

Overweight, Obesity, and Lung Function in Children and Adults—A Meta-analysis



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What is known about the topic? Overweight and obesity are associated with changes in lung function in children, adolescents, and adults. However, there is some conflicting evidence on whether these changes differ by age group, sex, or asthma status.

What does this article add to our knowledge? We provide comprehensive pooled estimates of the effect of obesity on lung function, stratified by age group (pediatrics vs adults) and asthma status. Moreover, we use meta-regression to evaluate the role of age and gender in these associations.

How does this study impact current management guidelines? Detrimental changes in lung function constitute yet another complication of obesity. These changes differ by age, sex, and asthma status; clinicians should take these characteristics into account when evaluating obesity and lung function.

BACKGROUND: There is conflicting evidence on the effect of obesity on lung function in adults and children with and without asthma. We aimed to evaluate the relation between overweight or obesity and lung function, and whether such relationship varies by age, sex, or asthma status.

METHODS: We searched PubMed, Scopus, CINAHL, Cochrane, and EMBASE for all studies (in English) reporting on obesity status (by body mass index) and lung function, from 2005 to 2017. Main outcomes were forced expiratory volume in 1 second (FEV₁), forced vital capacity (FVC), FEV₁/FVC, forced expiratory flow between 25th and 75th percentile of the forced vital capacity (FEF₂₅₋₇₅), total lung capacity (TLC), residual volume (RV), and functional residual capacity (FRC). Random-effects models were used to calculate the pooled risk estimates; each study was weighted by the inverse effect size variance. For each outcome, we compared overweight or obese (“obese”) subjects with those of normal weight.

RESULTS: All measures of lung function were decreased among obese subjects. Obese adults showed a pattern (lower FEV₁, FVC, TLC, and RV) different from obese children (more pronounced FEV₁/FVC deficit with unchanged FEV₁ or FVC). There were also seemingly different patterns by asthma status, in that subjects without asthma had more marked decreases in FEV₁, TLC, RV, and FRC than subjects with asthma. Subjects who were obese (as compared with overweight) had even further decreased FEV₁, FVC, TLC, RV, and FRC.

CONCLUSIONS: Obesity is detrimental to lung function, but specific patterns differ between children and adults. Physicians should be aware of adverse effects of obesity on lung function, and weight control should be considered in the management of airway disease among the obese. © 2017 American Academy of Allergy, Asthma & Immunology (J Allergy Clin Immunol Pract 2018;6:570-81)

Key words: Obesity; Childhood obesity; Lung function; Asthma; Meta-analysis

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The worldwide epidemic of obesity is a major public health problem, particularly in industrialized countries. Obesity is associated with numerous complications, including multiple detrimental effects on the respiratory system.¹ Several plausible mechanisms have been proposed to explain the observed association between obesity and respiratory symptoms, such as decreased total respiratory system compliance, increased airway resistance, reduced lung volumes, and altered ventilation and gas exchange.^{2,3} Overweight and obesity have also been associated with higher incidence of asthma,⁴ asthma morbidity, and resistance to therapy.⁵ Evidence shows that weight gain precedes the development of asthma symptoms⁶ and that obese individuals have later decreases in lung function.⁷ Conversely, weight loss results in improvement of asthma-related health outcomes in adults.^{8,9}

In adults, an inverse association between body mass index (BMI) and lung volumes indicates that obesity leads to a

Abbreviations used

BMI- Body mass index
CI- Confidence interval
FEF₂₅₋₇₅- Forced expiratory flow between 25th and 75th percentile of the forced vital capacity
FEV₁- Forced expiratory volume in 1 second
FRC- Functional residual capacity
FVC- Forced vital capacity
RV- Residual volume
TLC- Total lung capacity
WC- Waist circumference
WHR- Waist-to-hip ratio
WMD- Weighted mean difference

restrictive lung deficit.^{10,11} However, some studies have also reported slightly lower forced expiratory volume in 1 second/forced vital capacity (FEV₁/FVC) in adults with asthma.¹² On the other hand, several studies in children have reported that increased BMI is associated with normal, or even increasing, FEV₁ and FVC but low FEV₁/FVC, consistent with either an obstructive deficit or airway dysanapsis,^{13,14} with some reports showing differences by sex.¹⁵ Yet other studies have shown findings in children that may be suggestive of a restrictive deficit, which may be more similar to findings reported in adults.¹⁶⁻¹⁸ Such inconsistencies may partly be due to differences among study populations and outcome measures. More importantly, they suggest that the association between obesity and lung function may differ between children and adults. In this meta-analysis, we aim to further elucidate the relationship between overweight or obesity and lung function, and whether such relationship differs by age group or by asthma status.

METHODS

We prospectively registered the protocol for this meta-analysis on July 10, 2015, at http://www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42015023193.

Search and selection criteria

We searched PubMed, Scopus, CINAHL, and the Cochrane Database for all studies reporting obesity status and lung function in human subjects, published in English from 2005 (standardization of spirometry¹⁹) to January 2017, using the following keywords: ("Body Mass Index" OR "BMI" OR "percent body fat" OR "body fat distribution" OR "Waist Circumference" OR "Obesity" OR "Overweight" OR "Waist-hip ratio" OR "Adiposity" OR "abdominal obesity") AND [("FEV₁" OR "FVC" OR "FEV₁/FVC" OR "FEF₂₅₋₇₅" OR "PEFR" OR "TLC" OR "RV/TLC" OR "FRC" OR "lung function" OR "spirometry") NOT ("cystic fibrosis" OR "COPD" OR "cancer")].

Inclusion criteria were: (1) observational studies of children or adults with assessments of obesity and lung function; or (2) baseline data from experimental studies focused on obesity and lung function. Exclusion criteria were: (1) studies focused on cystic fibrosis or chronic obstructive pulmonary disease; (2) studies that included diseases or therapies that may affect the lung function of subjects (eg, cancer, radiotherapy); and (3) obesity secondary to specific diseases (eg, hypothyroidism, hypertension) or medical treatments. Our primary outcomes were spirometry measures (FEV₁, FVC, FEV₁/FVC, and forced expiratory flow between 25th and 75th percentile of the forced vital capacity

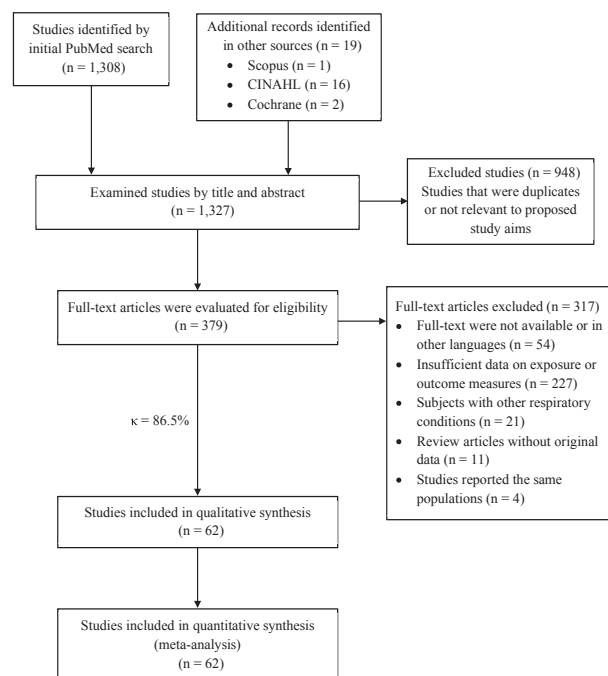


FIGURE 1. Study selection flowchart. κ = kappa agreement coefficient.

[FEF₂₅₋₇₅]). Secondary outcomes were measures of lung volume (total lung capacity [TLC], residual volume [RV], RV/TLC, and functional residual capacity [FRC]). Study subjects were classified as "normal weight (reference group)," "overweight," or "obese" by BMI (z-score in children and kg/m² in adults). Central or abdominal obesity was defined by waist circumference (WC) or waist-to-hip ratio (WHR).

Data abstraction and data analysis

The study was performed following the recommendations for reporting meta-analyses of observational studies by the Meta-analysis of Observational Studies in Epidemiology group²⁰ and the Preferred Reporting Items for Systematic Reviews and Meta-analyses guidelines.²¹ Titles, abstracts, contexts, and citations were independently assessed and analyzed by 2 investigators (Y-YH and JM). Disagreements were resolved through a mediator (EF).

For all outcomes analyzed, we calculated the pooled β coefficients (weighted mean difference [WMD]) and 95% confidence intervals (CI) using random-effects models to address the heterogeneity across the included studies. Each study was weighted by its inverse effect size variance. Some studies were included more than once when they had several comparisons (eg, overweight vs normal weight, and obese vs normal weight) or strata (eg, males and females, children [≤ 18 years] and adults [> 18 years]). Egger's test and funnel plots with pseudo 95% CI were used to examine small-study effects and publication bias. When possible, meta-regression was performed to explore potential sources of heterogeneity and test whether certain characteristics (eg, age-group, sex distribution) modify the effect of obesity on lung function; meta-regression was performed only when ≥ 10 studies reported a specific characteristic. All analyses were performed using STATA v13 (StataCorp, College Station, Tex).

TABLE I. Pooled estimates of overweight or obesity and lung function by age group and asthma

	FEV ₁ (%pred)	FVC (%pred)	FEV ₁ /FVC (%)	FEF ₂₅₋₇₅ (%pred)	TLC (%pred)	RV (%pred)	FRC (%pred)
All	-2.2 (-2.6, -1.8)	-2.2 (-3.7, -0.6)	-1.5 (-1.9, -1.2)	-5.4 (-7.3, -3.5)	-4.2 (-5.4, -3.0)	-6.6 (-9.3, -3.8)	-17.1 (-25.2, -9.0)
By age							
Adult	-2.4 (-2.9, -1.9)	-4.6 (-6.9, -2.2)	-1.0 (-1.4, -0.6)*	-3.3 (-10.1, 3.6)	-4.4 (-5.7, -3.0)	-5.4 (-8.2, -2.7)	-16.9 (-25.4, -8.2)
Child	-0.8 (-2.3, +0.6)	0.3 (-1.7, +2.3)	-2.4 (-3.0, -1.8)*	-4.7 (-6.9, -2.6)	-3.7 (-5.8, -1.5)	-33.0 (-44.2, -21.7)†	-18.5 (-24.4, -12.6)†
By asthma							
Asthma	-1.4 (-1.9, -0.9)	-1.7 (-3.7, +0.3)	-1.5 (-1.9, -1.0)	-3.2 (-6.3, -0.1)	-3.3 (-5.1, -1.5)	-5.3 (-9.4, -1.3)	-3.7 (-15.0, +7.6)
No asthma	-3.9 (-7.1, -0.7)	-2.8 (-7.8, +2.3)	-1.6 (-2.3, -0.8)	-4.4 (-10.0, +1.2)	-4.8 (-7.1, -2.5)	-7.6 (-11.7, -3.5)	-23.2 (-30.3, -16.1)
By age and asthma							
Adult, asthma	-1.7 (-2.3, -1.2)*	-3.2 (-6.0, -0.4)	-1.2 (-1.8, -0.6)	-3.3 (-10.1, +3.6)	-3.3 (-5.2, -1.4)	-4.1 (-8.2, -0.1)	-0.7 (-12.5, +11.0)*
Adult, no asthma	-6.9 (-11.1, -2.8)*	-7.5 (-11.4, -3.7)	-0.9 (-1.9, +0.1)	-	-5.3 (-8.2, -2.4)	-6.5 (-10.2, -2.7)	-23.6 (-31.1, -16.1)*
Child, asthma	0.4 (-1.2, +2.0)	0.4 (-0.6, +1.5)	-1.8 (-2.4, -1.3)	-2.5 (-6.6, +1.5)	-3.6 (-8.0, +0.8)	-	-
Child, no asthma	-0.9 (-5.4, +3.6)	2.8 (-6.8, +12.5)	-2.8 (-3.9, -1.8)	-4.4 (-10.0, +1.2)	-3.7 (-6.2, -1.3)	-	-
By weight group							
Overweight	0.37 (-1.7, +0.9)	-0.3 (-1.8, +1.2)	-1.2 (-1.9, -0.6)	-4.8 (-7.2, -2.4)	-2.0 (-4.1, +0.1)	-5.8 (-12.9, +1.4)	-8.2 (-19.7, +3.4)
Obese	-3.9 (-4.8, -2.9)	-3.2 (-5.2, -1.2)	-1.7 (-2.5, -0.9)	-4.6 (-8.1, -1.2)	-5.4 (-7.0, -3.9)	-7.4 (-11.6, -3.2)	-21.2 (-30.9, -11.5)

FEF₂₅₋₇₅, forced expiratory flow between 25th and 75th percentile of the forced vital capacity; FEV₁, forced expiratory volume in 1 s; FRC, functional residual capacity; FVC, forced vital capacity; RV, residual volume; TLC, total lung capacity.Shown are weighted mean differences (WMDs) for overweight/obese vs normal weight. Bold indicates statistical significance ($P < .05$).

*WMDs are significantly different between the groups (eg, WMD for adult vs child, or asthma vs no asthma).

†Only one study and thus only that study's effect size reported (not a pooled estimate).

RESULTS

A total of 1,327 articles were initially identified (Figure 1). After removal of duplicates and nonrelevant studies, 379 studies were evaluated. On the basis of full-text screening, the authors agreed on 328 of 379 articles (inter-reader $\kappa = 86.5\%$). After arbitration, and based on inclusion and exclusion criteria, a total of 62 studies were included for meta-analysis. Because very few studies reported WC or WHR, only studies using BMI to define overweight/obesity were included.

Forced expiratory volume in 1 second

When analyzing all selected studies (44 studies, $n = 23,460$ subjects),^{12,15-18,22-60} overweight/obese subjects had 2.2% lower percent-predicted FEV₁ (WMD -2.2, 95% CI = -2.6 to -1.8) than subjects of normal weight (Table I). The decrement was significant in adults (WMD -2.4%, 95% CI = -2.9 to -1.9) but not in children (-0.8%, 95% CI = -2.3 to 0.6; Figure 2), and more pronounced among overweight/obese subjects without asthma (-3.9%, 95% CI = -7.1 to -0.7) than in those with asthma (-1.4%, CI = -1.9, -0.9) (Figure E1, available in this article's Online Repository at www.jaci-inpractice.org). Similar results were found when analyzing adults only by asthma status: overweight/obese adults with asthma had 1.7% (95% CI = -2.3 to -1.2) lower FEV₁, whereas those without asthma had 6.9% (95% CI = -11.1 to -2.8) lower FEV₁ (Table I). These results were driven mainly by obesity (-2.5%, 95% CI = -3.4 to -1.5%, in subjects with asthma and -5.3%, 95% CI = -8.8 to -1.8, in those without) rather than by overweight (nonsignificant; data not shown).

When analyzing studies that reported FEV₁ as an absolute value (liters),⁶¹⁻⁶⁹ overweight/obese children had 410 mL (95% CI = 280 to 540 mL) higher FEV₁, whereas overweight/obese adults had 150 mL (95% CI = -260 to -40 mL) lower FEV₁ (Figure E2, available in this article's Online Repository at www.jaci-inpractice.org).

Forced vital capacity

In 30 studies included ($n = 16,913$), percent-predicted FVC decreased by 2.2% (95% CI = -3.7% to -0.6%) among overweight/obese subjects compared with those of normal weight.^{15-18,23-29,32-34,36,37,39,40,45,46,48,50,52-59} The decrement was significant in adults (-4.6% [95% CI = -6.9% to -2.2%]) but not in children (Figure 3), and more pronounced among obese subjects (-3.2% [95% CI = -5.2% to -1.2%]) than in overweight subjects (Figure E3, available in this article's Online Repository at www.jaci-inpractice.org). When stratifying by asthma status, FVC decreased further in adults without asthma (-7.5% [95% CI = -11.4% to -3.7%]) than in those with asthma (-3.2% [95% CI = -6.0% to -0.4%]). Among studies that reported FVC as absolute value (liters),^{51,61-70} overweight/obese children had an increased FVC (250 mL [95% CI = 190 to 300 mL]), whereas overweight/obese adults had a decreased FVC (-140 mL [95% CI = -250 to -40 mL], data not shown).

Forced expiratory volume in 1 second/forced vital capacity

For all 34 studies combined ($n = 28,494$), FEV₁/FVC was 1.5% (95% CI = -1.9% to -1.2%) lower among overweight/obese subjects^{12,15-18,23-29,31,34,35,38,40,45,47,48,50,53,55,57,59,61-63,66-71} (Table I). The decrement was more pronounced in children (-2.4%, [95% CI = -3.0% to -1.8%]) than in adults (-1.0% [95% CI = -1.4% to -0.6%]) (Figure 4), and it

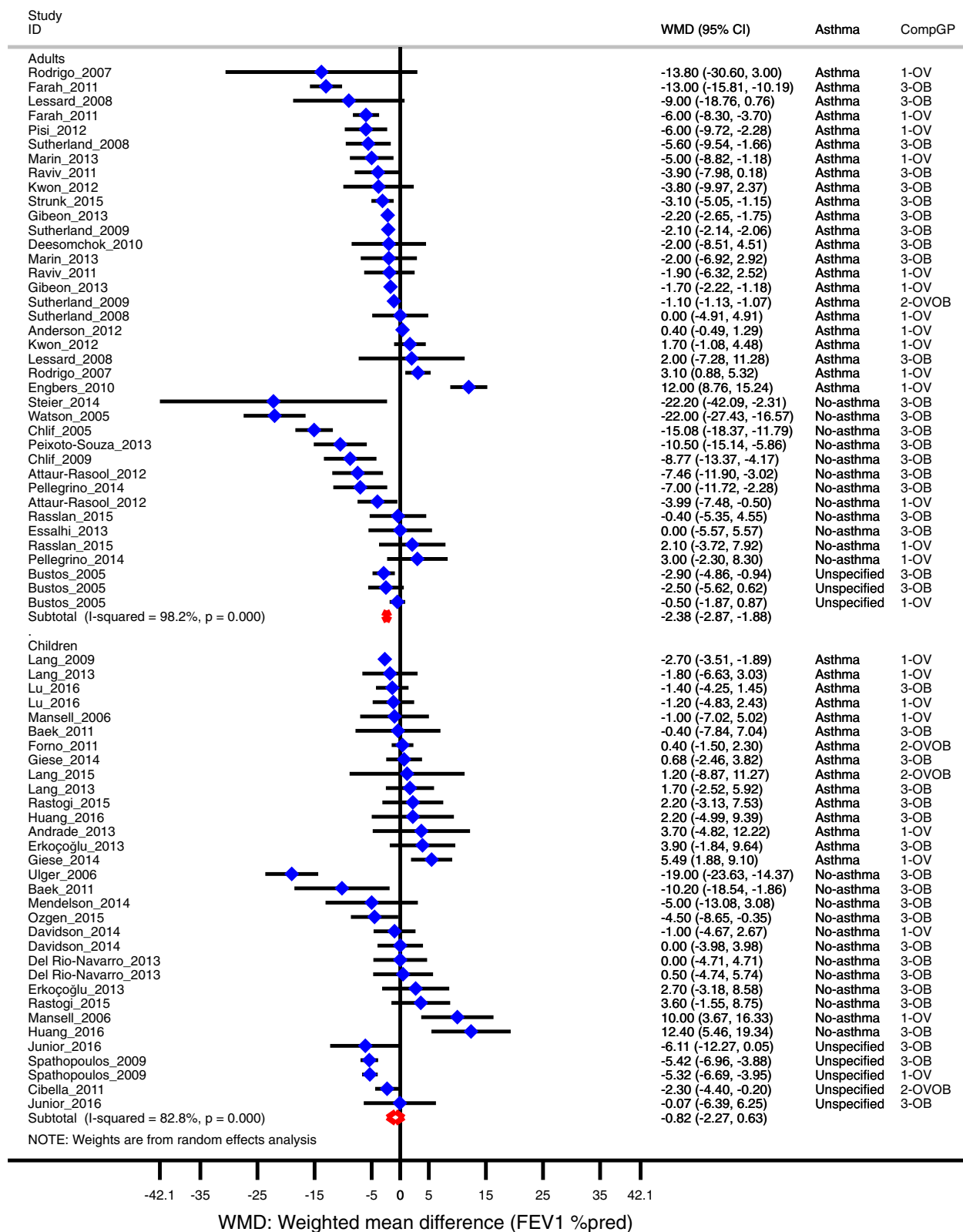


FIGURE 2. Obesity and FEV₁ (as percent of predicted) by age group. Forest plot for FEV₁ %pred, showing weighted mean difference (WMD) by study, for each comparison group (CompGP) versus normal-weight subjects. FEV₁, Forced expiratory volume in 1 second; OB, obese; OV, overweight; OVOB, overweight or obese.

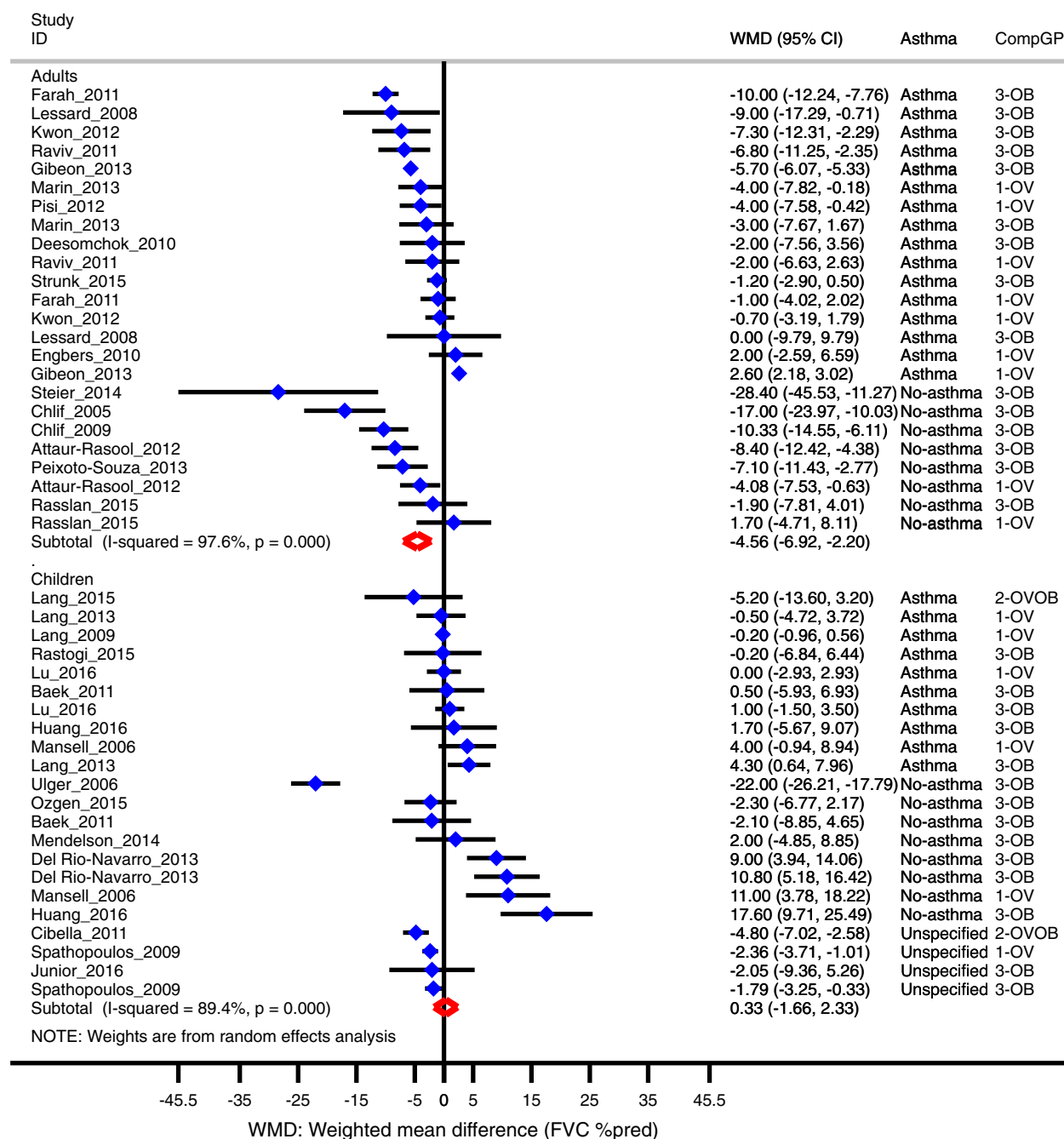


FIGURE 3. Obesity and FVC (as percent of predicted) by age group. Forest plot for FVC %pred, showing weighted mean difference (WMD) by study, for each comparison group (CompGP) versus normal-weight subjects. FVC, Forced vital capacity; OB, obese; OV, overweight; OVOB, overweight or obese.

was similar in subjects with (-1.5% [95% CI = -1.9% to -1.0%]) and without asthma (-1.6% [95% CI = -2.3% to -0.8%]) (Table I). When reviewing 12 studies that reported FEV_1/FVC as percent of predicted, FEV_1/FVC was lower among overweight/obese children (-1.7% [95% CI = -3.2% to -0.2%]) but slightly increased among overweight/

obese adults (1.3% [95% CI = 0.01% to 2.6%], data not shown).

Maximum mid-expiratory flow or FEF_{25-75}

Percent-predicted FEF_{25-75} was significantly decreased (-5.4% [95% CI = -7.3% to -3.5%]) among overweight/obese subjects in 16 studies ($n = 13,627$).^{16-18,28,32,33,43,45,46,50-52,54,55,58,74} The

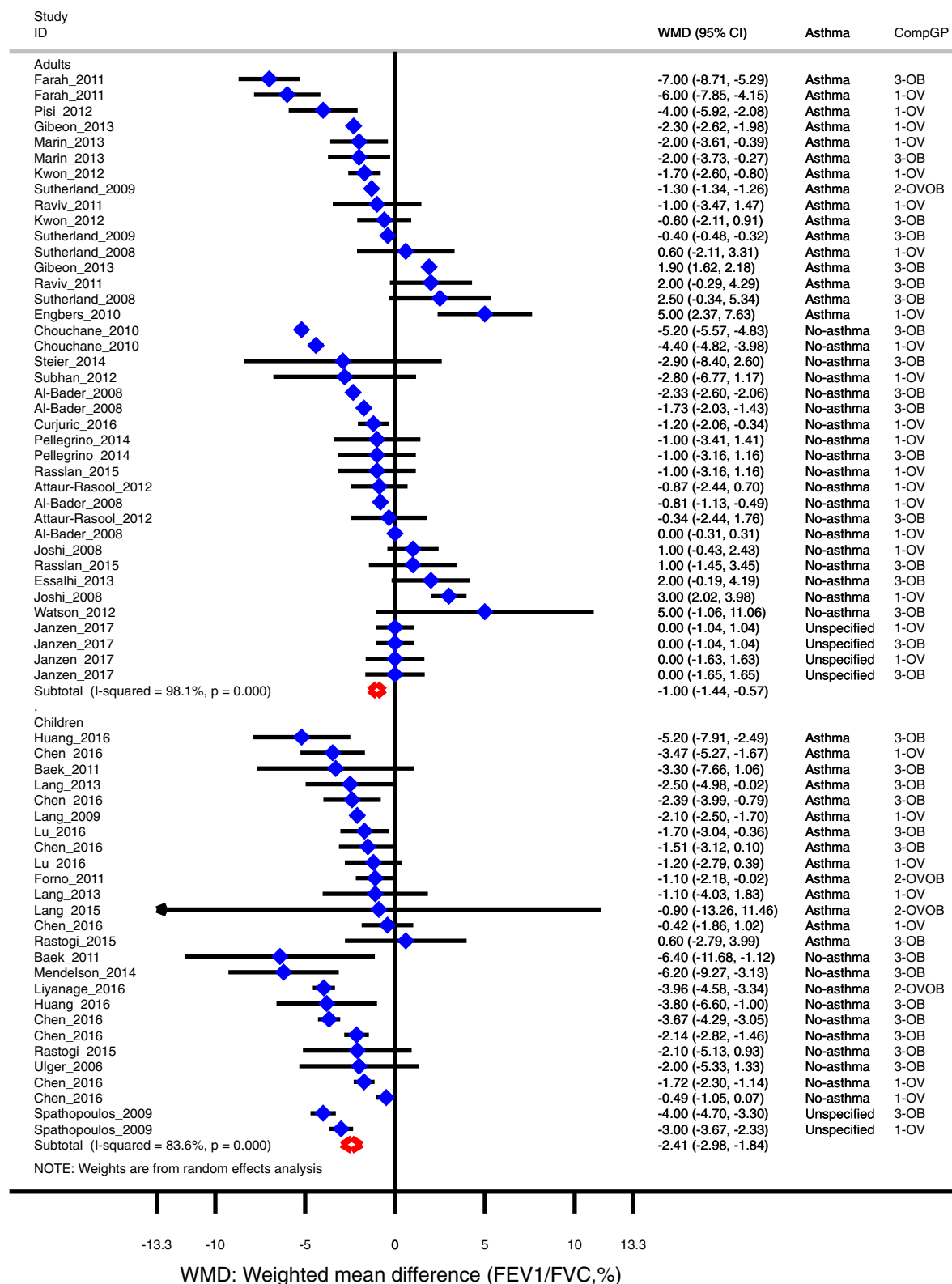


FIGURE 4. Obesity and FEV₁/FVC (%) by age group. Forest plot for FEV₁/FVC, showing weighted mean difference (WMD) by study, for each comparison group (CompGP) versus normal-weight subjects. FEV₁, Forced expiratory volume in 1 second; FVC, forced vital capacity; OB, obese; OV, overweight; OVOB, overweight or obese.

decrement was significant in children (-4.7% [95% CI = -6.9% to -2.6%]) but not in adults (Figure E4, available in this article's Online Repository at www.jaci-inpractice.org). It was significant only in subjects with asthma (-3.2% , [95% CI = -6.3% to -0.1%]), and after stratifying by weight, it was similarly decreased in overweight (-4.8% , [95% CI = -7.2% to -2.4%]) and obese (-4.6% , [95% CI = -8.1% to -1.2%]) subjects (Table I).

Total lung capacity

Overall, overweight/obese subjects had 4.2% (95% CI = -5.4% to -3.0%) lower percent-predicted TLC based on 16 studies ($n = 2,678$),^{10,23-25,31-33,35,38,40,41,46,50,51,53,73} with similar findings in children (-3.7% [95% CI = -5.8% to -1.5%]) and adults (-4.4% [95% CI = -5.7% to -3.0%]; Figure 5). The decrease was more pronounced in subjects without asthma (-4.8% [95% CI = -7.1% to -2.5%]) than among those with asthma (-3.3% [95% CI = -5.1% to -1.5%]; Figure E5, available in this article's Online Repository at www.jaci-inpractice.org), and in the obese (-5.4% [95% CI = -7.0% to -3.9%]) than in the overweight (-2.0% [95% CI = -4.1% to 0.1%]; Figure E6, available in this article's Online Repository at www.jaci-inpractice.org).

Residual volume

In 12 studies combined ($n = 2,085$), overweight/obese subjects had 6.6% (95% CI = -9.3% to -3.8%) lower percent-predicted RV.^{10,23-25,31-33,35,38,41,50,73} The decrement in RV was significant in adults (-5.4% [95% CI = -8.2% to -2.7%]) (Table I); only one study reported RV in children,⁵⁰ and thus no pooled analysis was performed. The effect was more pronounced in subjects without asthma (-7.6% [95% CI = -11.7% to -3.5%]) than in those with asthma (Figure 6), and in the obese (-7.4% [95% CI = -11.6% to -3.2%]) than in the overweight (Table I). Four studies reported RV/TLC ratio measures^{10,40,50,73}; there was no significant change in RV/TLC by overweight/obesity (data not shown).

Functional residual capacity

Overall, percent-predicted FRC was significantly lower among overweight/obese subjects than in those normal weight (-17.1% [$-25.2, -9.0$], 9 studies, $n = 1,235$).^{10,23,24,31,35,38,41,50,73} The decrement was more pronounced in subjects without asthma (-23.2% [$-30.3, -16.1$]; Figure 7), and in the obese (-21.2% [$-30.9\%, -11.5$]; Figure E7, available in this article's Online Repository at www.jaci-inpractice.org).

Assessment of publication bias and meta-regression

Egger tests showed no evidence of publication bias in any of the measures, except for RV ($P = .003$; Figure E8, available in this article's Online Repository at www.jaci-inpractice.org). There was marked heterogeneity ($I^2 > 70\%$) in all outcomes and analyses, except for TLC in children ($I^2 = 0\%$). Meta-regression analyses showed that age and sex distributions explain part of this heterogeneity. Studies with higher proportion of males showed a more pronounced effect of obesity on FEV₁ ($\beta = -0.09$, $P = .019$) in adults, and on FEV₁/FVC in subjects with asthma ($\beta = -0.04$, $P = .002$). Studies with higher mean age showed a more significant effect of obesity on FVC ($\beta = -0.17$, $P = .013$) in all subjects, and FEV₁/FVC in all subjects ($\beta = 0.06$, $P = .005$) (Figure E9, available in this article's Online Repository at www.jaci-inpractice.org).

DISCUSSION

In this meta-analysis, overweight/obesity is shown to be detrimental to lung function across age groups, regardless of asthma status. However, these detrimental effects differ between adults and children: obese adults have a more pronounced decline in FEV₁, FVC, TLC, and RV, whereas obese children show a more pronounced decline in FEV₁/FVC and FEF₂₅₋₇₅. Likewise, more marked decrements in FEV₁, TLC, RV, and FRC were found in subjects without asthma than in those with asthma. Compared with overweight subjects, the obese also had more marked decrements in FEV₁, FVC, TLC, RV, and FRC.

FEV₁, the most frequently used spirometric index, is a function of airway resistance and total lung compliance. Overweight or obesity^{12,24,25,27,28,34-37,39-42,56,58} was significantly associated with lower FEV₁ in the overall meta-analysis. However, the effect differed by age, with results driven by adults and no significant association in children. In fact, only a few individual studies reported a decreased FEV₁ in overweight/obese children,^{16-18,45,56,58} and the pooled analysis of studies reporting FEV₁ in liters showed that overweight/obese children had slightly higher absolute values. On the contrary, very few studies have shown an increased FEV₁ in overweight adults^{23,30} compared with adults of normal weight.

FVC, the total volume of air exhaled with maximally forced effort from a maximal inspiration, reflects the total compliance from both the lung and chest wall. Similar to FEV₁, overweight or obesity^{24-28,33,34,36,37,39,40,67} was negatively associated with FVC in adults, but there was no significant association in children. Likewise, our pooled analysis of studies reporting absolute FVC showed a slight increase in FVC in overweight^{46,66} or obese^{15,52,66} children. Thus, overweight/obesity is associated with lower FEV₁ and FVC in adults, but with either normal or higher FEV₁ and FVC in children. We have recently reported that overweight/obese children have an increased risk of airway dysanapsis,¹⁴ a phenomenon in which an asymmetrical growth of the lungs and airways leads to higher FEV₁ and FVC but with a more pronounced effect on FVC. Subjects with dysanapsis thus have a low FEV₁/FVC ratio but normal or supranormal FEV₁ and FVC. We found an increase in FEV₁ that appeared to be larger than the increase in FVC (WMD 410 mL vs 250 mL), but the current analysis is based on published study means rather than individual-level data, and thus we were not able to directly assess the association between obesity and dysanapsis.

Interestingly, the effect sizes for FEV₁ and FVC were much larger among subjects without asthma than among those with asthma, suggesting that obesity may have stronger effects on FEV₁ and FVC in healthy subjects. Although the reasons for this are beyond the scope of this analysis, mean FEV₁ and FVC in all included studies were markedly higher among nonasthmatics than among asthmatics (see Table E1 in this article's Online Repository at www.jaci-inpractice.org), and thus we hypothesize that the effect of obesity is more readily apparent in subjects without asthma because of their normal lung function, whereas subjects with asthma already have lower lung function due to their disease, and thus the effect of obesity may not be as prominent.

In contrast to FEV₁ and FVC, the overall decrease of FEV₁/FVC among overweight or obese subjects was more pronounced in children than in adults. Similar results were observed for FEF₂₅₋₇₅, which is the mean forced expiratory flow between 25% and 75% of the FVC: FEF₂₅₋₇₅ decreased significantly among

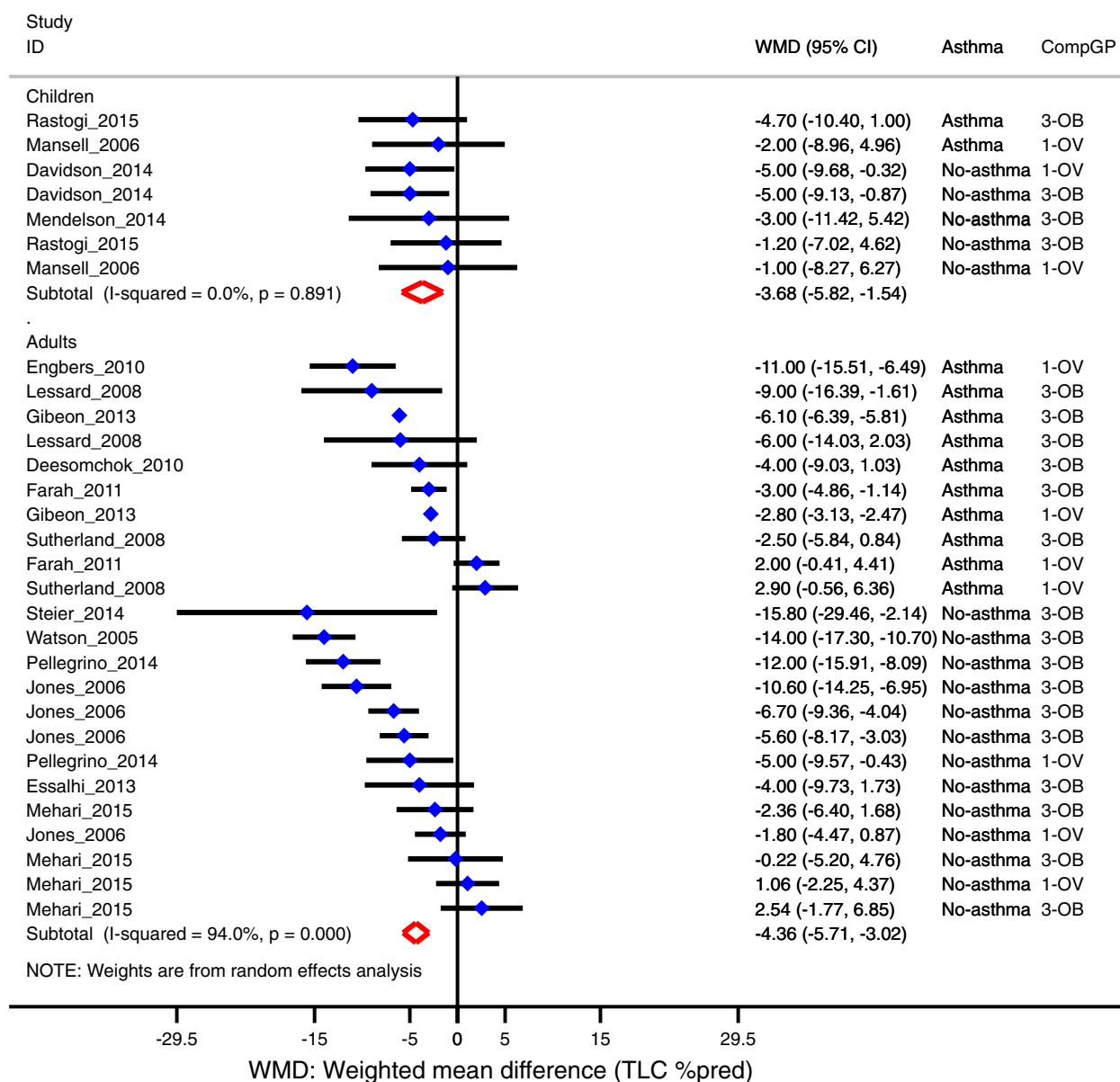


FIGURE 5. Obesity and TLC (as percent of predicted) by age group. Forest plot for TLC %pred, showing weighted mean difference (WMD) by study, for each comparison group (CompGP) versus normal-weight subjects. OB, Obese; OV, overweight; OVOB, overweight or obese; TLC, total lung capacity.

overweight or obese children^{16,17,45,52,58,74} with an overall 5.4% decrement, but there was no significant associations in adults. Only one individual study reported a 9% decrease in FEF₂₅₋₇₅ in asthmatic overweight adults.²⁸ FEF₂₅₋₇₅ can be highly variable and thus should be interpreted with caution, but it has been correlated with bronchodilator responsiveness in asthmatic children with normal FEV₁, suggesting clinically relevant reversible airflow obstruction.⁷⁵ Interestingly, the declines in FEV₁/FVC and FEF₂₅₋₇₅ were similar between overweight and obesity.

The effects of obesity on lung volumes have been better studied in adults. TLC is often used to identify a restrictive ventilatory deficit.⁷⁶ Although TLC may be preserved in most obese subjects, other than those with morbid obesity or

with excessive central adiposity,⁷⁷ our results indicate a reduction in TLC overall, with several individual studies showing that overweight or obesity diminished TLC both in adults^{10,23-25,33,35,40,41} and—to a lesser degree—in children.⁵¹ A more pronounced decrement in TLC was reported in obesity than in overweight, and in nonasthmatics than among asthmatics. Similarly, we observed that obesity was associated with lower RV in adults, and this association was seen both in asthmatics^{23-25,32,33,50} and nonasthmatics.^{10,35,38,40,41,50,51} Obesity was also associated with lower FRC among adults, which may be secondary to changes in the elastic properties of the chest wall that can lead to reduced airway caliber and increased airways resistance.⁷⁸ FRC was decreased only in

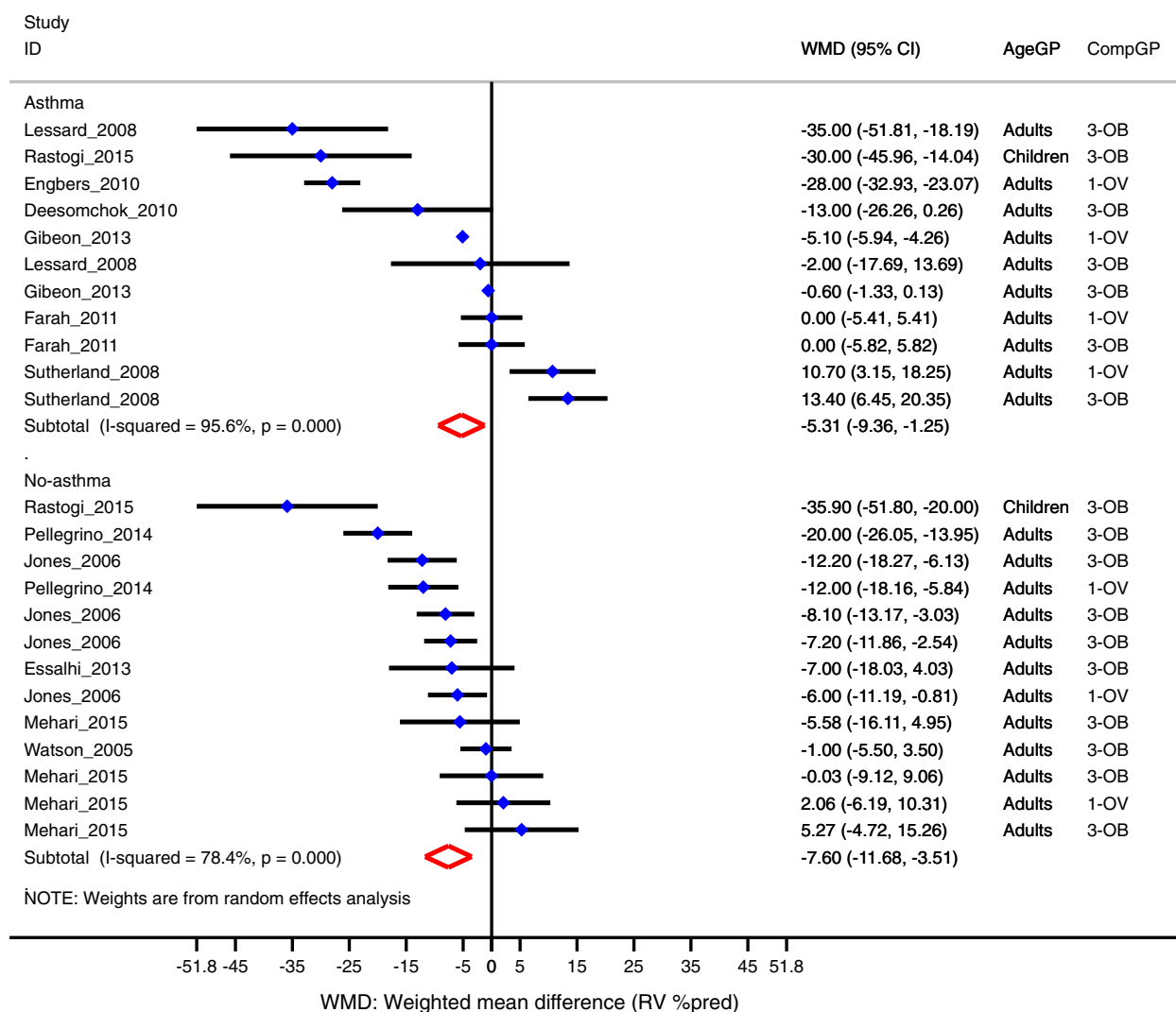


FIGURE 6. Obesity and RV (as percent of predicted) by asthma status. Forest plot for RV %pred, showing weighted mean difference (WMD) by study, for each comparison group (CompGP) versus normal-weight subjects. OB, Obese; OV, overweight; OVOB, overweight or obese; RV, residual volume.

overweight or obese nonasthmatics (approximately 23.2% lower compared with normal weight asthmatics), but not in asthmatics, suggesting again that obesity may have a more noticeable detrimental effect on lung volumes in otherwise healthy individuals. Only one study reported RV and FRC in children, and we were thus unable to perform a pooled analysis.

Strengths and limitations

To the best of our knowledge, this is the first meta-analysis to encompass all published studies on obesity and lung function. Because of large sample size, we were able to stratify the analysis by age group, asthma, and weight category. We were also able to perform meta-regression to evaluate potential effect modifiers such as age or gender.

We also recognize several limitations. First, few studies of obesity and lung function have used indices other than BMI (eg, percent body fat, WHR, etc.), and thus we had to focus on

BMI. Future efforts should aim to determine whether adiposity distribution has different effects on lung function. Second, most studies included in the analysis were cross-sectional, and thus a causal relationship between overweight or obesity and lung function cannot be determined. Third, most studies reported joint findings for males and females, and we could thus only evaluate the potential effect of sex by using the proportions from each individual study. Given the small number of studies reporting details on smoking, atopy, and race/ethnicity, we were unable to assess whether these factors modify the effect of obesity on lung function; moreover, we had no data on pubertal status and thus could not assess whether it constitutes an effect modifier among children. Because we did not have individual-level data for these studies, we were unable to perform more detailed analyses, including the association between obesity and airway dysanapsis. Finally, we had insufficient data on RV and FRC among children to perform a pooled analysis of these measures.

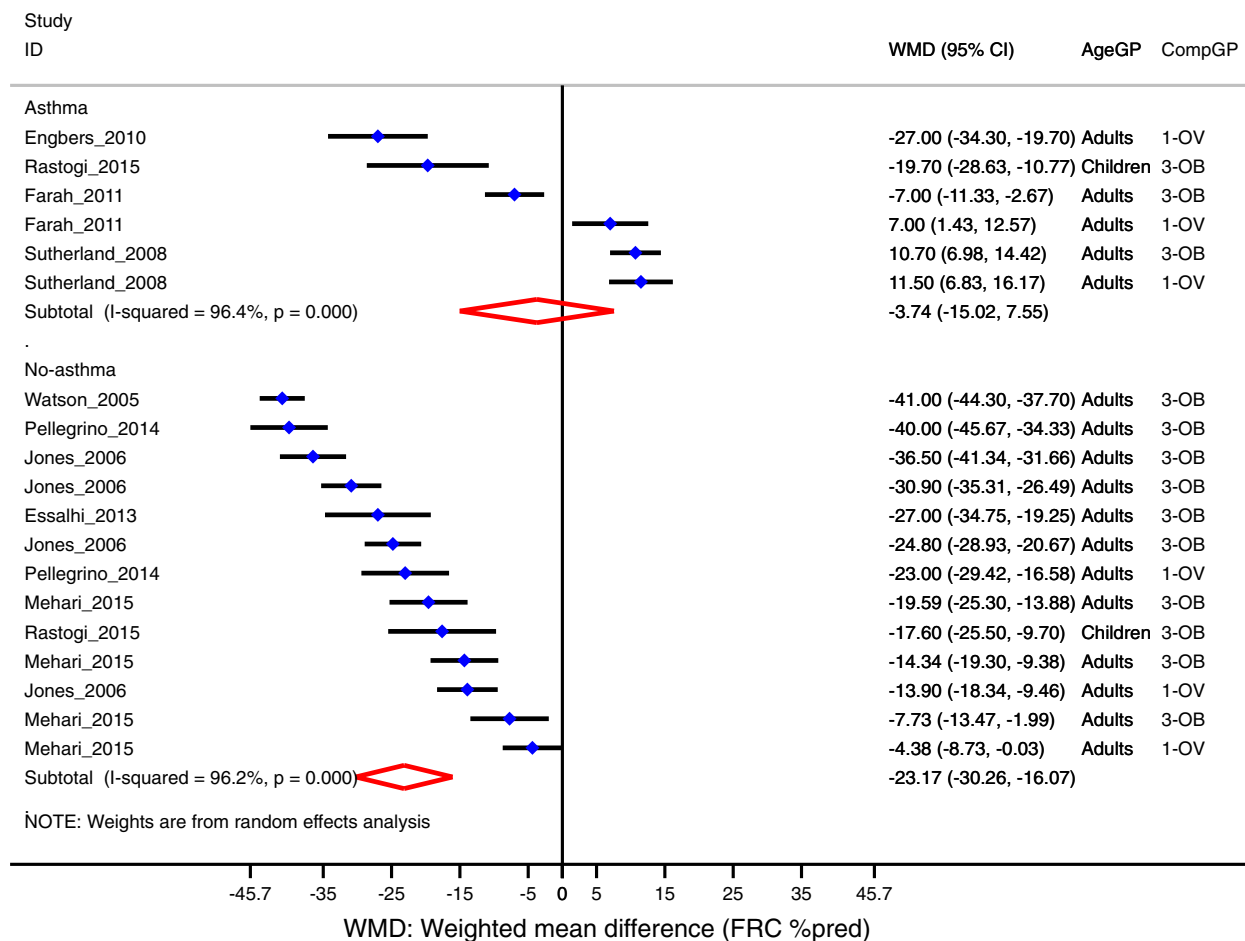


FIGURE 7. Obesity and FRC (as percent of predicted) by asthma status. Forest plot for FRC %pred, showing weighted mean difference (WMD) by study, for each comparison group (CompGP) versus normal-weight subjects. *FRC*, Functional residual capacity; *OB*, obese; *OV*, overweight; *OVOB*, overweight or obese.

CONCLUSIONS

Overweight and obesity have significant effects on lung function, including spirometric parameters and lung volumes. Overall, this association is observed regardless of age group and asthma status. However, specific patterns differed between children and adults. Although obesity affected lung function in subjects with asthma, subjects without asthma had even more pronounced reductions—particularly for lung volumes. Physicians should be aware of the adverse effects of obesity on lung function, and weight control should be considered in the management of airway diseases among obese individuals.

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TABLE E1. Spirometric values by age, asthma, and obesity status

	Control Normal weight	Control Overweight/obese	Asthma Normal weight	Asthma Overweight/obese
Adults				
FEV ₁ (%pred)	105.03 ± 6.64	97.34 ± 6.30	85.36 ± 16.04	82.62 ± 15.61
FVC (%pred)	106.27 ± 9.12	96.83 ± 4.34	97.47 ± 7.44	94.07 ± 8.44
FEV ₁ /FVC (%)	83.98 ± 4.60	83.26 ± 3.64	73.88 ± 7.26	72.86 ± 7.57
Children				
FEV ₁ (%pred)	100.23 ± 5.16	99.35 ± 6.97	91.07 ± 4.77	91.94 ± 4.64
FVC (%pred)	102.04 ± 3.43	105.04 ± 12.13	99.71 ± 4.23	100.25 ± 5.42
FEV ₁ /FVC (%)	92.27 ± 3.71	89.02 ± 4.68	85.20 ± 6.34	83.32 ± 5.79

FEV₁, Forced expiratory volume in 1 s; FVC, forced vital capacity.

The mean (±SD) reported FEV₁, FVC, and FEV₁/FVC for all studies included in the corresponding analyses.

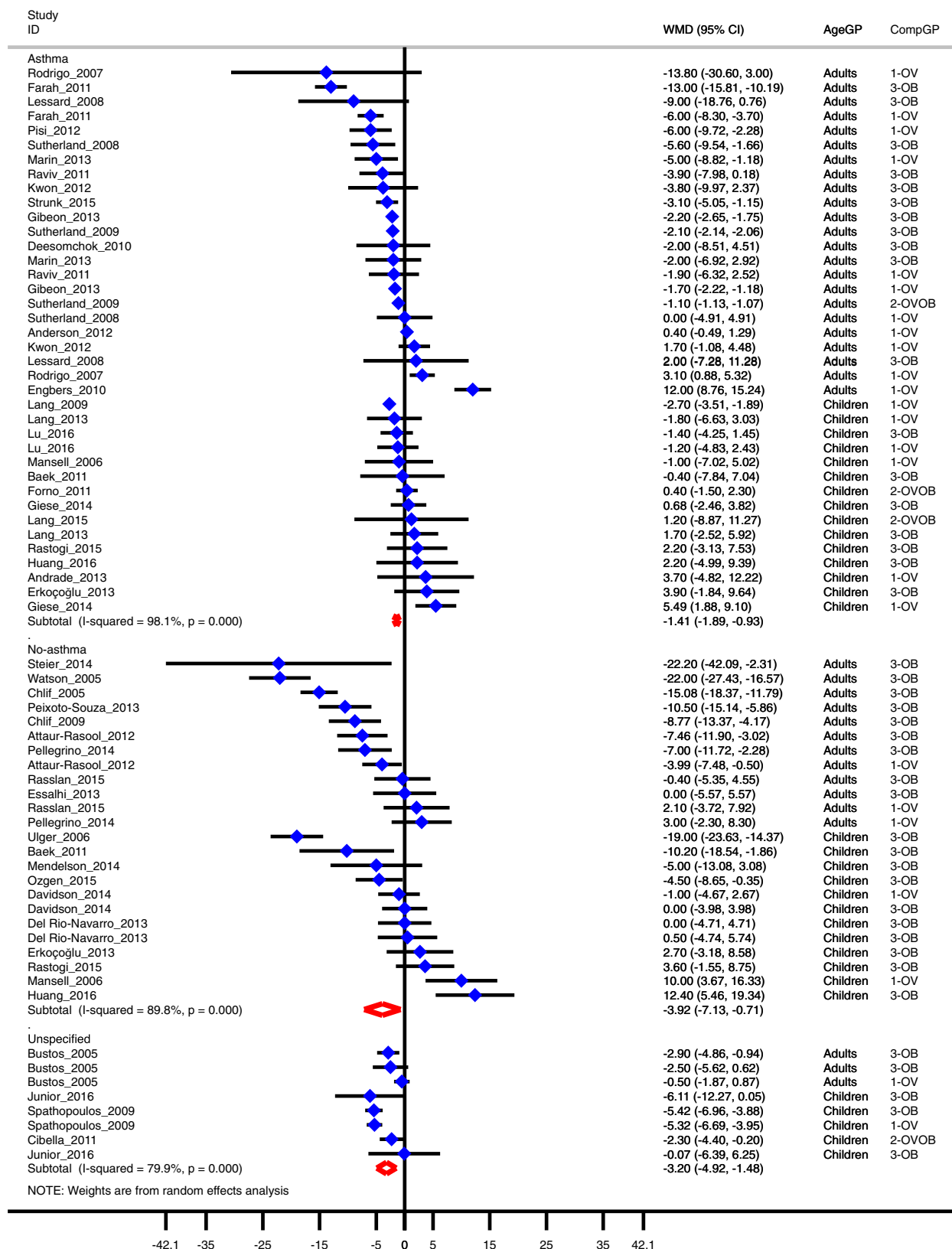


FIGURE E1. Obesity and FEV₁ (%pred) by asthma status. FEV₁, Forced expiratory volume in 1 second; OB, obese; OV, overweight; OVOB, overweight or obese; WMD, weighted mean difference.

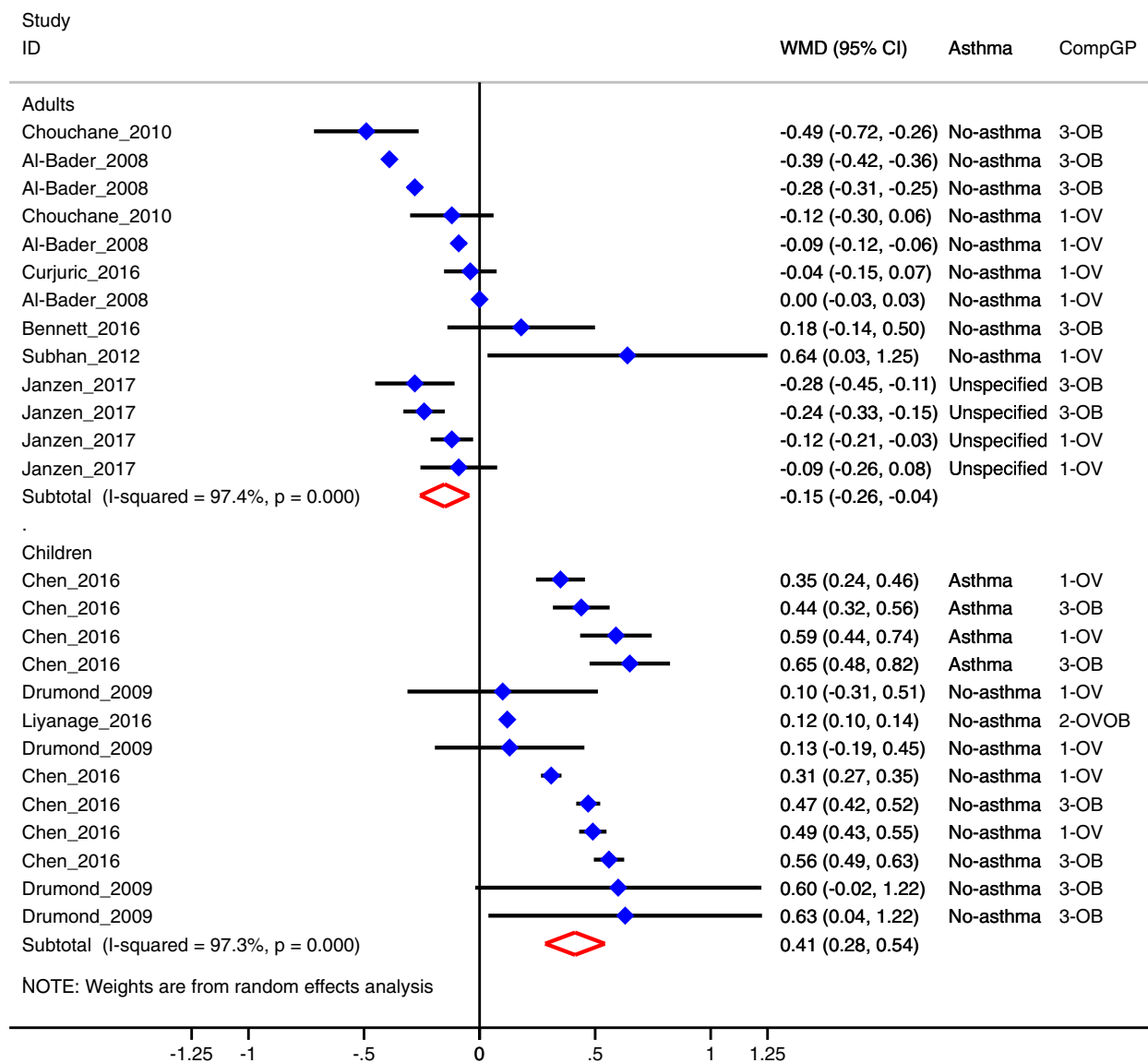


FIGURE E2. Obesity and FEV₁ (liters) by age group. FEV₁, Forced expiratory volume in 1 second; OB, obese; OV, overweight; OVOB, overweight or obese; WMD, weighted mean difference.

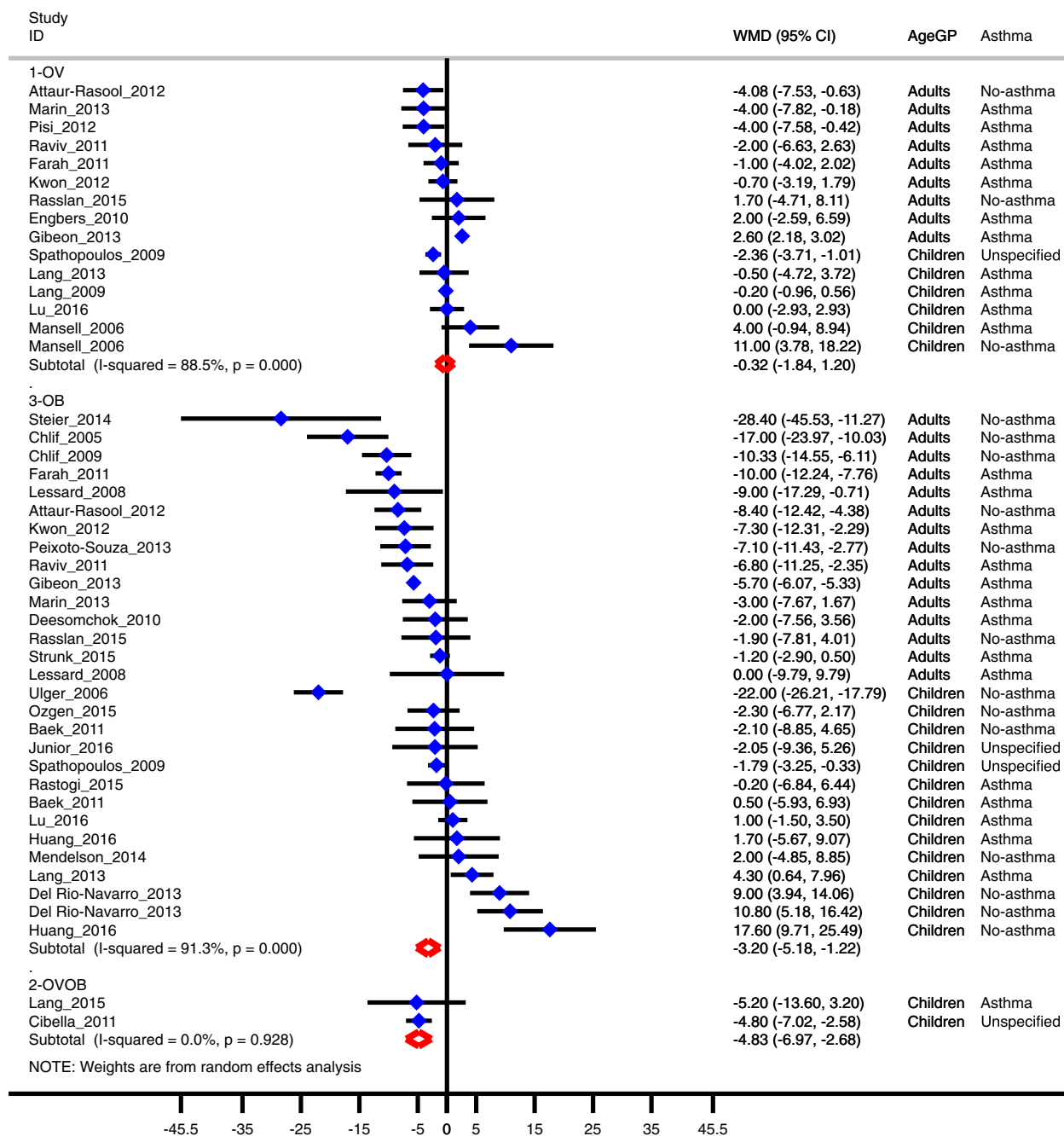


FIGURE E3. Obesity and FVC (%pred) by weight group. FVC, Forced vital capacity; OB, obese; OV, overweight; OVOB, overweight or obese; WMD, weighted mean difference.

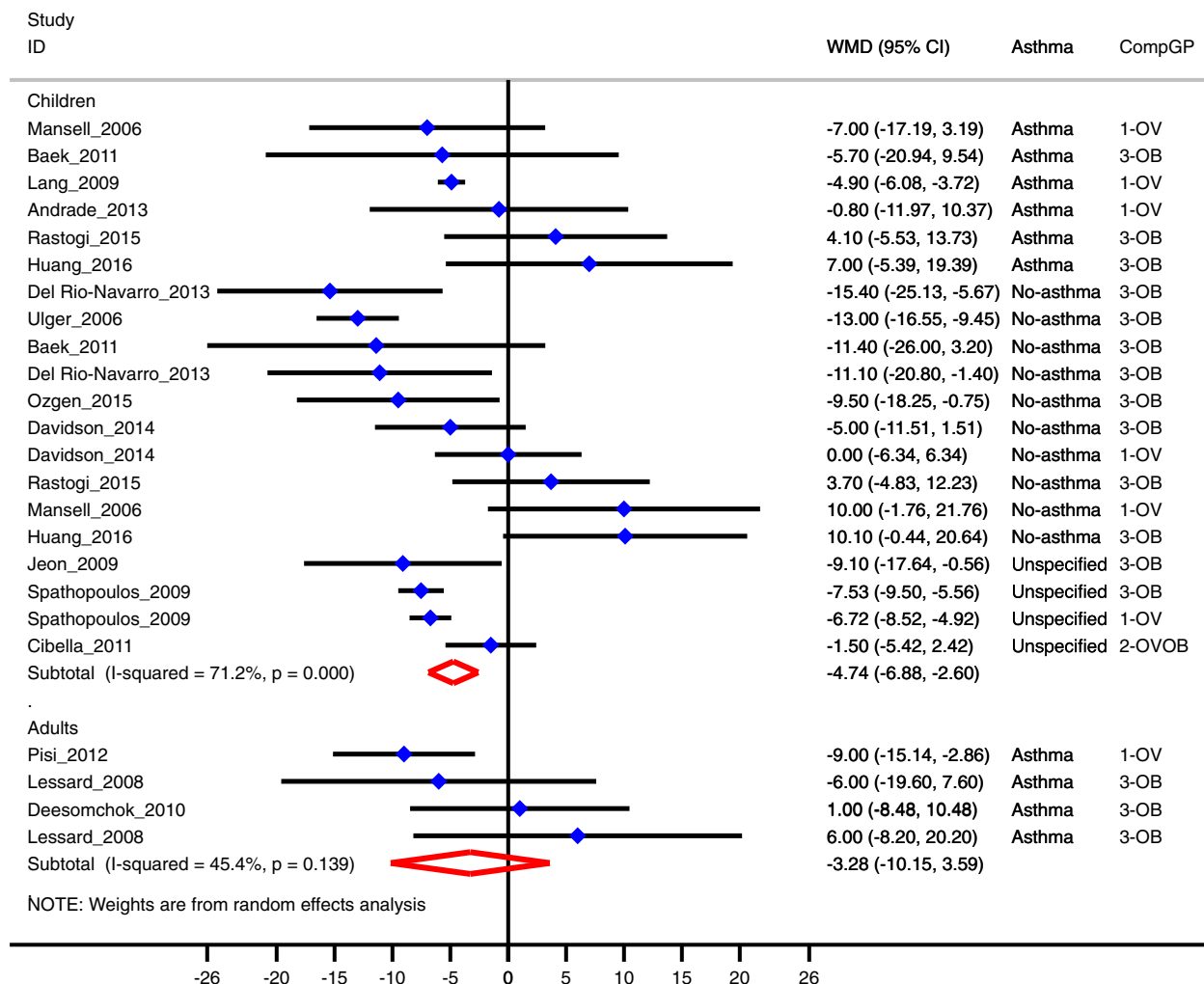


FIGURE E4. Obesity and FEF_{25-75} (%pred) by age group. FEF_{25-75} , Forced expiratory flow between 25th and 75th percentile of the forced vital capacity; *OB*, obese; *OV*, overweight; *OVOB*, overweight or obese; *WMD*, weighted mean difference.

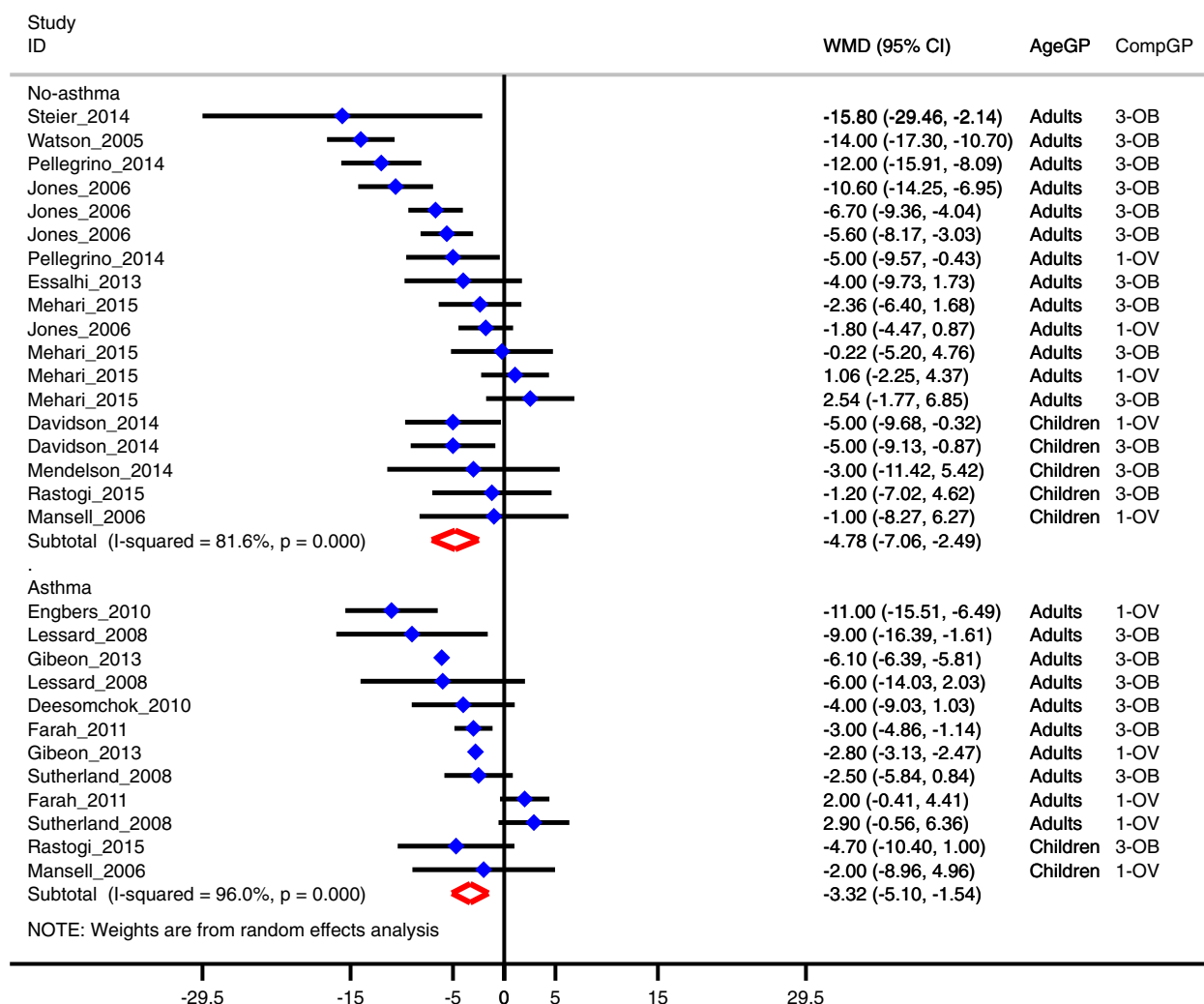


FIGURE E5. Obesity and TLC (%pred) by asthma status. *OB*, obese; *OV*, overweight; *OVOB*, overweight or obese; *TLC*, total lung capacity; *WMD*, weighted mean difference.

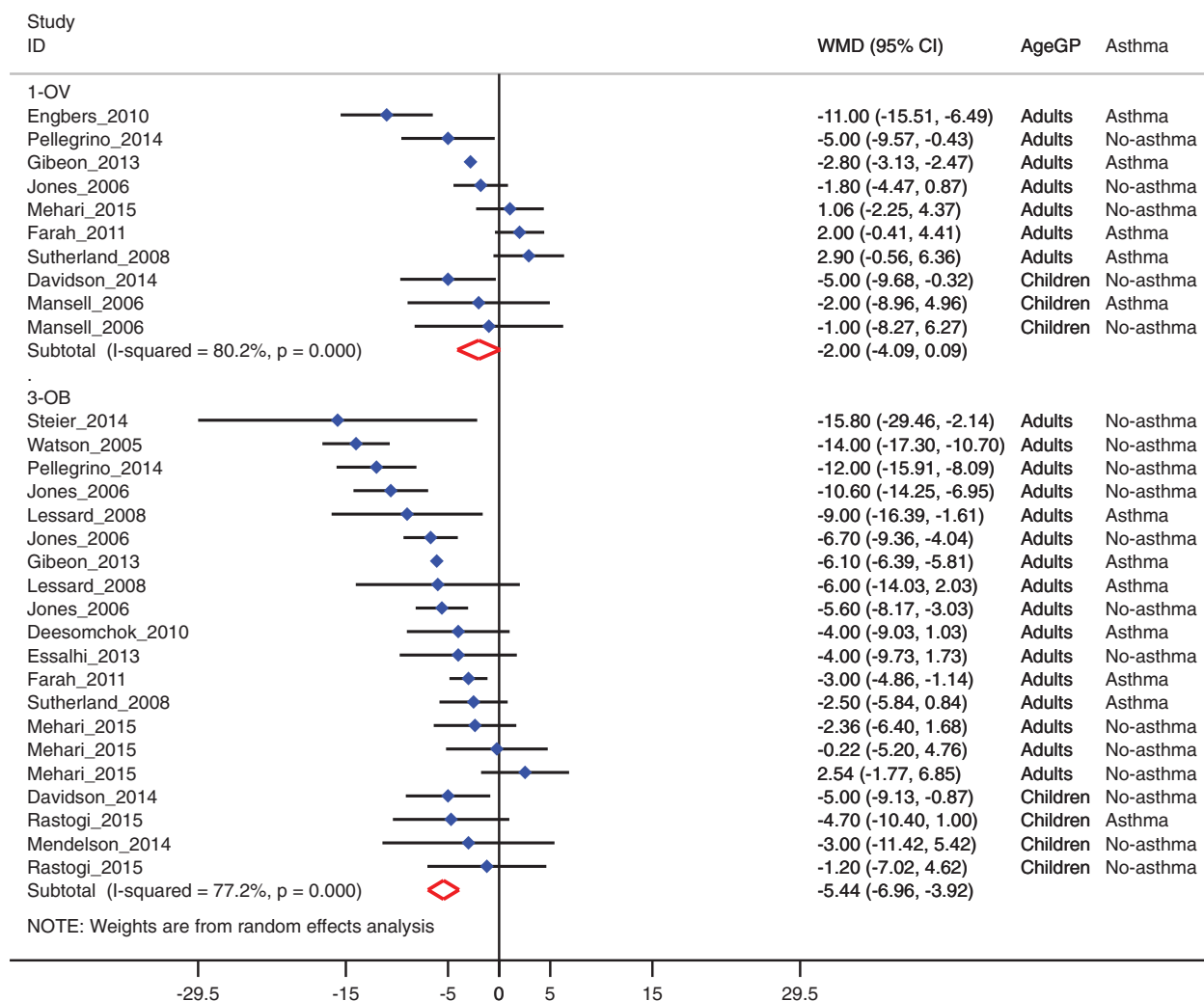


FIGURE E6. Obesity and TLC (%pred) by weight group. *OB*, obese; *OV*, overweight; *OVOB*, overweight or obese; *TLC*, total lung capacity; *WMD*, weighted mean difference.

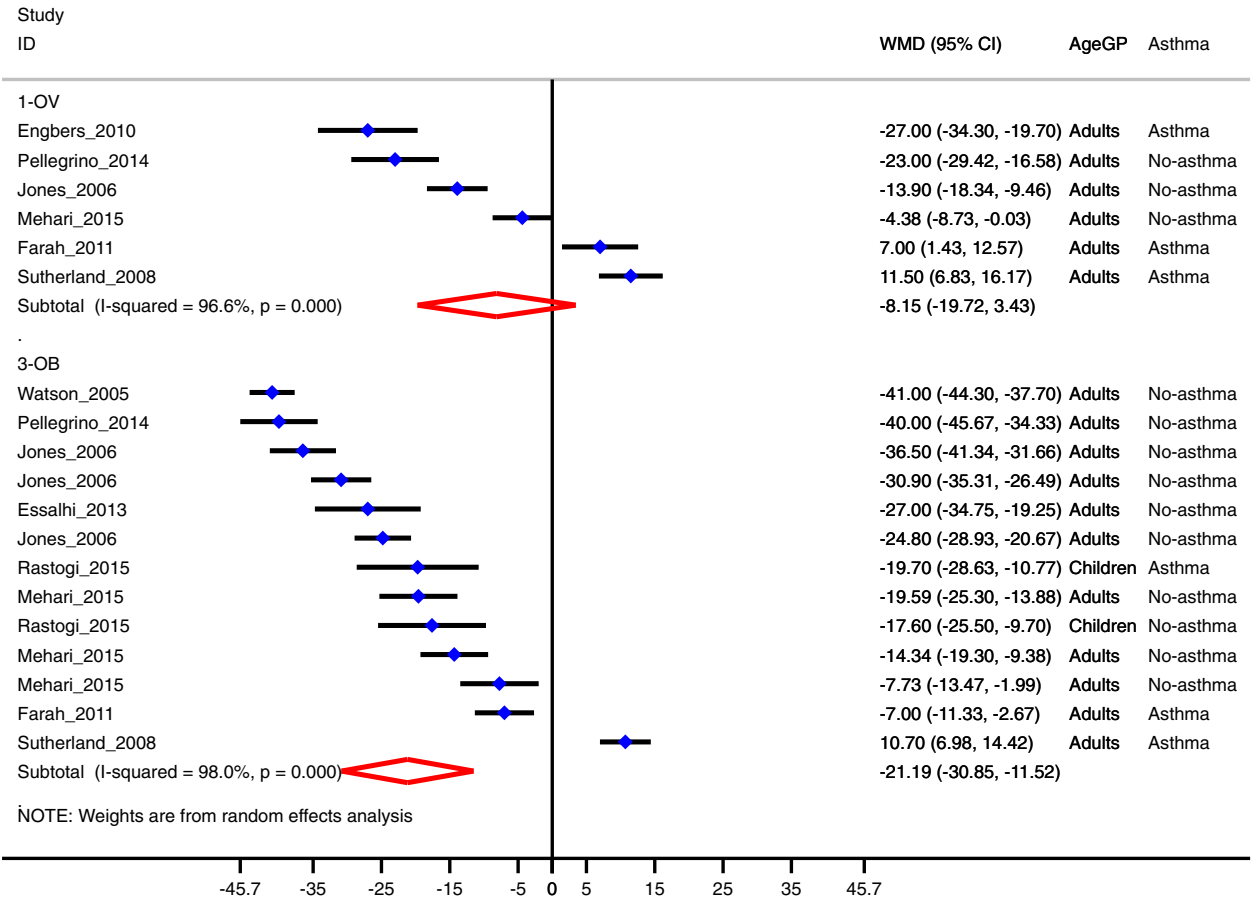


FIGURE E7. Obesity and FRC (%pred) by weight group. *FRC*, Functional residual capacity; *OB*, obese; *OV*, overweight; *OVOB*, overweight or obese; *WMD*, weighted mean difference.

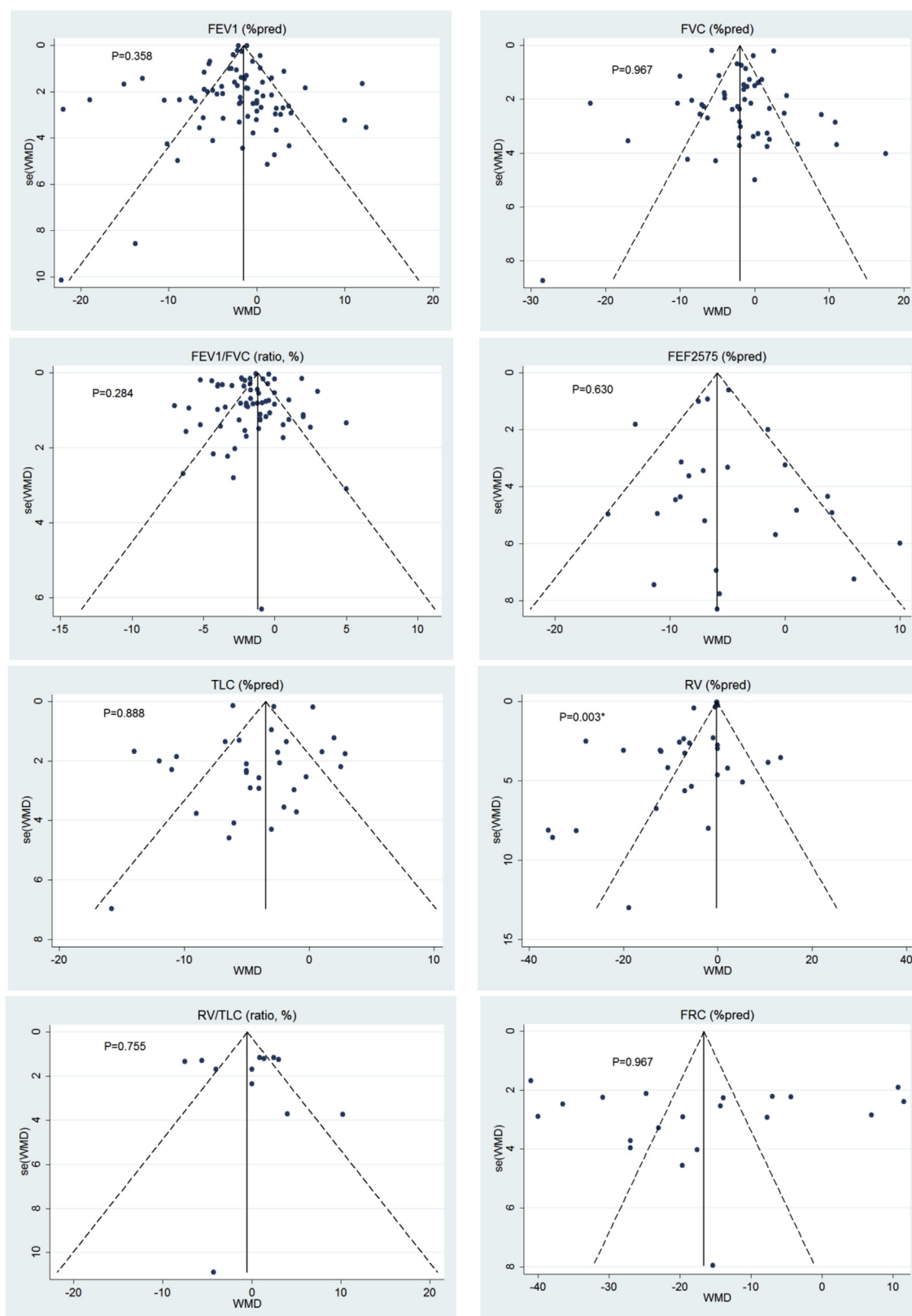
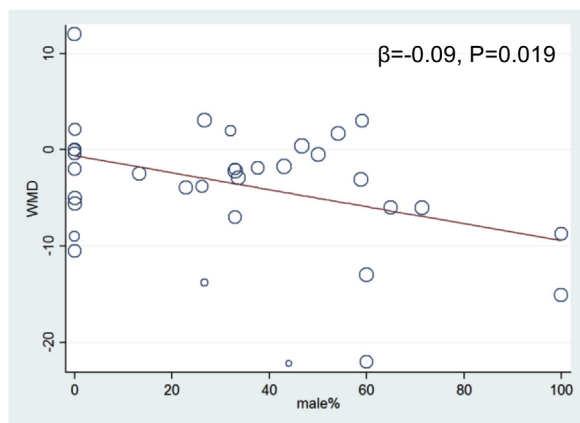
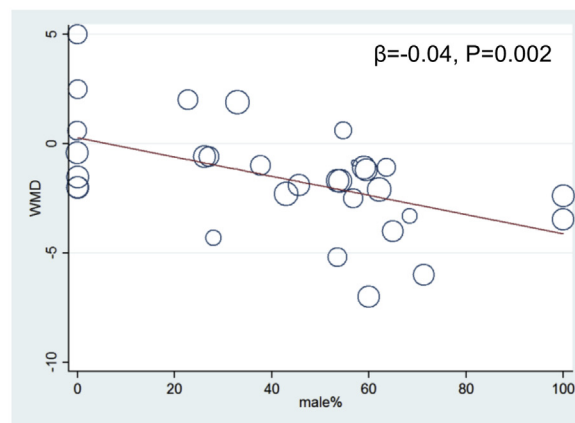


FIGURE E8. Funnel plots and Egger's test for small-study effects. *FEF₂₅₋₇₅*, Forced expiratory flow between 25th and 75th percentile of the forced vital capacity; *FEV₁*, forced expiratory volume in 1 second; *FRC*, functional residual capacity; *FVC*, forced vital capacity; *RV*, residual volume; *TLC*, total lung capacity; *WMD*, weighted mean difference.

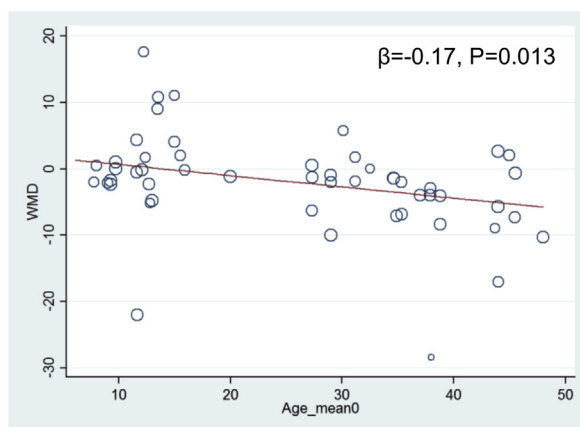
A FEV₁ (%pred) by gender in adults



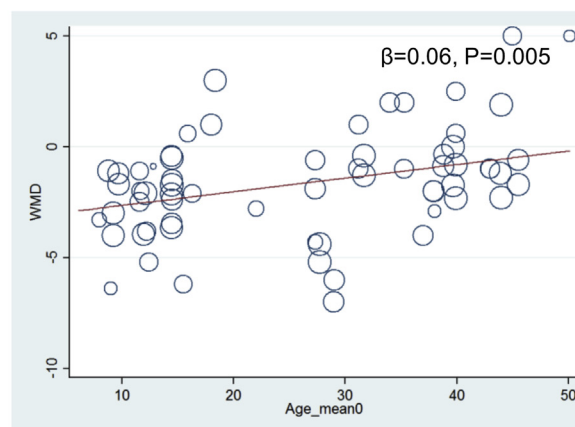
B FEV₁/FVC (%) by gender in asthmatics



C FVC (%pred) by age in children and adults



D FEV₁/FVC (%) by age in children and adults



E TLC (%pred) by age in non-asthmatics

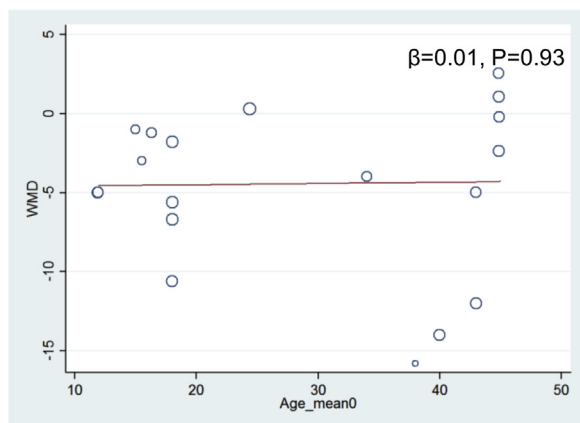


FIGURE E9. Effect modification of obesity on lung function by age and gender. *FEV₁*, forced expiratory volume in 1 second; *FVC*, forced vital capacity; *TLC*, total lung capacity.

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