

Comparative efficacy of long-acting β 2-agonists as monotherapy for chronic obstructive pulmonary disease: a network meta-analysis

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Purpose: Long-acting β 2-agonists (LABAs) have demonstrated efficacy in patients with COPD in clinical trials. The purpose of this study was to assess the comparative efficacy of all available dosages of all LABA monotherapies using a network meta-analysis.

Methods: A systematic literature review identified 33 randomized controlled trials of LABA monotherapies (salmeterol 50 μ g twice daily [BID]; formoterol 12 μ g BID; indacaterol 75, 150, and 300 μ g once daily [OD]; olodaterol 5 and 10 μ g OD, and vilanterol 25 μ g OD). Clinical efficacy was evaluated at 12 and 24 weeks in terms of trough forced expiratory volume in 1 second (FEV_1), transition dyspnea index focal score, St George's Respiratory Questionnaire total score, and rate of COPD exacerbations. The relative effectiveness of all LABA monotherapies was estimated by Bayesian network meta-analysis.

Results: At 12 and 24 weeks, indacaterol 300 and 150 μ g OD were associated with statistically significant improvement in trough FEV_1 compared to all other LABA monotherapies; vilanterol 25 μ g OD was superior to formoterol 12 μ g BID. At 12 weeks, indacaterol 75 μ g OD was associated with significant improvement in trough FEV_1 compared to formoterol 12 μ g BID and olodaterol (5 and 10 μ g OD); salmeterol 50 μ g BID was superior to formoterol 12 μ g BID and olodaterol 5 μ g OD. Indacaterol 300 μ g OD was also associated with significant improvement in transition dyspnea index focal score compared to all other LABAs at 12 or 24 weeks. Indacaterol 150 μ g OD had significantly better results in exacerbation rates than olodaterol 5 μ g and olodaterol 10 μ g OD.

Conclusion: Indacaterol 300 μ g, followed by 150 and 75 μ g, were the most effective LABA monotherapies for moderate to severe COPD.

Keywords: COPD, long-acting β 2-agonists, network meta-analysis, systematic literature review, indacaterol

Introduction

COPD is a chronic, progressive disease of the lung characterized by poor airflow, shortness of breath, and cough, and leads to long-term decline in lung function.¹ Approximately 5% of the world population (~329 million people) are affected by COPD,² which is correlated with tobacco use,³ older age,⁴ pollution,^{5,6} and genetics.^{1,7,8} This disease is a major cause of morbidity and mortality, and was responsible for 3 million deaths globally as estimated by the World Health Organization in 2012.^{1,6,9,10} The World Health Organization also estimates that over one-third of premature deaths attributable to COPD in low- and middle-income countries are due to indoor exposure to smoke.¹¹ In addition, COPD patients may experience frequent exacerbations, respiratory infections, and COPD-related hospitalizations that contribute to a substantial

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social and economic burden,¹² accounting for an estimated \$18 billion in direct medical costs in the USA and ~€38.7 billion in the European Union.¹⁰

There is no cure for COPD, but appropriate pharmacologic therapy is critical in reducing the frequency and severity of symptoms. Bronchodilators, which alter airway smooth muscle tone, are central to the management of COPD symptoms. Long-acting β_2 -agonists (LABAs) and long-acting muscarinic antagonists (LAMAs) are two commonly used bronchodilators.¹ LABA monotherapy is contraindicated for patients with asthma, due to an increased risk of the exacerbation of asthma symptoms.¹³

A variety of LABAs with different durations of action, routes of administration, delivery devices, and associated rates of exacerbation, breathlessness, and bronchodilator effects are currently available.^{1,14} Commonly used LABAs include twice-daily (BID) salmeterol 50 μg and formoterol 12 μg , which have a duration of action of 12 hours. Newer agents such as indacaterol 75/150/300 μg ,¹⁵ olodaterol 5/10 μg ,¹⁶ and vilanterol 25 μg ¹⁷ are given once daily (OD) with a duration of action of 24 hours. (Indacaterol 150 and 300 μg , olodaterol 10 μg , and vilanterol 25 μg are not commercially available in the USA.) Given the variety of available LABAs for the treatment of COPD, physicians are faced with the difficulty of choosing the LABA with optimal efficacy. Randomized controlled trials (RCTs) have evaluated the efficacy of long-acting LABA monotherapies against placebo and/or short-acting LABAs. In RCTs, indacaterol was found to have a significantly greater bronchodilator effect than placebo, formoterol 12 μg BID, and salmeterol 50 μg BID.^{15,18,19} In addition, olodaterol (5/10 μg) was superior to placebo and formoterol 12 μg BID,^{16,20} and vilanterol 25 μg OD was superior to placebo.^{17,21,22} In addition, several earlier network meta-analyses (NMAs) have indirectly compared the efficacy among a limited number of LABAs/LAMAs.^{23,24} In 2013, Cope et al compared 40 RCTs in a Bayesian meta-analysis and found that indacaterol (150/300 μg), glycopyrronium 50 μg , and tiotropium 5 μg were superior to other LABAs, with indacaterol dominant in forced expiratory volume in 1 second (FEV_1) and St George's Respiratory Questionnaire (SGRQ) score improvement.²³ In 2014, Roskell et al compared olodaterol 5 μg and indacaterol (75/150 μg) in a meta-analysis of 18 RCTs, and found no significant differences in their primary analysis.²⁴

However, studies evaluating the comparative efficacy of all currently available LABAs, including the newer agents in different doses, have not been conducted. Thus, this study aimed to evaluate the comparative efficacy of all available

LABA monotherapy inhalers trialed in patients with moderate to severe COPD using an NMA. LABAs included in the network were salmeterol 50 μg BID (inhalation powder), formoterol 12 μg BID (inhalation powder), indacaterol 75/150/300 μg OD (inhalation powder), olodaterol 5 and 10 μg OD (inhalation spray), and vilanterol 25 μg OD (inhalation powder). (Indacaterol 150 and 300 μg , olodaterol 10 μg , and vilanterol 25 μg are not commercially available in the USA.) The efficacy of these LABAs was evaluated using the following outcomes: 1) trough FEV_1 at 12 and 24 weeks; 2) transition dyspnea index (TDI) focal score at 12 and 24 weeks; 3) SGRQ total score at 12 and 24 weeks; and 4) rate of exacerbation.

Methods

Study identification and selection

A systematic literature review was conducted to update an earlier systematic review completed in 2013.²³ The updated search was performed in MEDLINE and MEDLINE-In-Process, EMBASE, and Cochrane databases through Ovid for RCTs evaluating the efficacy of LABA monotherapies (indacaterol [indacaterol inhalation powder], salmeterol [salmeterol xinafoate inhalation powder], olodaterol [olodaterol inhalation spray], vilanterol [vilanterol inhalation powder], and formoterol [formoterol inhalation powder]) trialed in patients with moderate to severe COPD. The studies identified from the updated search spanned from January 1, 2013 to March 24, 2015, while the earlier search had extended back to 1989.²³ Full-text terms and common abbreviations, listed in the [Supplementary material](#), were used for the search strategy. Eligible studies from both the earlier and updated systematic literature reviews were included in the current meta-analysis.

All articles identified in the initial database search were screened for relevance based on title, abstract, and full-text articles. RCTs that reported at least one of the outcomes of interest for the targeted interventions among adults with moderate to severe COPD were selected. To be included into the network, trials were further required to include a comparison of at least two of the interventions of interest or one of the above interventions against placebo. The selection criteria for the study population, interventions, comparators, and outcomes are detailed in Table 1. The screening process was independently conducted by and reconciled between two researchers, and in the event of a discrepancy, a third researcher was consulted.

Trials were excluded if they were duplications, conference abstracts only, <12 weeks in duration, or if the patient

Table 1 Study selection criteria for inclusion in the network meta-analysis

Characteristic	Inclusion criteria
Population	Adults with moderate to severe COPD
Interventions	Monotherapies: Indacaterol (75 μ g OD or 150 μ g OD or 300 μ g OD) Olodaterol (5 μ g OD or 10 μ g OD) Vilanterol (25 μ g OD) Salmeterol (50 μ g BID) Formoterol (12 μ g BID)
Comparators	Any of the interventions listed above or placebo
Outcomes	Trough FEV ₁ at 12 and 24 weeks SGRQ total score at 12 and 24 weeks TDI focal score at 12 and 24 weeks Rate of exacerbation (trial duration)
Study design	Randomized controlled clinical study

Abbreviations: BID, twice daily; COPD, Chronic Obstructive Pulmonary Disease; FEV₁, forced expiratory volume in 1 second; OD, once daily; SGRQ, St George's Respiratory Questionnaire; TDI, transition dyspnea index.

population, trial design, intervention, comparator, or outcomes did not meet the inclusion criteria (Table 1).

Outcome measures

Six continuous outcomes and one rate outcome were included in the NMA. Continuous outcomes included trough FEV₁, TDI focal score, and SGRQ total score at 12 and 24 weeks. In the absence of 12- and 24-week data, data within a 2-week range for each time point of interest were allowed (ie, between 10 and 14 weeks for the 12-week time point and between 22 and 26 weeks for the 6-month time point). Differences between the least square mean at follow-up or the change from baseline for the active treatment versus the comparator were used for the network analysis. To be included in the network, outcomes had to be reported for each treatment group in a clear manner to allow reliable estimation of the treatment differences and their associated standard errors.

Rates of exacerbation were compared between the treatment groups at the end of trial follow-up. To be included in the network, this outcome had to be reported as the number of events of exacerbation with the total patient years of follow-up. If such event rates were not available, the rates were then calculated as the number of total events divided by the total patient-years which allowed the rates of exacerbations accumulated over differing periods of follow-up to be compared (assuming the risk of exacerbations remained constant over time). Severity of the exacerbation could not be incorporated into the analysis due to lack of granular severity reporting within the trials.

Network meta-analyses

NMA combines data from several different randomized comparisons of different treatments to deliver an internally consistent set of estimates while respecting the randomization within each trial. This NMA was carried out within a generalized linear model framework with a link function which specified the relationship between the outcome and the model coefficients to be estimated. When an outcome was continuous, such as trough FEV₁, the likelihood was modeled as normal. When the outcome was an event rate, such as the per patient-year event rate of exacerbation, the likelihood was modeled as Poisson.^{25,26} Random effect models were utilized for this analysis. The estimation was performed under a Bayesian context, using noninformative prior distributions for parameters. The model was evaluated using the Deviance Information Criterion, a measure which combines model fit and complexity. This analysis was estimated using a Bayesian Markov Chain Monte Carlo model. All analyses were implemented using the statistical software R (v3.2.2; Ross Ihaka and Robert Gentleman, open source) and OpenBUGS (v3.2.3; OpenBUGS Foundation).

Sensitivity analyses

Because trough FEV₁ was the primary efficacy outcome of the majority of the RCTs, sensitivity analyses were conducted for the FEV₁ 12- and 24-week outcomes to test the robustness of the NMA results. Specifically, because concomitant medications and COPD severity are potential treatment effect modifiers, the sensitivity analyses included: 1) a subset of trials with no concomitant LAMA usage (all trials which permitted concomitant usage were excluded); 2) a meta-regression adjusting for disease severity (adjusting for the percent of patients with severe/very severe COPD); and 3) a meta-regression adjusting for inhaled corticosteroid (ICS) use (adjusting for the percent of patients with ICS use within each trial).

Results

Evidence base

The updated systematic review identified 9^{16,17,20–22,27–30} full-text articles detailing 12 RCTs that met the inclusion criteria (Figure 1). These were pooled with 21 LABA monotherapy RCTs identified in the previous search,^{15,18,19,31–48} resulting in a total of 33 RCTs included in the NMA. A list of included studies and details of the systematic literature search can be found in Figure 1, and the details of each study's own inclusion criteria are listed in [Table S1](#). All studies were double-blind, multicenter RCTs (Figure 2), ranging from 12 weeks

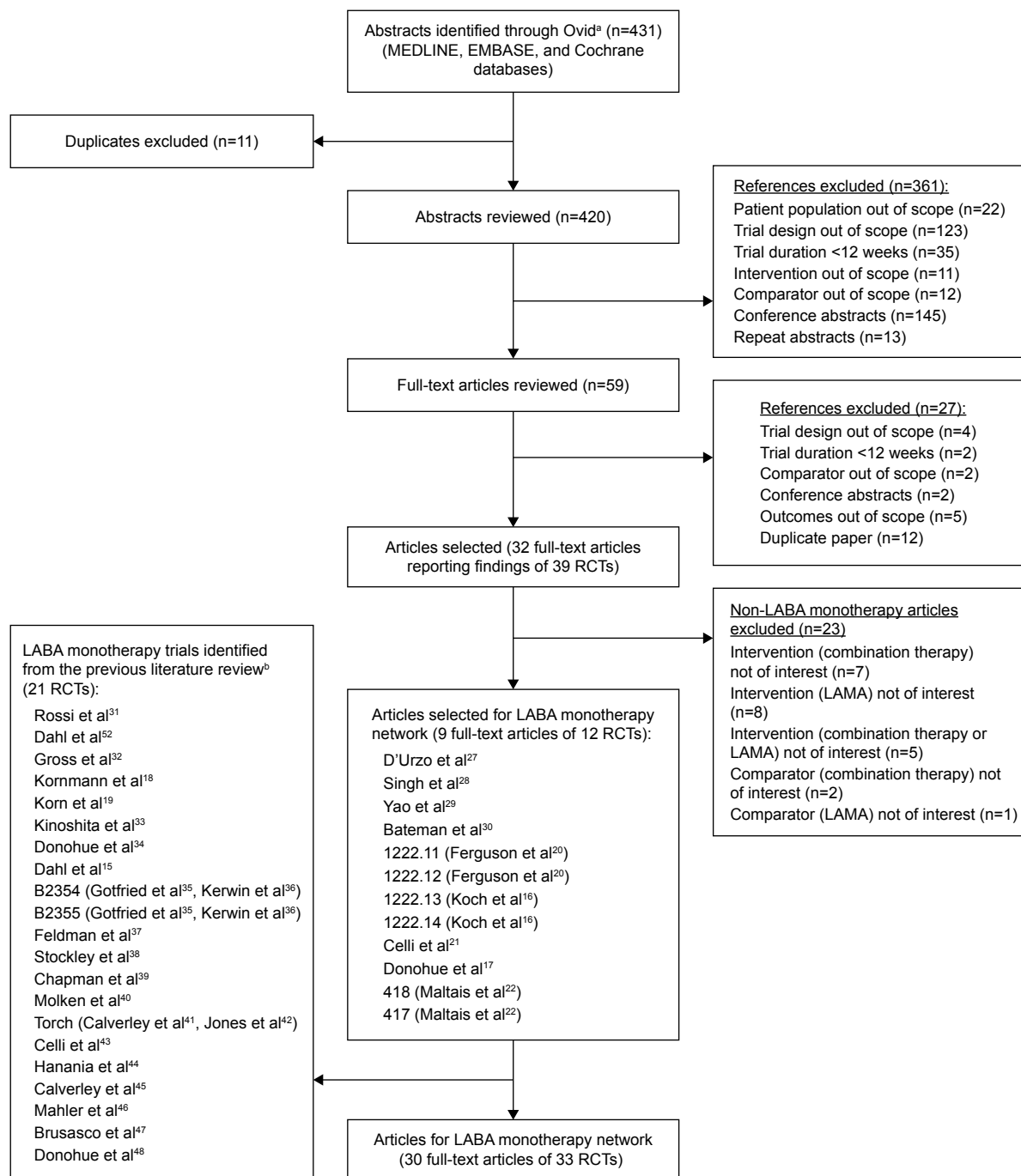


Figure 1 PRISMA diagram showing selection of LABA monotherapy trials.

Notes: ^aSearch was performed for abstracts published between January 1, 2013 and March 24, 2015. ^bPrior search was performed for abstracts published between 1989 and January 1, 2013.

Abbreviations: LABA, long-acting β_2 -agonist; LAMA, long-acting muscarinic antagonist; RCT, randomized controlled trial.

to 3 years in duration. All studies were placebo controlled, with the exception of one head-to-head study which compared the efficacy of indacaterol 150 μg OD to salmeterol 50 μg BID.¹⁹ The studies were predominantly conducted in multiple countries simultaneously, although four were limited to the USA^{32,35,36,44} and one was limited to the Netherlands.⁴⁰ The majority of the studies were conducted in patients over

the age of 40 with a smoking history of ≥ 10 pack-years and predicted FEV₁ of $\leq 80\%$. Each trial predominantly enrolled male patients, and the mean age was >60 years in all trials. The percentage of ICS use, current smokers, and patients with severe or very severe COPD varied among studies. Patient characteristics of the selected trials are further detailed in [Table S2](#).

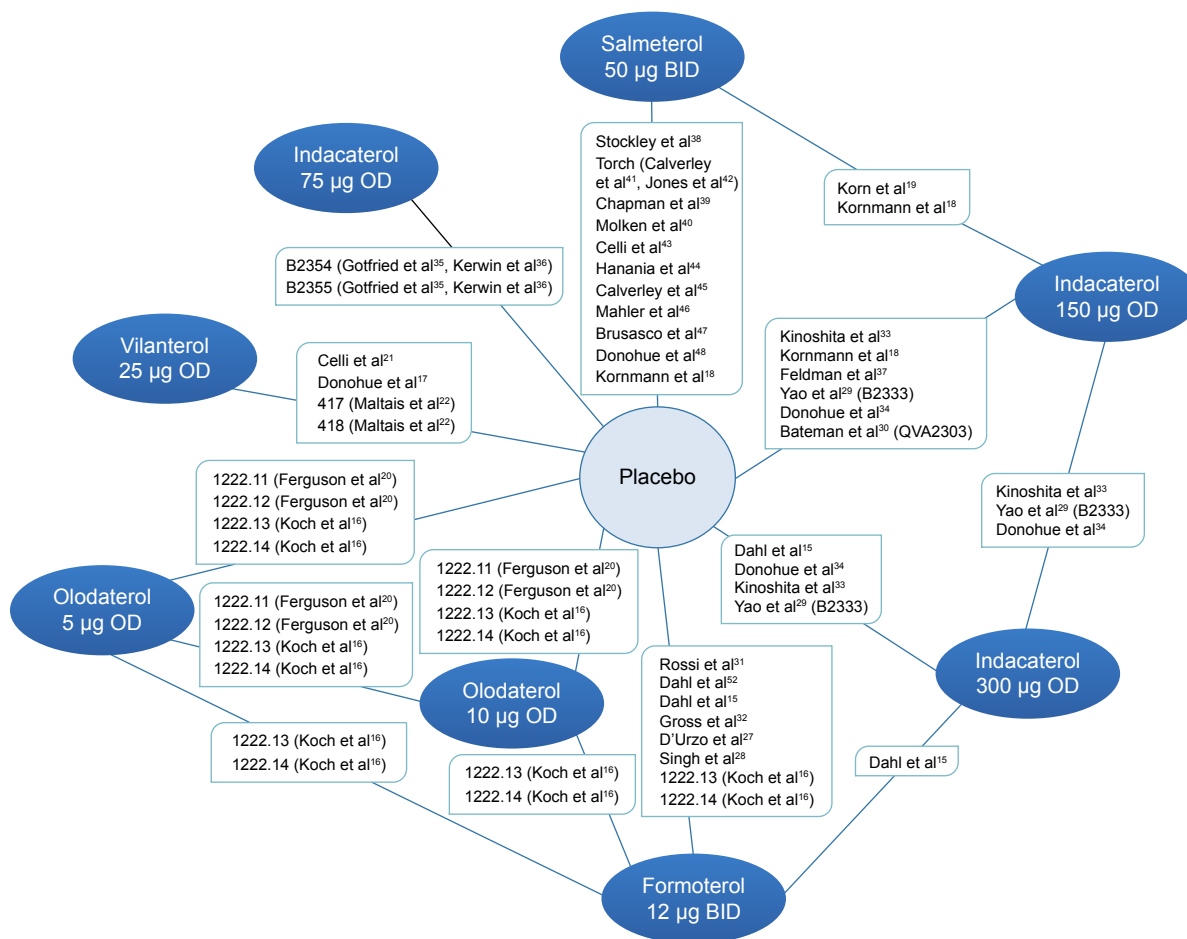


Figure 2 Network diagram of LABA monotherapy trials included in network meta-analysis.

Note: N=33 total randomized controlled trials.

Abbreviations: BID, twice daily; OD, once daily; LABA, long-acting beta agonist.

Network meta-analysis

The 33 RCTs were synthesized in the NMA; a network diagram of the included studies is detailed in Figure 2. The network for each outcome measure consisted of a subset of the presented network based on the availability of different outcomes within the 33 RCTs.

Trough FEV₁ at 12 and 24 weeks

Changes in baseline trough FEV₁ at 12 and 24 weeks were reported in a total of 24 and 19 trials, respectively. All interventions were found to be significantly better than placebo in terms of FEV₁, at both 12 and 24 weeks.

Relative to placebo at 12 weeks, indacaterol 300 µg (difference: 0.167 L, 95% credible interval: [0.151, 0.183]) had the largest difference in change in baseline trough FEV₁, followed by indacaterol 150 µg (0.163 L [0.148, 0.177]), indacaterol 75 µg (0.129 L [0.099, 0.157]), salmeterol 50 µg BID (0.105 L [0.085, 0.125]), vilanterol 25 µg OD (0.098 L [0.076, 0.120]), olodaterol 10 µg OD (0.083 [0.063, 0.103]),

olodaterol 5 µg OD (0.073 [0.053, 0.092]), and formoterol 12 µg BID (0.071 L [0.057, 0.085]; Figure 3A). Indacaterol 300 µg OD and indacaterol 150 µg OD were associated with significantly better trough FEV₁ compared to indacaterol 75 µg OD, salmeterol 50 µg BID, vilanterol 25 µg OD, olodaterol 10 µg OD, olodaterol 5 µg OD, and formoterol 12 µg BID, and were not statistically different from each other. Indacaterol 75 µg was associated with significantly better trough FEV₁ compared to olodaterol 10 µg OD, olodaterol 5 µg OD, and formoterol 12 µg BID. Salmeterol 50 µg BID was associated with significantly better trough FEV₁ compared to olodaterol 5 µg OD and formoterol 12 µg BID. There were no significant differences between indacaterol 75 µg OD, salmeterol 50 µg BID, and vilanterol 25 µg OD.

Relative to placebo at 24 weeks, indacaterol 300 µg (0.162 L [0.143, 0.181]) had the largest difference in change in baseline trough FEV₁, followed by indacaterol 150 µg (0.147 L [0.129, 0.164]), vilanterol 25 µg OD (0.094 L [0.065, 0.124]), salmeterol 50 µg BID (0.082 L [0.066, 0.098]),

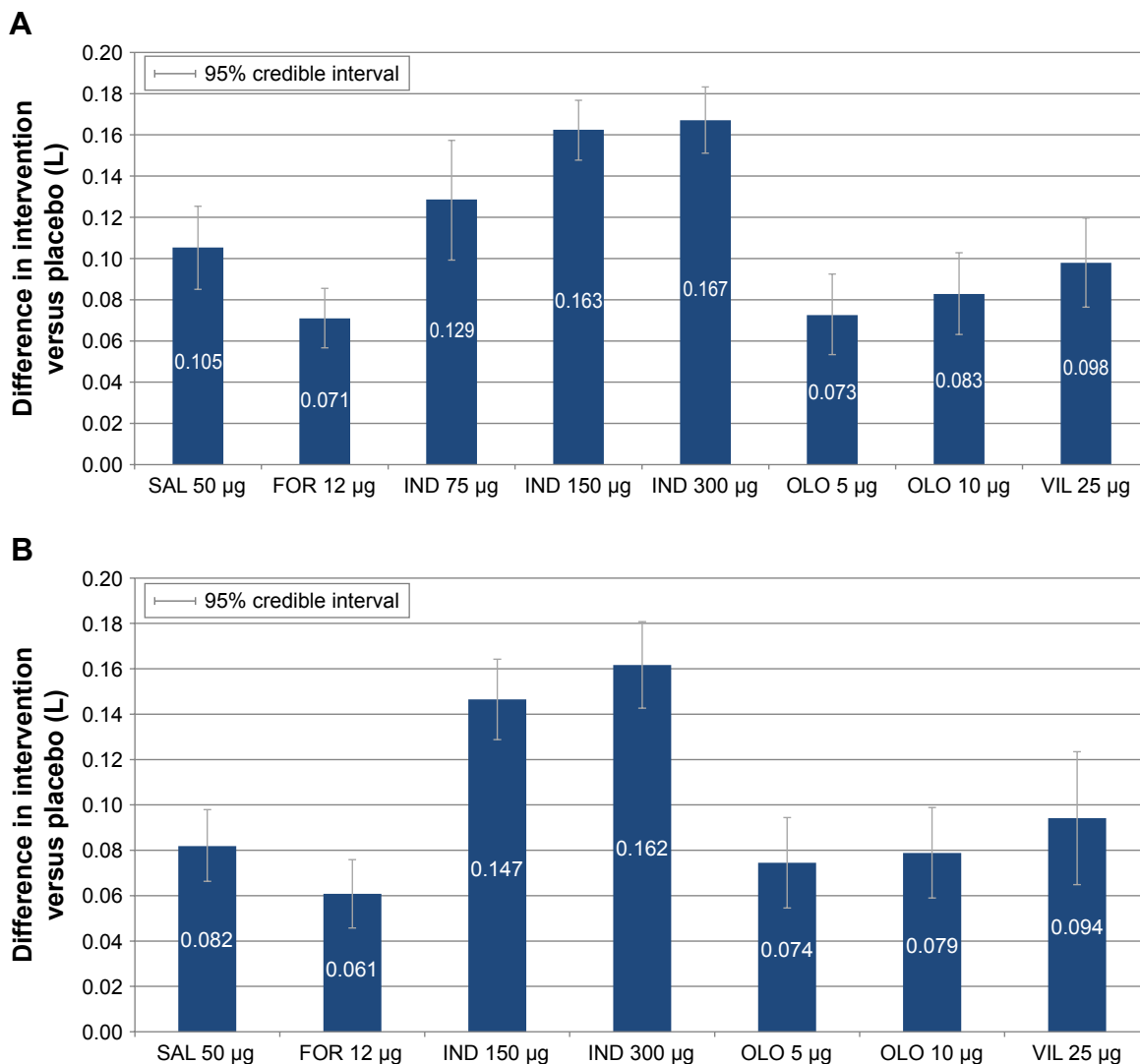


Figure 3 Change from baseline differences in trough FEV₁ (L) for intervention versus placebo at 12 and 24 weeks. **(A)** Trough FEV₁ at 12 weeks and **(B)** trough FEV₁ at 24 weeks.

Abbreviations: FEV₁, forced expiratory volume in 1 second; FOR, formoterol; IND, indacaterol; OLO, olodaterol; SAL, salmeterol; VIL, vilanterol.

olodaterol 10 µg OD (0.079 L [0.059, 0.099]), olodaterol 5 µg OD (0.074 [0.055, 0.094]), and formoterol 12 µg BID (0.061 [0.046, 0.076]; Figure 3B). Indacaterol 75 µg OD was not included in the 24-week analysis. As in the 12-week analysis, indacaterol 300 µg OD and indacaterol 150 µg OD were associated with significantly better trough FEV₁ compared to vilanterol 25 µg OD, salmeterol 50 µg BID, olodaterol 10 µg OD, olodaterol 5 µg OD, and formoterol 12 µg BID, and were not statistically different from each other (Table 2). In addition, vilanterol 25 µg OD had significantly higher mean trough FEV₁ than formoterol 12 µg BID. No other significant differences were observed at 24 weeks.

TDI focal score at 12 and 24 weeks

Changes in baseline mean TDI focal scores at 12 and 24 weeks were reported in 14 and 15 trials, respectively. At 12 and

24 weeks, all interventions were found to be significantly better than placebo. Relative to placebo at 12 weeks, indacaterol 300, 150, and 75 µg OD (1.171 [0.906, 1.401], 1.051 [0.826, 1.291], and 0.831 [0.330, 1.336], respectively) had the highest difference in TDI focal scores at 12 weeks, followed by olodaterol 10 µg OD (0.734 [0.278, 1.166]), vilanterol 25 µg OD (0.665 [0.284, 1.054]), olodaterol 5 µg OD (0.629 [0.187, 1.058]), formoterol 12 µg BID (0.618 [0.281, 0.925]), and salmeterol 50 µg BID (0.555 [0.246, 0.887]; Figure 4A). Indacaterol 300 µg OD and indacaterol 150 µg OD were associated with significantly higher mean TDI focal score compared to salmeterol 50 µg BID and formoterol 12 µg BID. Indacaterol 300 µg OD was also associated with significantly higher mean TDI focal score compared to olodaterol 5 µg OD and vilanterol 25 µg OD (Table 3). No other significant differences were observed at 12 weeks.

Table 2 Results of random effect network meta-analysis for change from baseline in trough FEV₁ (L) at 12 and 24 weeks

Comparators	Interventions					
	12 weeks			24 weeks		
	IND 75 μ g	IND 150 μ g	IND 300 μ g	IND 150 μ g	IND 300 μ g	
	Difference in change from baseline (95% CrI)	Difference in change from baseline (95% CrI)	Difference in change from baseline (95% CrI)	Difference in change from baseline (95% CrI)	Difference in change from baseline (95% CrI)	P-value (better), %
PLBO	0.129 (0.099, 0.157)	0.163 (0.148, 0.177)	0.167 (0.151, 0.183)	0.147 (0.129, 0.164)	0.162 (0.143, 0.181)	> 99
SAL 50 μ g	0.023 (-0.013, 0.059)	0.057 (0.039, 0.075)	0.062 (0.039, 0.085)	0.065 (0.043, 0.087)	0.080 (0.056, 0.104)	> 99
FOR 12 μ g	0.058 (0.024, 0.090)	0.092 (0.072, 0.110)	0.096 (0.077, 0.115)	0.086 (0.063, 0.108)	0.101 (0.079, 0.122)	> 99
IND 75 μ g	N/A	0.034 (0.002, 0.067)	0.038 (0.006, 0.072)	N/A	N/A	N/A
IND 150 μ g	-0.034 (-0.067, -0.002)	N/A	0.005 (-0.011, 0.021)	N/A	0.015 (-0.004, 0.034)	94
IND 300 μ g	-0.038 (-0.072, -0.006)	-0.005 (-0.021, 0.011)	N/A	-0.015 (-0.034, 0.004)	N/A	N/A
OLO 5 μ g	0.056 (0.019, 0.092)	0.090 (0.065, 0.113)	0.094 (0.070, 0.119)	0.072 (0.046, 0.099)	0.087 (0.060, 0.114)	> 99
OLO 10 μ g	0.046 (0.011, 0.080)	0.080 (0.055, 0.103)	0.084 (0.060, 0.109)	0.068 (0.042, 0.094)	0.083 (0.056, 0.110)	> 99
VIL 25 μ g	0.031 (-0.006, 0.066)	0.065 (0.039, 0.090)	0.069 (0.042, 0.095)	0.052 (0.018, 0.087)	0.068 (0.033, 0.103)	> 99

Note: *P (better) denotes the probability that the intervention dose (column) is more effective than the comparator dose (row).

Abbreviations: 95% CrI, 95% credible interval; FEV₁, forced expiratory volume in 1 second; FOR, formoterol; IND, indacaterol; N/A, not applicable; OLO, olodaterol; PLBO, placebo; SAL, salmeterol; VIL, vilanterol.

Relative to placebo at 24 weeks, indacaterol 300 μ g OD (1.184 [0.942, 1.433]) had the highest difference in TDI focal scores at 24 weeks, followed by indacaterol 150 μ g OD (0.894 [0.653, 1.139]), salmeterol 50 μ g BID (0.696 [0.423, 0.965]), vilanterol 25 μ g OD (0.693 [0.297, 1.093]), formoterol 12 μ g BID (0.594 [0.359, 0.838]), olodaterol 5 μ g OD (0.556 [0.143, 0.975]), and olodaterol 10 μ g OD (0.501 [0.097, 0.920]; Figure 4B). Indacaterol 75 μ g OD was not included in the 24-week analysis. Indacaterol 300 μ g OD was associated with a significantly higher mean TDI focal score compared to all other LABAs (including indacaterol 150 μ g OD; Table 3). No other significant differences were observed at 24 weeks.

SGRQ total score at 12 and 24 weeks

Changes from baseline in SGRQ total score at weeks 12 and 24 were reported in a total of 14 and 16 trials, respectively. At 12 and 24 weeks, all interventions were found to be significantly better than placebo. No significant differences were noted at 12 or 24 weeks between the different LABAs, except that indacaterol 150 μ g was significantly better than salmeterol 50 μ g BID (-1.776 [-3.430, -0.023]) at week 24 (Table 4).

Relative to placebo, the numerically best SGRQ scores at 12 weeks belonged to (in order) olodaterol 10 μ g OD (-4.144 [-6.089, -2.161]), indacaterol 150 μ g (-4.022 [-5.096, -2.962]), indacaterol 300 μ g (-4.922, -2.501), and indacaterol 75 μ g OD (-3.691 [-5.825, -1.509]), followed by formoterol 12 μ g BID (-3.150 [-4.464, -1.890]), olodaterol 5 μ g OD (-3.047 [-5.014, -1.107]), and salmeterol 50 μ g BID (-2.710 [-4.463, -0.935]). For 24 weeks, the best scores belonged to olodaterol 10 μ g OD (-3.589 [-5.704, -1.429]), indacaterol 150 μ g OD (-3.155 [-4.504, -1.752]), and vilanterol 25 μ g OD (-2.906 [-5.042, -0.769]), followed by indacaterol 300 μ g OD (-2.843 [-4.321, -1.407]), formoterol 12 μ g BID (-1.401 [-2.694, -0.113]), and salmeterol 50 μ g BID (-1.379 [-2.559, -0.286]; Figure 5). Vilanterol 25 μ g OD was not included in the 12-week analysis, and indacaterol 75 μ g OD was not included in the 24-week analysis.

Exacerbation rate

A total of 14 trials that reported the exacerbation rate were included in the evidence network including salmeterol 50 μ g BID, formoterol 12 μ g BID, indacaterol 150 μ g OD, indacaterol 300 μ g OD, olodaterol 5 μ g OD, olodaterol 10 μ g OD, and placebo. The exacerbation rates were significantly lower for salmeterol 50 μ g BID, indacaterol 150 μ g OD, and indacaterol 300 μ g OD, compared with placebo. In addition, indacaterol 150 μ g OD was significantly better than olodaterol

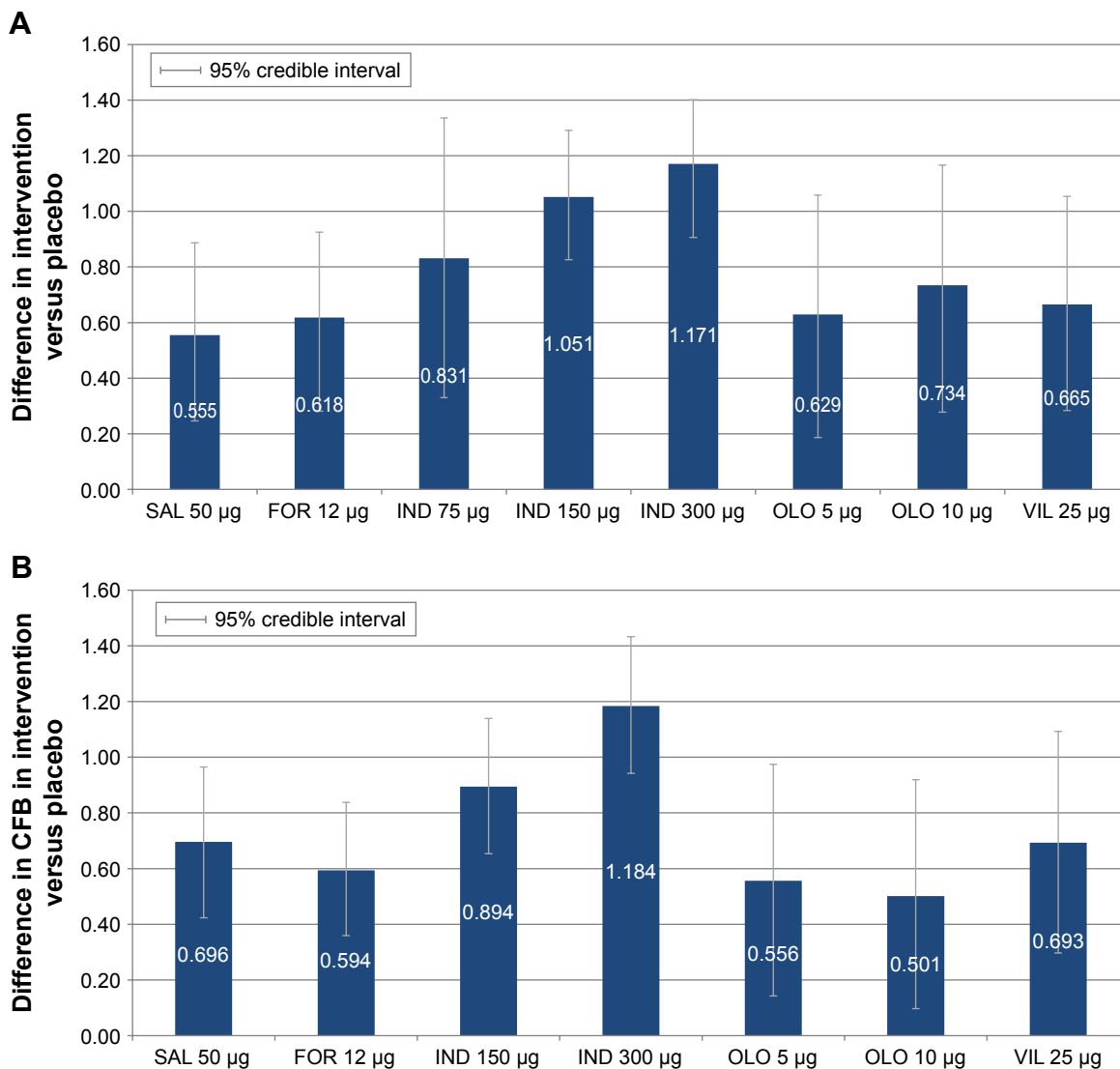


Figure 4 Difference in change from baseline TDI focal score of intervention versus placebo at 12 and 24 weeks. **(A)** TDI focal score at 12 weeks and **(B)** TDI focal score at 24 weeks.

Abbreviations: FOR, formoterol; IND, indacaterol; OLO, olodaterol; SAL, salmeterol; TDI, transition dyspnea index; VIL, vilanterol; CFB, change from baseline.

5 µg OD (0.773 [0.590, 0.991]) and olodaterol 10 µg OD (0.737 [0.565, 0.939]; Table 5 and Figure 6).

Sensitivity analysis for trough FEV₁

A summary of the NMA results for trough FEV₁ after adjusting for female percentage, disease severity, ICS use, and the subgroup with no concomitant LAMA use at 12 and 24 weeks is presented in Figure 7. All the changes were minimal, ranging from -0.005 to 0.004 L for week 12 outcomes and from -0.006 to 0.012 L for week 24 outcomes, illustrating that the NMA results were robust.

Discussion

This study is the first NMA to analyze the comparative efficacy of all currently available LABAs, including the

newer agents for the treatment of moderate to severe COPD. Thus, this study provides the most up-to-date understanding of the treatment landscape for COPD in terms of LABA monotherapies as well as the most complete comparative analysis of effective treatment options and dosages in terms of efficacy outcomes: FEV₁, TDI focal score, SGRQ, and exacerbation rate. The results indicate that indacaterol was the most effective LABA monotherapy for the treatment of COPD, similar to the findings of earlier studies comparing LABA efficacy.^{23,24}

Specifically, indacaterol 150 µg OD and indacaterol 300 µg OD were associated with significant improvement in 12- and 24-week trough FEV₁ compared to all other LABAs, and indacaterol 75 µg OD was associated with significant improvement in trough FEV₁ at week 12

Table 3 Results of the random effect network meta-analysis for change from baseline in TDI focal score at 12 and 24 weeks

Comparators	Interventions					
	12 weeks			24 weeks		
	IND 75 μg	IND 150 μg	IND 300 μg	IND 150 μg	IND 300 μg	
	Difference in change from baseline (95% CrI)	Difference in change from baseline (95% CrI)	Difference in change from baseline (95% CrI)	Difference in change from baseline (95% CrI)	Difference in change from baseline (95% CrI)	P-value (better), %
PLBO	0.831 (0.330, 1.336)	1.051 (0.826, 1.291)	1.171 (0.906, 1.401)	0.894 (0.653, 1.139)	1.184 (0.942, 1.433)	>99
SAL 50 μg	0.277 (-0.317, 0.862)	0.497 (0.209, 0.773)	0.616 (0.227, 0.939)	0.198 (-0.117, 0.524)	0.488 (0.147, 0.846)	89
FOR 12 μg	0.213 (-0.379, 0.831)	0.433 (0.093, 0.824)	0.552 (0.222, 0.883)	0.300 (-0.012, 0.604)	0.590 (0.318, 0.855)	97
IND 75 μg	N/A	0.220 (-0.331, 0.778)	0.339 (-0.242, 0.889)	N/A	N/A	N/A
IND 150 μg	-0.220 (-0.778, 0.331)	N/A	0.119 (-0.160, 0.326)	N/A	0.290 (0.026, 0.563)	98
IND 300 μg	-0.339 (-0.889, 0.242)	-0.119 (-0.326, 0.160)	N/A	-0.290 (-0.563, -0.026)	N/A	N/A
OLO 5 μg	0.202 (-0.451, 0.871)	0.422 (-0.057, 0.921)	0.541 (0.064, 1.004)	0.338 (-0.147, 0.803)	0.628 (0.174, 1.073)	92
OLO 10 μg	0.097 (-0.558, 0.778)	0.317 (-0.151, 0.831)	0.436 (-0.030, 0.916)	0.393 (-0.065, 0.848)	0.683 (0.237, 1.124)	95
VIL 25 μg	0.166 (-0.450, 0.804)	0.386 (-0.051, 0.840)	0.505 (0.043, 0.941)	0.201 (-0.260, 0.668)	0.491 (0.027, 0.964)	81

Note: *P (better) denotes the probability that the intervention dose (column) is more effective than the comparator dose (row).

Abbreviations: 95% CrI, 95% credible interval; FOR, formoterol; IND, indacaterol; N/A, not applicable; OLO, olodaterol; PLBO, placebo; SAL, salmeterol; TDI, transition dyspnea index; VIL, vilanterol.

Table 4 Results of the random effect network meta-analysis for change from baseline in SGRQ total score at 12 and 24 weeks

Comparators	Interventions					
	12 weeks			24 weeks		
	IND 75 μg	IND 150 μg	IND 300 μg	IND 150 μg	IND 300 μg	
	Difference in change from baseline (95% CrI)	Difference in change from baseline (95% CrI)	Difference in change from baseline (95% CrI)	Difference in change from baseline (95% CrI)	Difference in change from baseline (95% CrI)	P-value (better), %
PLBO	-3.691 (-5.825, -1.509)	-4.022 (-5.096, -2.962)	-3.704 (-4.922, -2.501)	-3.155 (-4.504, -1.752)	-2.843 (-4.321, -1.407)	>99
SAL 50 μg	-0.981 (-3.800, 1.763)	-1.312 (-3.166, 0.558)	-0.994 (-3.119, 1.060)	-1.776 (-3.430, -0.023)	-1.464 (-3.260, 0.410)	94
FOR 12 μg	-0.542 (-3.002, 1.963)	-0.872 (-2.442, 0.758)	-0.555 (-2.090, 0.976)	-1.754 (-3.575, 0.086)	-1.443 (-3.237, 0.259)	96
IND 75 μg	N/A	-0.331 (-2.695, 2.050)	-0.013 (-2.472, 2.435)	N/A	N/A	N/A
IND 150 μg	0.331 (-2.050, 2.695)	N/A	0.318 (-1.060, 1.640)	N/A	0.312 (-1.424, 1.937)	34
IND 300 μg	0.013 (-2.435, 2.472)	-0.318 (-1.640, 1.060)	N/A	-0.312 (-1.937, 1.424)	N/A	N/A
OLO 5 μg	-0.644 (-3.522, 2.359)	-0.975 (-3.165, 1.224)	-0.657 (-2.827, 1.553)	-0.230 (-2.744, 2.285)	0.081 (-2.429, 2.541)	47
OLO 10 μg	0.453 (-2.499, 3.335)	0.122 (-2.054, 2.317)	0.440 (-1.771, 2.617)	0.434 (-2.078, 3.000)	0.746 (-1.825, 3.219)	26
VIL 25 μg	N/A	N/A	N/A	-0.249 (-2.742, 2.327)	0.062 (-2.499, 2.684)	48

Note: *P (better) denotes the probability that the intervention dose (column) is more effective than the comparator dose (row).

Abbreviations: 95% CrI, 95% credible interval; FOR, formoterol; IND, indacaterol; N/A, not applicable; OLO, olodaterol; PLBO, placebo; SAL, salmeterol; SGRQ, St. George's Respiratory Questionnaire; VIL, vilanterol.

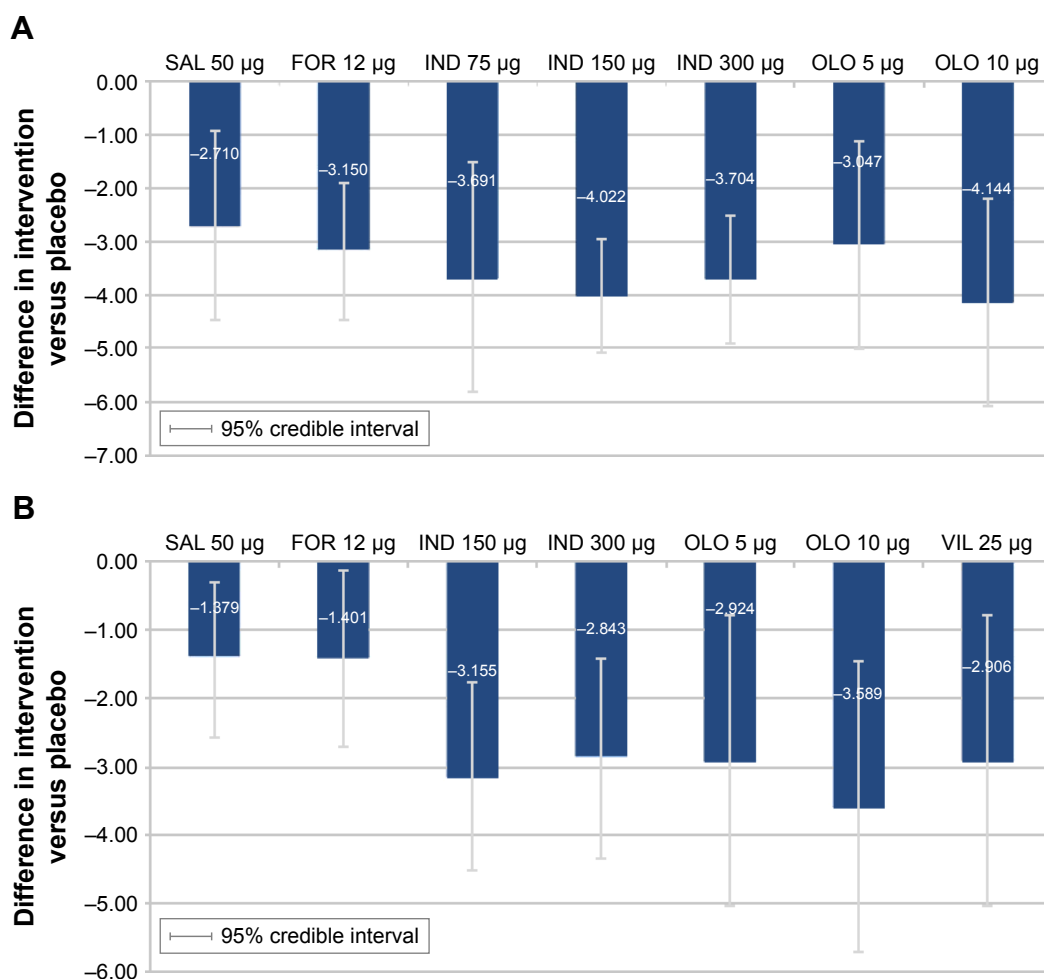


Figure 5 Change from baseline difference in SGRQ total score for intervention versus placebo at 12 and 24 weeks. **(A)** SGRQ total score at 12 weeks and **(B)** SGRQ total score at 24 weeks.

Abbreviations: FOR, formoterol; IND, indacaterol; OLO, olodaterol; PLBO, placebo; SAL, salmeterol; SGRQ, St George's Respiratory Questionnaire; VIL, vilanterol.

compared to formoterol and olodaterol (both 5 and 10 µg doses). In addition, indacaterol, 300 µg in particular, showed statistical superiority over other LABAs in TDI score, and indacaterol 150 µg showed statistical superiority over olodaterol 5 µg and olodaterol 10 µg OD in exacerbation rates. Olodaterol 10 µg OD showed numerical superiority in SGRQ

scores at 12 and 24 weeks, although the results were not statistically different from the other LABAs.

The outcomes compared in this meta-analysis each have valid thresholds for clinically relevant differences versus placebo. For example, for FEV₁, a widely accepted threshold, is a change of 100 mL from baseline; for TDI focal

Table 5 Results of random effect network meta-analysis for exacerbation rate

Comparators	Interventions			
	IND 150 µg		IND 300 µg	
	Rate ratio (95% CrI)	P-value (better) % ^a	Rate ratio (95% CrI)	P-value (better) % ^a
PLBO	0.729 (0.607, 0.866)	>99	0.817 (0.692, 0.959)	>99
SAL 50 µg	0.895 (0.737, 1.089)	88	1.004 (0.834, 1.220)	52
FOR 12 µg	0.845 (0.657, 1.072)	93	0.945 (0.760, 1.159)	73
IND 150 µg	N/A	N/A	1.128 (0.909, 1.378)	13
IND 300 µg	0.897 (0.726, 1.100)	87	N/A	N/A
OLO 5 µg	0.773 (0.590, 0.991)	98	0.865 (0.674, 1.094)	89
OLO 10 µg	0.737 (0.565, 0.939)	>99	0.826 (0.645, 1.035)	96

Note: ^aP (better) denotes the probability that the intervention dose (column) is more effective than the comparator dose (row).

Abbreviations: 95% CrI, 95% credible interval; FOR, formoterol; IND, indacaterol; N/A, not applicable; OLO, olodaterol; PLBO, placebo; SAL, salmeterol.

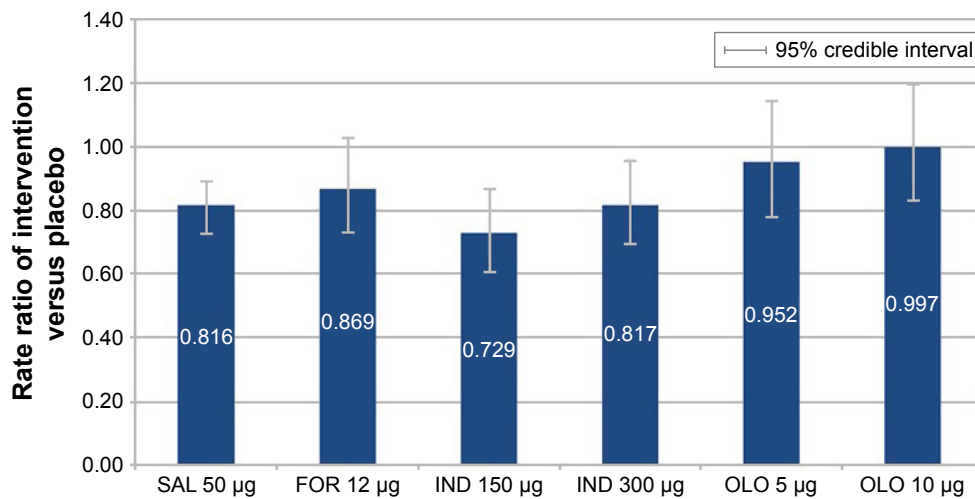


Figure 6 Exacerbation rate (rate ratio) of intervention versus placebo.

Abbreviations: FOR, formoterol; IND, indacaterol; OLO, olodaterol; SAL, salmeterol.

score, a ≥ 1 unit score reduction; for SGRQ total score, a reduction of 4 units; and for exacerbation rate, an annual rate reduction of 20%.⁴⁹ These outcomes were used for the determination of efficacy against placebo in respective clinical trials; however, the validity of using these thresholds for post hoc active-arm comparisons has not been empirically evaluated. Thus, NMAs such as the current analysis are useful for comparing active treatments by testing for statistically significant differences between treatment outcomes after showing clinically meaningful efficacy against placebo. Future prospective studies evaluating the thresholds for clinically meaningful differences between active treatments in COPD therapy trials are needed.

The results of this study add to and update the pre-existing literature on the comparative efficacy of LABAs in the treatment of COPD, while coming to similar conclusions as previous studies about the efficacy of indacaterol. For example, a 2013 NMA on the comparative efficacy of long-acting bronchodilators for COPD found that indacaterol was associated with higher trough FEV₁ and superior improvement in SGRQ score over comparative LABAs.²³ In addition, a 2012 comparative effectiveness study evaluated indacaterol for COPD versus placebo, formoterol, and salmeterol in RCTs using the outcomes trough FEV₁, SGRQ, and TDI total scores. It found that indacaterol was as good as or superior to these bronchodilators in all the outcomes measured, and that indacaterol 300 µg resulted in the best overall efficacy.⁵⁰ A 2014 systematic review compared efficacy outcomes (FEV₁, SGRQ and TDI scores, exacerbations, and use of rescue medication at 12 weeks) for olodaterol and indacaterol and determined that these drugs had similar efficacy.²⁴ However, a comment published later in 2014 noted that the study

suffered from several limitations including a restricted search date resulting in exclusion of relevant clinical trials, study design heterogeneity, and reliance on data from other NMAs rather than primary data within RCTs.⁵¹

In the current analysis, only trials of the inhalation powder form of formoterol were included, in order to maintain consistency with the delivery device of the other comparators. However, nebulized formoterol may be beneficial for patients who are unable to use inhalation powder for reasons including frailty, arthritis, visual impairment, compromised mental capacity, exacerbation, difficulty using an inhaler, or inadequate hand/breath coordination.

Important differences may exist between real-world practice and clinical trial populations, such as training for the use of inhalers, adherence to treatment, and routine medical care, all of which may limit the applicability of the current results. Some limitations inherent to NMAs apply to the results of this study. For example, although the trials included in the NMA were of good caliber, the validity of the current findings depends on the quality, biases, and study and patient characteristic reporting consistency of the included RCTs. Some variation existed in their inclusion criteria regarding the concomitant use of LABA and ICSs, smoking history, age, the severity of COPD, and exacerbation history. Though sensitivity analyses have been conducted for our main outcome FEV₁, meta-regression analyses of study-level data can be prone to ecological bias (ie, the association between the study-level effect patient characteristics and treatment effects may not reflect the individual-level effect modification of a covariate). Thus, there is a risk of residual confounding bias. Since there was only a single head-to-head trial, the ability to check the consistency of the direct and

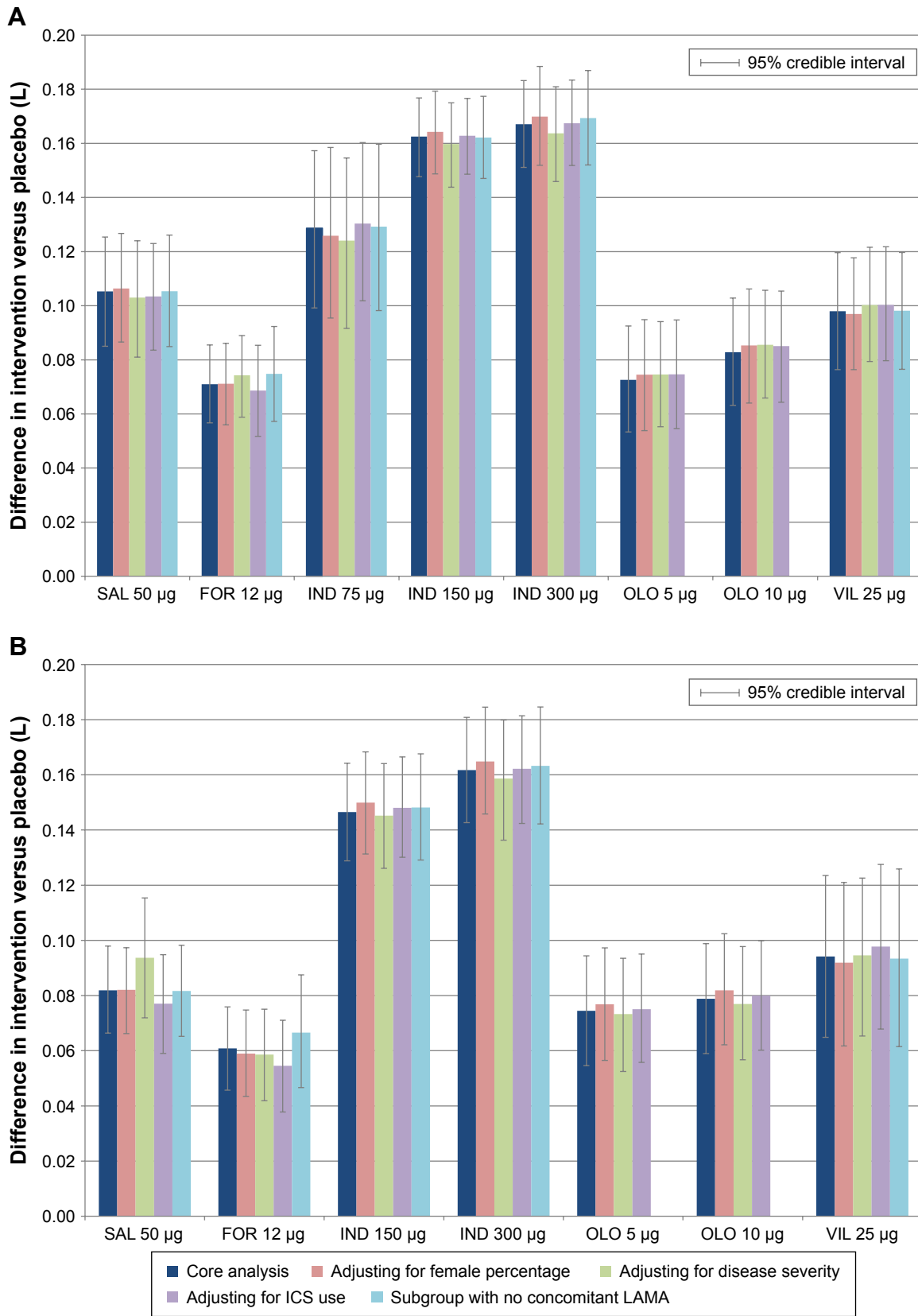


Figure 7 Sensitivity analysis for change from baseline in trough FEV₁ (L). **(A)** Trough FEV₁ at 12 weeks and **(B)** trough FEV₁ at 24 weeks.

Abbreviations: FEV₁, forced expiratory volume in 1 second; FOR, formoterol; ICS, inhaled corticosteroid; IND, indacaterol; LAMA, long-acting muscarinic antagonist; OLO, olodaterol; SAL, salmeterol; VIL, vilanterol.

indirect evidence was limited. However, in this head-to-head trial, indacaterol 150 μg was associated with a 0.06 L higher FEV_1 compared to salmeterol 50 μg ,¹⁹ which is consistent with the 0.057 L estimated in this analysis. In addition, other outcomes, which are important in the measurement of COPD treatment efficacy and safety and played an essential role in treatment decisions, such as the use of rescue treatments and the severity of exacerbations, were not assessed in this study. Future studies are warranted to further evaluate these outcomes among different treatment options for COPD patients. Lastly, exacerbations were expected to be defined differently among the included studies, and the NMA results might be subject to those inconsistencies, if any. Because the number of studies that contained that study outcome (exacerbations) was small, no subgroup analysis was conducted in this study. Future research may be needed to conduct subgroup analysis among studies with consistent criteria and definitions, when there are sufficient studies.

Conclusion

In conclusion, indacaterol 300 μg OD, followed by 150 μg OD, and 75 μg OD, were the most effective LABA monotherapies for COPD in terms of trough FEV_1 and TDI focal scores.

Acknowledgments

Medical writing assistance was provided by Shelley Batts, PhD, an employee of Analysis Group, Inc., with financial support from Novartis. We would like to thank Jenny Guo of Analysis Group for helping with part of the data analysis and Noelle Thew of Analysis Group for helping audit the manuscript. Funding for this research was provided by Novartis.

Author contributions

All authors had full access to all of the data in the study and take responsibility for the integrity of the data and accuracy of the data analysis. All authors contributed substantially to the study design, data analysis and interpretation, and the writing of the manuscript. The study sponsor was involved in all stages of the study research and manuscript preparation, but all authors participated in the design of the study and contributed to the manuscript development. Data were collected by Analysis Group and analyzed and interpreted in collaboration with all other authors. All the authors vouch for the accuracy and completeness of the data reported and the adherence of the study to the protocol, and all the authors made the decision to submit the manuscript for publication.

Disclosure

J-BG, PG, PA, and DLK are employees of Novartis and own stock/stock options. KAB, EXD, and JES are employees of Analysis Group Inc., which has received consultancy fees from Novartis. JFD is a member of the Data Safety Monitoring Board for Novartis, AstraZeneca, Gilead, CSA Medical, and Insmmed, and is a consultant to AstraZeneca, Sunovion, and GlaxoSmithKline. The authors report no other conflicts of interest in this work.

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