (N = 1545)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Age — yr</strong></td>
<td>65.8±7.95</td>
<td>65.1±8.49</td>
<td>65.1±8.26</td>
</tr>
<tr>
<td><strong>Male sex — no. (%)</strong></td>
<td>270 (70.7)</td>
<td>262 (69.1)</td>
<td>260 (72.4)</td>
</tr>
<tr>
<td><strong>White race — no. (%)†</strong></td>
<td>339 (88.7)</td>
<td>334 (88.1)</td>
<td>315 (87.7)</td>
</tr>
<tr>
<td><strong>BMI‡</strong></td>
<td>27.3±5.67</td>
<td>27.8±1.17</td>
<td>27.7±1.52</td>
</tr>
<tr>
<td><strong>Smoking status — no. (%)§</strong></td>
<td>134 (36.6)</td>
<td>129 (34.0)</td>
<td>115 (32.0)</td>
</tr>
<tr>
<td><strong>Cigarette consumption — pack‑yr¶</strong></td>
<td>44.2±21.61</td>
<td>43.5±27.74</td>
<td>43.5±27.19</td>
</tr>
<tr>
<td><strong>Baseline eosinophil count — cells/mm3</strong></td>
<td>451.3±281.5</td>
<td>453.5±283.4</td>
<td>452.5±280.25</td>
</tr>
<tr>
<td><strong>Maintenance therapy — no. (%)‖</strong></td>
<td>72 (18.8)</td>
<td>89 (23.2)</td>
<td>111 (34.7)</td>
</tr>
<tr>
<td><strong>No. of exacerbations in the previous 12 mo</strong></td>
<td>2.3±1.77</td>
<td>2.3±1.75</td>
<td>2.2±1.01</td>
</tr>
<tr>
<td><strong>Prebronchodilator FEV1 — % of predicted normal value</strong></td>
<td>42.4±11.8</td>
<td>43.5±12.0</td>
<td>43.1±12.2</td>
</tr>
<tr>
<td><strong>Postbronchodilator lung function</strong></td>
<td>42.7±13.5</td>
<td>43.5±12.8</td>
<td>43.1±12.2</td>
</tr>
<tr>
<td><strong>FEV1:FVC ratio — % of predicted</strong></td>
<td>43.5±11.8</td>
<td>43.5±11.8</td>
<td>43.5±11.8</td>
</tr>
<tr>
<td><strong>FEV1 — liters</strong></td>
<td>42.2±12.1</td>
<td>42.5±12.3</td>
<td>42.5±12.3</td>
</tr>
<tr>
<td><strong>Current diagnosis of asthma — no. (%)</strong></td>
<td>17 (4.5)</td>
<td>28 (7.0)</td>
<td>36 (9.8)</td>
</tr>
<tr>
<td><strong>Previous diagnosis of asthma — no. (%)</strong></td>
<td>39 (10.0)</td>
<td>38 (10.0)</td>
<td>38 (10.0)</td>
</tr>
</tbody>
</table>

*Plus–minus values are means ±SD. Benralizumab or placebo was given every 8 weeks (the first three doses were given every 4 weeks). FEV1 denotes forced expiratory volume in 1 sec—second, FVC forced vital capacity, ICS inhaled glucocorticoid, LABA, long-acting β2-agonist, and LAMA long-acting muscarinic antagonist.

†Race was reported by the patient.

‡Body-mass index (BMI) is the weight in kilograms divided by the square of the height in meters.

§Data are for smoking status as assessed at the time of entry into the trial.

¶Data for cigarette consumption are measured before entry into the trial.

‖One patient in the 30-mg benralizumab group in GALATHEA was receiving an ICS and a LAMA. One patient in the 10-mg benralizumab group in TERRANOVA was receiving an ICS and a LAMA. One patient in the 10-mg benralizumab group in TERRANOVA was receiving an ICS, LABA, and LAMA. These four patients are not included here.

---

The New England Journal of Medicine
Downloaded from nejm.org at UNIV OF MANCHESTER JOHN RYLANDS LIB on May 28, 2019. For personal use only. No other uses without permission. Copyright © 2019 Massachusetts Medical Society. All rights reserved.
tary Appendix). The difference (benralizumab vs. placebo) in the change from baseline in SGRQ total score was −1.011 (95% CI, −2.887 to 0.865) in the 30-mg benralizumab group and −2.136 (95% CI, −4.020 to −0.251) in the 100-mg benralizumab group (Table S3 and Fig. S4 in the Supplementary Appendix).

In TERRANOVA, the difference (benralizumab vs. placebo) in the mean change from baseline in prebronchodilator FEV1 was 15 ml (95% CI, −29 vs. placebo) in the mean change from baseline in SGRQ total score in the 10-mg, 30-mg, and 100-mg benralizumab groups, respectively (Table S3 and Fig. S4 in the Supplementary Appendix). The difference (benralizumab vs. placebo) in the change from baseline in SGRQ total score in the 10-mg, 30-mg, and 100-mg benralizumab groups was −1.011 (95% CI, −3.192 to 1.171), −1.388 (95% CI, −3.562 to 0.786), and −0.602 (95% CI, −2.763 to 1.560), respectively (Table S3 and Fig. S4 in the Supplementary Appendix). Over the course of the trial, the SGRQ total scores for patients in the placebo group showed large improvements, with mean changes of −3.913 in GALATHEA and −6.863 in TERRANOVA (Table 2).

In both trials, all benralizumab doses led to substantial depletion of blood eosinophils from week 4 to the end of the trial, whereas no depletion of eosinophils occurred with placebo (Fig. S5 in the Supplementary Appendix). In a GALATHEA substudy (153 patients, 7%), we analyzed sputum eosinophil counts and found a correlation between the baseline blood eosinophil count and the baseline percentage of sputum eosinophils (Spearman rank correlation coefficient, 0.57). Benralizumab produced substantial depletion of sputum eosinophils by week 24 (mean, 0.02% for 30 mg [24 patients] and 0.13% for 100 mg [17 patients], as compared with 5.38% for placebo [29 patients]).

**Prespecified Subgroup Analyses**

Data on treatment response according to previous exacerbations and baseline blood eosinophil counts are provided in Figures S6, S7, and S8 in the Supplementary Appendix. There was no association between baseline eosinophil count (divided into categories ranging from <150 to >400 per cubic millimeter) and treatment effect.

**Safety**

In both trials, the types and frequencies of adverse events were similar in the benralizumab and placebo groups. Mortality (all-cause and adverse event–related) was low (<4% in each group) (Table 3). The most common adverse events were related to COPD or respiratory conditions. Fewer than 14% of patients in each group had a positive antidrug-antibody response (data not shown). These responses had no apparent effect on clinical outcomes.

**Discus**

In the GALATHEA and TERRANOVA trials, involving patients with moderate to very severe COPD who were receiving double or triple inhaled therapy, had a history of COPD exacerbations, and had blood eosinophil counts of at least 220 per cubic millimeter, the annual rates of COPD exacerbations associated with benralizumab given as add-on maintenance treatment over 56 weeks were not significantly lower than those associated with placebo. The approved benralizumab dose for the treatment of patients with severe eosinophilic asthma is 30 mg. Further studies will be needed to determine whether a higher dose of benralizumab may be required to achieve a treatment response in patients with COPD than in patients with asthma. However, the fact that the dose of benralizumab we used reduced blood eosinophils to very low counts suggests that such a strategy may not be successful.

The results we observed with benralizumab were, in general, similar to those of the METREO (Mepolizumab vs. Placebo as Add-on Treatment for Frequently Exacerbating COPD Patients Characterized by Eosinophil Level) and METREX (Mepolizumab vs. Placebo as Add-on Treatment for Frequently Exacerbating COPD Patients) phase 3 trials, which evaluated the efficacy and safety of mepolizumab (an anti–interleukin-5 monoclonal antibody) for patients with COPD and a history of exacerbations. In METREX (but not in METREO), mepolizumab at a dose of 100 mg was associated with a significantly lower annual rate of moderate or severe COPD exacerbations than placebo among patients who had baseline blood eosinophil counts of at least 150 per cubic millimeter at screening or at least 300 per cubic millimeter in the previous year. Key differences between our trials and those trials include the sizes of the patient populations included in the primary analysis, which were larger in GALATHEA (1120 patients) and TERRANOVA (1545) than in METREO (674) and
Table 2. Analysis of Efficacy in Patients with Baseline Blood Eosinophil Counts of 220 per Cubic Millimeter or Greater.*

<table>
<thead>
<tr>
<th>End Point</th>
<th>GALATHEA</th>
<th>TERRANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Benralizumab</td>
<td>Benralizumab</td>
</tr>
<tr>
<td></td>
<td>30 mg (N = 382)</td>
<td>100 mg (N = 379)</td>
</tr>
<tr>
<td>Exacerbations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated annual rate (95% CI)</td>
<td>1.19 (1.04–1.36)</td>
<td>1.03 (0.90–1.19)</td>
</tr>
<tr>
<td>Rate ratio, benralizumab vs. placebo (95% CI)†</td>
<td>0.96 (0.80–1.15)</td>
<td>0.83 (0.69–1.00)</td>
</tr>
<tr>
<td>Unadjusted P value</td>
<td>0.65</td>
<td>0.05</td>
</tr>
<tr>
<td>Severe exacerbations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated annual rate (95% CI)</td>
<td>0.25 (0.19–0.33)</td>
<td>0.12 (0.08–0.17)</td>
</tr>
<tr>
<td>Rate ratio, benralizumab vs. placebo (95% CI)‡</td>
<td>1.20 (0.80–1.80)</td>
<td>0.57 (0.36–0.91)</td>
</tr>
<tr>
<td>Lung function</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of patients with data</td>
<td>329</td>
<td>326</td>
</tr>
<tr>
<td>Change from baseline to wk 56 in prebronchodilator FEV₁ — liters</td>
<td>0.014±0.282</td>
<td>0.031±0.294</td>
</tr>
<tr>
<td>Health-related quality of life</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of patients with data</td>
<td>338</td>
<td>331</td>
</tr>
</tbody>
</table>

* Plus–minus values are means ±SD.
† Rates are from a negative binomial model with adjustment for treatment group, eosinophil-count stratum (220 to 299 per cubic millimeter or ≥300 per cubic millimeter), geographic region, background therapy (ICS plus LABA, LABA plus LAMA, or triple therapy [ICS, LABA, and LAMA]), and number of previous exacerbations. The trial was designed to test against an alpha level of 0.04.
‡ Confidence intervals have not been adjusted for multiplicity, and inferences drawn from the intervals may not be reproducible.
§ Scores on the St. George’s Respiratory Questionnaire (SGRQ), a 50-item health-related quality-of-life questionnaire, range from 0 to 100, with higher scores indicating worse quality of life (a minimal clinically important difference is a decrease of 4 points).
METREX (836). In addition, different cutoff values for the eosinophil count were used (220 per cubic millimeter in GALATHEA and TERRANOVA as compared with 150 per cubic millimeter in METREO and METREX), and patients had to receive treatment with triple inhaled therapy in METREO and METREX, whereas treatment with dual or triple inhaled therapy was required in GALATHEA and TERRANOVA. Furthermore, all patients in METREO and METREX had been receiving long-term treatment with inhaled glucocorticoids before enrollment, whereas up to 9% of patients in GALATHEA and TERRANOVA had not been receiving inhaled glucocorticoids. Moreover, in METREO and METREX, the patients’ history of asthma was not well characterized. In GALATHEA and TERRANOVA, no more than 10% of patients had a current secondary or previous diagnosis of asthma; these patients were unlikely to have disproportionately affected the results.

In our trials, adverse events and serious adverse events were balanced across the treatment groups, and all-cause mortality was less than 4% across all treatment groups. These safety data are consistent with those reported in the phase 3 trials of benralizumab for severe, uncontrolled eosinophilic asthma.18,19

The data from our two large trials showed improvements in SGRQ total score in the placebo groups that were greater than anticipated. An other potential limitation of the trials is that we did not account for an effect of the type of exacerbation treatment (i.e., systemic glucocorticoids only vs. antibiotics only vs. antibiotics plus glucocorticoids) on the response to benralizumab in
Table 3. Safety of Benralizumab during the Trial Period (Safety Analysis Population).

<table>
<thead>
<tr>
<th>Adverse Event*</th>
<th>GALATHEA</th>
<th>TERRANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Benralizumab, 30 mg (N = 554)</td>
<td>Benralizumab, 100 mg (N = 552)</td>
</tr>
<tr>
<td>Any adverse event</td>
<td>427 (77.1)</td>
<td>445 (80.6)</td>
</tr>
<tr>
<td>Adverse event leading to death</td>
<td>15 (2.7)</td>
<td>11 (2.0)</td>
</tr>
<tr>
<td>Any severe adverse event</td>
<td>151 (27.3)</td>
<td>177 (32.1)</td>
</tr>
<tr>
<td>Adverse event leading to discontinuation of trial agent</td>
<td>30 (5.4)</td>
<td>33 (6.0)</td>
</tr>
<tr>
<td>COPD-related event</td>
<td>98 (17.7)</td>
<td>83 (15.0)</td>
</tr>
<tr>
<td>Viral upper respiratory tract infection</td>
<td>83 (15.0)</td>
<td>95 (17.2)</td>
</tr>
<tr>
<td>Bronchitis</td>
<td>60 (10.8)</td>
<td>86 (15.6)</td>
</tr>
<tr>
<td>Upper respiratory tract infection</td>
<td>69 (12.5)</td>
<td>75 (13.6)</td>
</tr>
<tr>
<td>Lower respiratory tract infection</td>
<td>50 (9.0)</td>
<td>32 (5.8)</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>32 (5.8)</td>
<td>29 (5.3)</td>
</tr>
<tr>
<td>Urinary tract infection</td>
<td>24 (4.3)</td>
<td>23 (4.2)</td>
</tr>
<tr>
<td>Death from any cause</td>
<td>15 (2.7)</td>
<td>12 (2.2)</td>
</tr>
</tbody>
</table>

* Adverse events were classified in accordance with the Medical Dictionary for Regulatory Activities, version 20.0, preferred terms.
the analysis plan. Modifying the trial design to account for greater changes than anticipated in clinical outcomes in the placebo group during the trial and for the effects of the different therapies used to treat exacerbations could help in the planning of future trials involving similar patients with COPD.

COPD is a complex condition driven by a diverse range of mechanisms, which leads to a wide spectrum of clinical presentations.20 Biologic agents such as benralizumab target a discrete potential pathologic mechanism (eosinophilic inflammation). By week 4, and through to week 56, benralizumab resulted in substantial depletion of blood eosinophils, and substantial depletion of sputum eosinophils had occurred by week 24. However, in contrast to the results in benralizumab-treated patients with severe eosinophilic asthma,18,19 this eosinophil depletion did not correspond to a significant difference in the rate of exacerbations. This finding, together with the effect on eosinophils — with minimal effect on the COPD exacerbation rate — that was observed in the mepolizumab trials, suggests that eosinophil depletion is unlikely to ameliorate exacerbation outcomes for the majority of patients with COPD. Future investigation is required to identify additional clinical factors or biomarkers that may characterize the patients with COPD who are most likely to benefit from anti–interleukin-5 receptor antibody therapy.

Supported by AstraZeneca (GALATHEA and TERRANOVA) and Kyowa Hakko Kirin (GALATHEA). Dr. Singh is supported by the National Institute for Health Research Manchester Biomedical Research Centre.

Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

We thank Debra Scalet, Ph.D., of JK Associates and Michael A. Nissen, E.L.S., of AstraZeneca for writing and editing assistance with an earlier version of the manuscript.

APPENDIX

The authors’ full names and academic degrees are as follows: Gerard J. Criner, M.D., Bartolome R. Celli, M.D., Christopher E. Brightman, M.D., Alvar Agusti, M.D., Ph.D., Alberto Papi, M.D., Dave Singh, M.D., Don D. Sin, M.D., Claus V. Vogelmeier, M.D., Frank C. Sciurba, M.D., Mona Baladhel, M.D., Vibeke Backer, M.D., Motokazu Kato, M.D., Ph.D., Alejandra Ramirez-Venezagas, M.D., Yu-Feng Wei, M.D., Leif Bjørner, M.D., Vivian H. Shih, Dr.Ph., Maria Jison, M.D., Sean O’Quinn, M.P.H., Natalya Makulova, M.D., Ph.D., Paul Newbold, Ph.D., Mitchell Goldman, M.D., and Ubaldo J. Martin, M.D.

The authors’ affiliations are as follows: the Department of Thoracic Medicine and Surgery, Lewis Katz School of Medicine, Temple University, Philadelphia (G.J.C.); Pulmonary and Critical Care Division, Brigham and Women’s Hospital, Harvard Medical School, Boston (B.R.C.); the Institute for Lung Health, Leicester National Institute for Health Research Biomedical Research Centre, Department of Respiratory Sciences, University of Leicester, Leicester (C.E.B.); the University of Manchester, Manchester University NHS Hospital Trust, Manchester (D.S.); and the Respiratory Medicine Unit, Nuffield Department of Medicine, University of Oxford, Oxford (M.B.) — all in the United Kingdom; Respiratory Institute, University of California, Los Angeles School of Medicine, Los Angeles (M.G.); the Department of Respiratory and Chest Medicine, E-Da Hospital, Taichung, Taiwan (V.B.); Kishiwada City Hospital, Osaka, Japan (M.K.); the Departmentamento de Investigación en Tabaco y EPOC, Instituto Nacional de Enfermedades Respiratorias, Spain (C.F.V.); the Department of Respiratory Medicine, University of Ferrara, Ferrara, Italy (A.P.); the Centre for Heart Lung Innovation, St. Paul’s Hospital, Vancouver, BC, Canada (D.D.S.); the Department of Medicine, Pulmonary and Critical Care Medicine, University Medical Center Giessen and Marburg, Philipps-Universität Marburg, German Center for Lung Research (DZL), Marburg, Germany (C.F.V.); University of Pittsburgh School of Medicine, Pittsburgh (F.C.S.); the Department of Respiratory Medicine, Bispebjerg University Hospital, Copenhagen (V.B.); Kishiwada City Hospital, Osaka, Japan (M.K.); the Consorcio de Biomedicina, Mexico City (A.R.-V.); the Division of Respiratory and Chest Medicine, E-Da Hospital and I-Shou University, Kaohsiung, Taiwan (Y.-F.W.); and the Department of Respiratory Medicine and Allergology, Skane University Hospital, Lund University, Lund, Sweden (L.B.); and AstraZeneca, Gaithersburg, MD (V.H.S., M.J., S.O., N.M., P.N., M.G., U.J.M.).

REFERENCES


9. Kerckhof M, Sonnappa S, Postma DS,

Copyright © 2019 Massachusetts Medical Society.