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Early View

Review

Ethnic variation in asthma healthcare utilisation and exacerbation: systematic review and meta-analysis

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Title: Ethnic variation in asthma healthcare utilisation and exacerbation: systematic review and meta-analysis

Running Title: Ethnic variation in asthma healthcare outcomes

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Abstract

Background

Patients from ethnic minority groups (EMGs) frequently report poorer asthma outcomes, however a broad synthesises summarizing ethnic disparities is yet to be undertaken.

Objective

What is the magnitude of ethnic disparities in asthma healthcare utilisation, exacerbations and mortality?

Methods

MEDLINE, EMBASE and Web of Science databases were searched for studies reporting ethnic variation in asthma healthcare outcomes (primary care attendance, exacerbation, emergency department [ED] visit, hospitalisation, hospital readmission, ventilation / intubation, and mortality) between White and EMGs. Estimates were displayed using forest plots and random-effects models were used to calculate pooled estimates. We conducted subgroup analyses to explore heterogeneity, including by specific ethnicity (Black, Hispanic, Asian, and Other).

Results

65 studies, comprising 699,882 patients, were included. Most studies (92.3%) were conducted in the U.S.A. Patients from EMGs had evidence suggestive of lower levels of primary care attendances (OR:0.72, 95%CI:0.48-1.09), but substantially higher ED visits (OR:1.74, 95%CI:1.53-1.98), hospitalisations (OR:1.63, 95%CI:1.48-1.79) and ventilation / intubation (OR:2.67, 95%CI:1.65-4.31) when compared to White patients. We also found evidence suggestive of increased hospital readmissions (OR:1.19, 95%CI:0.90-1.57) and exacerbation rates (OR:1.10, 95%CI:0.94-1.28) among EMGs. No eligible studies explored disparities in mortality. ED attendances were much higher among Black and Hispanic patients, while Asian and other ethnicities had similar rates to White patients.

Conclusions

EMGs had higher secondary care utilisation and exacerbations. Despite the global importance of this issue, the majority of studies were performed in the U.S.A. Further research into the causes of these disparities, including whether these vary by specific ethnicity, is required to aid the design of effective interventions.

Systematic review registration: The review was registered on PROSPERO (registration number: CRD42020200392)**.**

Keywords: ED visits, ethnic minority group, healthcare, hospitalisation, readmission

1 Introduction

Asthma is one of the most common chronic diseases in the world, affecting over 400 million patients (1). Although it is prevalent across society (2), the burden of asthma is known to disproportionately affect patients from ethnic minority groups (EMGs). Compared with White Americans, EMGs have higher asthma prevalence, morbidity and adverse outcomes (3,4). Higher rates of emergency department (ED) visits, hospital admission and asthma mortality have been reported among EMGs when compared to White patients (3,4).

Language barriers, poorer housing conditions and inadequate self-management have previously been considered as potential contributors to the observed ethnic disparities in asthma outcomes (5,6). Belonging to an EMG is associated with lower socioeconomic status in many countries (7), which can make it difficult to disentangle differences driven by ethnic factors such as culture, from those related to socioeconomic disadvantage. A recent study by the Severe Asthma Research Program in the U.S.A. found that the greater ED use observed in Blacks was entirely explained after accounting for socioeconomic circumstances and environmental factors (8). Cultural differences in asthma medication adherence and health literacy (9,10) have also been previously identified and are known to materially affect asthma outcomes (11,12).

Despite substantial literature examining ethnic differences in asthma outcomes, previous systematic reviews have been limited to specific countries, populations (e.g. paediatrics) or

outcomes (13,14). Despite a well-established literature on the topic from the U.S.A., where issues around ethnic disadvantage are of particular interest, these studies have yet to be systematically synthesised. A broader analysis, including all relevant evidence worldwide, would help improve knowledge of potential ethnic inequalities and facilitate an investigation of where disparities are largest, and action is most needed to improve and standardize care.

2 Methods

2.1 Search strategy

A search strategy was developed to identify studies reporting differences in asthma healthcare outcomes and resource utilisation between White and EMGs (see Tables S1 & S2 in the Online Repository). The specific outcomes of interest were primary care attendance, asthma exacerbation, ED visit, hospitalisation, ventilation / intubation, hospital readmission, and asthma mortality. Three electronic databases (MEDLINE, EMBASE and Web of Science) were searched from inception (i.e. 1946 for MEDLINE, 1974 for EMBASE and 1997 for Web of Science) on January 4, 2023. Individual search results were combined, duplicates removed automatically using an online software (Covidence, Veritas Health Innovation Ltd, Australia) and manually checked. This systematic review was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses [PRISMA] statement (15) and it was registered on PROSPERO prior to data extraction (registration number: CRD42020200392). Patient representatives were not involved in the design, analysis or interpretation of the study.

2.2 Study eligibility and selection

Studies were eligible if they were reported in peer-reviewed journals and all participants had a physician-diagnosed or self-reported asthma. Asthma was defined as either a physician-diagnosed or self-reported asthma (e.g. asthma diagnosis reported by the patient but not

corroborated through linkage to medical records). We excluded ecological studies as these are prone to the ecological bias (16). Due to resource constraints our analysis was limited to studies published in English language although a recent study concluded that this restriction is unlikely to have a material impact on the conclusion of a systematic review (17). Titles and abstracts were screened independently by three reviewers (AA-I, AB and DMcC) and full-texts were retrieved if potentially relevant. Three reviewers (AA-I, AB and DMcC) screened the full-text articles. Two independent reviewers (AA-I and DMcC) conducted backward and forward citation searches on all studies initially included from the electronic search using Scopus (Elsevier, U.S.A.) and Web of Science (Clarivate Analytics, U.S.A.). Authors were not contacted to provide additional data outside that available in the published study. Throughout the process, disagreements were resolved by consensus or through referral to an additional reviewer (JB).

2.3 Data extraction and risk of assessment

Three reviewers (AA-I, AB & DMcC) extracted data in duplicate using a pre-defined data extraction form (Table S3). We extracted details on the study (country, design, clinical setting and time period), characteristics of the population (e.g., size, mean age, sex), statistical methodology (e.g., confounder adjustment).

Odds ratios (ORs) and their corresponding 95% confidence intervals (CIs) comparing relevant outcomes were extracted. The principal quantitative synthesis involved a comparison of White vs EMGs. Univariable and multivariable effect estimates were retrieved, however the multivariable estimate was used when possible. Unadjusted effect estimates and 95% CIs were calculated manually where necessary using the methods outlined in the Cochrane Handbook (18). Where studies presented multiple eligible estimates (e.g., separate estimates comparing Black vs. White and Asian vs. White), we used a within-study meta-analysis to calculate a pooled estimate comparing all EMGs vs. White patients for that study.

The methodological quality of the included studies was assessed using the Newcastle–Ottawa Quality Assessment Scale (NOQAS) for cohort, case-control studies (19) and cross-sectional (20), using a predefined assessment criteria (Table S4). Studies were scored across three domains: selection of participants, comparability, and ascertainment or assessment of the exposure and outcome. Domain scores were totalled, and each study was awarded an overall quality rating (poor or good).

2.4 Data synthesis and analysis

Descriptive statistics including means, medians and percentages were calculated to summarise study characteristics. Meta-analyses were conducted using a random effects model, as described by DerSimonian and Laird (21), with the degree of statistical heterogeneity assessed using the

I^2 statistic. Hazard ratios and relative risks were treated as ORs to facilitate the pooling of estimates. We conducted sensitivity analyses restricting to studies deemed good quality. We undertook several pre-specified subgroup analyses to explore heterogeneity including by specific ethnic groups (Black, Hispanic, Asian and Other), patient age (paediatric vs. others), study data collection frame (pre- vs. post- 2010) and healthcare financing (public vs. private). Subgroups were only compared if they comprised at least four studies in line with recommendations (22). Both funnel plots and Egger's test were used to investigate potential small study effects for all outcomes comprising at least 10 studies (23). Analyses were performed using STATA (version 14).

3 Results

The electronic search identified 9,941 unique studies (Figure 1), of which 205 were retained after title and abstract screening. A further 154 studies were excluded after full-text review due to failing to report a relevant outcome or exposure (n=63), an ecological study design (n=51), comprising non-asthmatic patients (n=28), or conference abstracts (n=12), leaving 51 eligible studies. An additional 14 studies were included following the forward and backward citation searches. Eight of the included studies were only included in the narrative synthesis: three studies (24–26) presented only narrative results, and five (27–31) did not provide sufficient details for comparative effect estimates to be derived. Therefore, 57 of the 65 studies were included in the meta-analysis.

3.1 Quality Assessment and small study effects

The methodological quality of the included studies was deemed good in 37 (56.9%) studies (see Table S5). The most common factor for a study being deemed poor quality was a failure to adjust for at least age and/or sex, which occurred in all but three of the 28 poor-quality studies. Within the cohort studies, there were also potential issues with outcome ascertainment resulting from patient self-report (n=8, 38.1% of poor-quality studies), whereas in cross-sectional studies the response rate was frequently unsatisfactory (n=12, 60.0%). Overall, studies differed considerably in the level of statistical adjustment used in their analysis. Of those that performed some adjustment (n=39), most (89.7%) adjusted for age and/or sex, while some additionally accounted for income (41.0%), asthma severity (33.3%) and education (30.8%) (Table S6).

There was some evidence of small study effects in studies investigating ED visits ($P<0.001$), with the funnel plot displaying a marked asymmetry in which substantially more studies reported marked ethnic disparities than would have been expected (Figure S1). However, no indication of small study effects was observed for hospitalisations (Figure S2).

3.2 Study characteristics

The 65 included studies comprised 699,882patients with the population size varying considerably across studies from 80 to 133,509 patients. Most studies (n=35, 53.8%) were published before 2010 and the majority were conducted in the U.S.A. (n=60, 92.3%), including three set in both the U.S.A. and Canada (32–34). Three studies (35–37) were conducted in the U.K, while a single study was conducted in New Zealand (38), and Canada (39) (Table 1). The majority of studies were cohort (n=44, 67.7%) or cross-sectional (n=20, 30.8%), with only one employing a case-control design. The median age of study populations was 35.2 years (IQR: 10.1, 49.5) with 23 (43.1%) studies reporting solely on paediatric patients. Most studies investigated the effect of ethnicity on multiple outcomes, but most commonly reported on differences in ED visits (n=41, 40.6%) and hospitalisations (n=33, 32.7%). Studies rarely investigated differences in exacerbation (n=10, 9.9%), hospital readmission (n=6, 5.9%), ventilation / intubation (n=5, 5.0%) and primary care attendance (n=4, 4.0%). None of the studies included in our review reported on asthma mortality (Table 1).

3.3 The association between ethnicity and healthcare utilisation

Primary care attendances was lower among EMG patients when compared to White patients, however this was imprecisely estimated (OR: 0.72, 95% CI: 0.48, 1.09, I^2=70.5%; Table 2 & Figure S3) compared to White patients. However, EMGs had higher secondary healthcare utilisation (ED visits, hospital admission and hospital readmission). The proportion attending

ED was higher (OR: 1.74, 95% CI: 1.53, 1.98) among patients of EMGs than their White counterparts, although there was evidence of between-study heterogeneity (I^2=90.3%; Figure 2). Findings of higher ED visits among EMGs were largely consistent across individual studies (91.7%) including within a recent study from the U.S.A. which reported that 14% of White patients attended the ED in the past 12 months due to their asthma compared to 32% of Black patients (adjusted OR: 2.34, 95% CI: 1.65, 3.33, P<0.001) and 23% of Hispanic patients (adjusted OR: 2.17, 95% CI: 1.51, 3.10, P<.001) (40). Similarly, EMGs were substantially more likely to be hospitalised (OR: 1.63, 95% CI: 1.48, 1.79, I^2=43.1%; Figure 3), while there was a trend for increased rates of hospital readmissions (OR: 1.19, 95% CI: 0.90, 1.57, I^2=78.0%; Figure S4). EMGs were also more likely to be ventilated / intubated (OR: 2.67, 95% CI: 1.65, 4.31, I^2=74.2%; Figure S5). The magnitude of these differences varied between studies and there was substantial heterogeneity between studies across all outcomes.

3.4 The association between ethnicity and asthma exacerbations

Few studies explored the association between ethnicity and asthma exacerbation (Table 2) with most (71.4%) reporting higher rates among EMGs (pooled OR: 1.10, 95% CI: 0.94, 1.28, I^2=78.8%; Figure S6).

3.5 Sensitivity and Subgroup analyses

Our overall conclusions were similar in sensitivity analyses restricted to studies deemed good quality, however we found a stronger and statistically significant relationship between EMGs and lower primary care attendance in this analysis (OR: 0.61, 95% CI: 0.44, 0.83, I^2=6.9%; Table 2). The pooled estimate for the other outcomes were similar when restricting to good quality studies, and in most cases, the heterogeneity was substantially reduced (Table 2).

The pattern of secondary healthcare utilisation differed by specific ethnicity (Table S7). Rates of ED visits were much higher among Black (OR: 1.86, 95% CI: 1.68, 2.06) and Hispanic (OR: 1.52, 95% CI: 1.35, 1.71) patients (P=0.001), while Asian (OR: 0.97, 95% CI: 0.59, 1.61) and those from other ethnicities (OR: 1.13, 95% CI: 0.86, 1.48) had similar rates to White patients. Black patients also had higher rates of hospitalisation (OR: 1.69, 95% CI: 1.40, 2.06) than Hispanic patients (OR: 1.33, 95% CI: 1.09, 1.62), Asian patients (1.42, 95% CI: 0.85,2.38) or those from other ethnicities (OR: 1.23, 95% CI: 0.88, 1.72) (P=0.068), and higher rates of readmission (OR: 1.76, 95% CI: 1.61, 1.91) than those from other ethnicities (OR: 1.05, 95% CI: 0.97, 1.13) (P<0.001). There was little evidence of any difference in disparities by age (ED visits and hospitalisations) or time-period (ED visits; Table S7). Data was not available to allow robust subgroup analyses for other outcomes, and no subgroup analyses comparing healthcare system funding models was possible.

4 Discussion

In this systematic review, comprising 65 studies and 699,882asthma patients, we found that patients from EMGs had higher secondary healthcare utilisation, evidence to suggest increased rates of exacerbation and, when restricting to high-quality studies, reduced primary care attendances when compared to White patients. Black and Hispanic patients had particularly high rates of secondary healthcare utilisation, while rates among those from Asian and other ethnicities were relatively similar to White patients. Despite the global importance of this issue, the vast majority of relevant research was conducted in the U.S.A. and most eligible studies were published at least ten years ago.

Our findings are consistent with other systematic reviews in asthma (13,14), which have reported poorer healthcare outcomes among EMGs. Importantly, these reviews were limited to only UK-based studies (published more than 15 years ago) (13), or paediatric patients (14), while the current review provides an update of this evidence and includes all relevant studies worldwide regardless of patient demographics. The findings in this review are also consistent with findings of ethnic disparities across a broad array of diseases and outcomes (41–44). Compared to White patients, Black patients had greater chronic obstructive pulmonary disease severity (41,42) and were more likely to be admitted to hospital for respiratory causes (42). Additionally, increased hospitalisation and mortality have been observed among EMGs in coronary health disease, congestive heart failure and cerebrovascular disease (43,44).

Minority ethnicity has been related to increased obesity and comorbidities, which are known correlates of asthma morbidity (45), and is strongly associated with lower socioeconomic status in many countries (7). Evidence from the Severe Asthma Research Program in the U.S.A. has found that socioeconomic factors are a strong mediator of ethnic disparities in asthma ED attendance (8). This could be particularly relevant for the results of our review as the studies included were overwhelmingly based in the U.S.A., where issues relating to variable healthcare insurance and poverty are common among EMGs, and in particular Black and Hispanic patients (46,47). We did not find any evidence of higher rates of ED attendance among Asian patients, who have a more similar socioeconomic status to the White population within the U.S.A. (47).

EMGs, particularly those with limited English proficiency living in countries where this is the primary language (48) and limited reading ability (10), are known to have lower health literacy (11). This is important as poor health literacy has been associated with incorrect metered-dose inhaler technique (10), increased likelihood of inpatient visits (48,49), emergency care (49) and worse asthma control (48). EMGs express greater concern regarding preventive asthma medications (50) and are known to have poorer adherence to their maintenance asthma medications, which has been consistently associated with poorer outcomes in several studies (12). Inadequate living conditions among EMGs may also contribute to the development and severity of asthma symptoms, and reduced asthma control, possibly due to increased allergen exposure (14).

When restricting to higher quality studies we found evidence of lower primary care attendances, but higher secondary healthcare utilisation, among the EMGs which may reflect differences in healthcare seeking behaviour (13,51). The decision to seek primary or secondary care interventions are influenced by various factors, including those related to socioeconomic circumstances and specialist accessibility (52). One USA-based study reported significantly fewer primary care attendances among African Americans when compared to whites even within the same insurance scheme, suggesting that cultural factors and personal beliefs may also be important contributory factors (53). Substantial evidence has shown that African American patients are more reliant on ED services for asthma and other conditions (54,55). Similarly, studies have demonstrated poor awareness of the need for preventative care among Black men who often wait until symptoms appear to seek treatment, and sometimes prioritise treatment for their family rather than themselves (56).

There is some evidence that EMGs have poorer satisfaction with their healthcare providers and have been reported to receive poorer care with lower levels of adherence to guidelines and a greater propensity to underestimate asthma severity than their White counterparts (57–59). Children from minority background are less likely to have their asthma treatment escalated and use more oral corticosteroid at all treatment steps (60–62). Racism and mistrust of healthcare providers have also been shown to result in fewer visits to primary healthcare centres and an

increased tendency to attend ED, which could have contributed to our results (56). It should be noted that many of the other potential drivers of poorer outcomes among EMGs cited previously, including lower socioeconomic status and poorer housing conditions, may also be driven by racism or structural inequality as a root cause (63).

Given the myriad of factors that are potentially driving ethnic disparities, solutions are unlikely to be straightforward. Evidence suggests that culturally-sensitive and tailored interventions are required to mitigate asthma ethnic disparities (64). A recently updated Cochrane review demonstrated the benefits of culturally-specific asthma education programmes in reducing severe asthma exacerbations in minority children, compared to generic programmes or usual care (64). A citywide asthma management program directed towards poor, minority, urban children in the U.S.A. found that adherence to anti-inflammatory guidelines by primary care providers reduced asthma-related hospitalisations, ED visits, and outpatients visits (65). Interventions to improve medication adherence and health literacy are typically cited as potential techniques to reduce health inequalities, however, more work is needed to evaluate their cost-effectiveness and explore their impact on healthcare outcomes (66,67). A recent review of patient and family-led interventions aiming to improve inhaled corticosteroid adherence among Black/African Americans reported that no randomised controlled trials have found a statistically significant improvement in adherence (68).

This review is novel as it is the first to systematically report on the association of ethnicity on various aspects of asthma healthcare outcomes and it was not restricted to specific countries or patient demographics. Our results provide an at-a-glance summary of all relevant studies and our exploration of heterogeneity highlights specific subgroups where disparities are largest and action is urgently needed to standardise care.

Several of the studies included in our primary analysis were of low quality and there were high levels of heterogeneity for several outcomes, which could be related to differences in outcome classification, exposure definition, methodology (e.g. type of effect estimate) or study definition and may hinder the interpretability of our results. However, this was largely reduced when restricted to high-quality studies and our overall conclusions of increased secondary healthcare utilisation and exacerbations among EMGs were unaltered. Although we used subgroup analyses to explore heterogeneity, this was limited by the analyses that were reported in the primary studies. Data on important subgroups, for example sex-specific estimates, were generally not available. We restricted our review to studies which use White patients as their reference group which may have biased our analysis to Northern American and European countries.

Our primary analysis presented all EMGs combined; however, this is unlikely to be valid. Although we presented separate estimates for Black, Hispanic and Asian patients, important

differences are likely to exist even within these groups. For example, Mexican Americans have markedly lower asthma morbidity than Puerto Ricans (4). The majority of the studies included in this review were based in the U.S.A., which may limit the generalisability of our results. We believe that this is an important finding in itself and may suggest a lack of research into the magnitude and drivers of ethnic disparities in asthma outcomes within many countries. Despite our finding of a broad literature on ethnic disparities among adults living in the U.S.A., this evidence had not previously been considered within a systematic review prior to the present study. Consequently, our results provide new and important evidence for practitioners in that region. Surprisingly, no studies have explored ethnic differences in mortality using individual patient data and this is an important area for future research. Lastly, our study did not include data on intermediate outcomes such as asthma control.

Conclusion

In summary, EMGs with asthma had substantially higher rates of secondary healthcare utilisation and exacerbations with evidence suggestive of lower primary care attendances. Despite the global importance of this issue, the vast majority of relevant studies were from the U.S.A. and it remains largely unclear if these disparities are replicated in other countries with different populations and healthcare funding models. Further research into the causes of these disparities, including whether these vary by specific ethnicity, is required to aid the design of effective interventions. To understand the mechanisms behind these disparities it is likely that

innovative ways of combining qualitative and quantitative studies and of examining mediation effects will need to be pursued or developed further (69–71).

Author Contributions: AA-I (guarantor) conducted the search, screened the articles, performed data curation, analysed data, wrote, and edited the original draft. JB, LGH & CR were instrumental in designing and developing the search strategy. AB & DMcC both screened and extracted data from articles. JB conceived the idea for the review, supervised the work, assisted with data analysis, drafting, and editing the original and subsequent drafts. FK monitored the progress of work, revised, and edited the draft paper. LGH, AB, DMcC & CR edited the draft paper.

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Table 1: Demographic and characteristics of 56 studies evaluating asthmatic patients' healthcare utilisation

Study ID	Country	Design	Patients	Female (%)	Mean Age, years	Clinical Setting	Exposure	Outcomes Measured
Mitchell 1988(38)	New Zealand	CS	355	NS	5.8	Gen Pop	Asian	Readmission
Lozano 1995(72)	USA	CS	1,945	41.7	8.1	Insurance	Black	ED Visit, Hosp, PCA
Sarpong 1997(73)	USA	CS	138	65.0	10.1	Sec Care	Black	Hosp
Joseph 1998(74)	USA	CS	570	38.0	NS	Sec Care	Black	ED Visit, Hosp
Zoratti 1998(25)	USA	CSS	2,073	65.0	30.7	Insurance	Black	ED Visit, Hosp, PCA
Blixen 1999(53)	USA	CS	193	77.2	37.3	Hosp Record	Black	ED Visit, PCA
Meurer 2000(75)	USA	CSS	307	NS	NS	Gen Pop	Black, Hispanic	ED Visit
Eisner 20011(76)	USA	CS	242	73.0	40.5	Gen Pop	Black, Hispanic, Asian	Hosp
Krishnan 2001(77)	USA	CSS	5,062	71.6	44.0	Gen Pop	Black	ED Visit, Hosp
Ortega 2001a(78)	USA	CS	1,002	37.0	5.3	Gen Pop	Black, Hispanic	ED Visit, Hosp
Ortega 2001b(79)	USA	CS	897	37.3	NS	Gen Pop	Black, Hispanic	ED Visit, Hosp
Amre 2002(39)	Canada	CS	457	44.1	NS	ED Record	Other	ED Visit, Hosp
Diette 2002(80)	USA	CS	6,590	70.1	NS	Gen Pop	Black, Other	Hosp
Lafata 2002(81)	USA	CS	452	37.0	8.7	Insurance	Black, Other	ED Visit, Hosp
Weber 2002(32)	USA & Canada	CS	1,805	65.3	35	ED Record	Black, Hispanic	Hosp
Bloomberg 2003(33)	USA	CS	8,761	37.2	NS	Hosp Rec	Black, Other	Readmission
Boudreaux 2003a(34)	USA & Canada	CS	1,800	65.2	34.7	ED Record	Black, Hispanic	ED Visit, Hosp
Boudreaux 2003b(82)	USA & Canada	CS	1,095	40.2	7.8	ED Record	Black, Hispanic	Hosp, Intu
Shields 2004(83)	USA	CS	5,773	40.6	NS	Insurance	Black	ED Visit, Hosp
Carroll 2005(84)	USA	CS	4,315	100	NS	Insurance	Black	ED Visit, Hosp
Grant 2005(85)	USA	CSS	152	61.8	NS	Gen Pop	Black	ED Visit, Hosp
Griswold 2005(86)	USA	CS	3,151	63.1	35.2	Gen Pop	Black, Hispanic, Other	ED Visit
Ash 2006(87)	USA	CS	10,145	67.4	NS	Hosp Rec	Black, Hispanic, Other	Readmission
Meng 2006(88)	USA	CSS	4,359	68.2	NS	Gen Pop	Black, Hispanic, Asian, Other	ED Visit
DeWalt 2007(89)	USA	CSS	150	NS	7.7	Gen Pop	Black	ED Visit, Hosp
Erickson 2007(90)	USA	CS	678	71.2	61.1	Hosp Rec	Black	ED Visit, Hosp
Forester 2008(91)	USA	CSS	80	45.0	9	Gen Pop	Black, Hispanic	Hosp

Haselkorn 2008(92)	USA	CS	2,128	71.9	50.3	Gen Pop	Black	ED Visit
Chandra 2009(93)	USA	CS	1,232	55.7	NS	Hosp Rec	Black, Hispanic	Hosp
Crocker 2009(94)	USA	CSS	1,485	NS	NS	Gen Pop	Black, Hispanic	ED Visit, Hosp
Diette 2009(95)	USA	CSS	406	42.3	10.2	Gen Pop	Black, Other	Hosp, PCA
Gorman 2009(96)	USA	CSS	133,509	51.7	45.2	Gen Pop	Black, Hispanic, Asian, Other	ED Visit
Haselkorn 2009(97)	USA	CS	563	31.3	NS	Gen Pop	Other	Exacerbation
Kim 2009(98)	USA	CSS	982	36.2	NS	Gen Pop	Black, Hispanic	ED Visit
Wright 2009(99)	USA	CSS	1,313	38.0	NS	Gen Pop	Black, Hispanic	ED Visit
Carroll 2010(100)	USA	CS	306	42.2	8.1	Hosp Rec	Black, Hispanic	Exacerbation
Canino 2012(101)	USA	CSS	804	43.6	10.6	Gen Pop	Hispanic	ED Visit
Hasegawa 2014(102)	USA	CS	86,224	NS	NS	Insurance	Black, Hispanic, Other	ED Visit
Kenyon 2014(103)	USA	CS	36,601	38.9	NS	Hosp Rec	Black, Hispanic, Other	Readmission
Lee 2014(104)	USA	CSS	1,323	67.2	74.4	Gen Pop	Black, Hispanic, Asian, Other	ED Visit
Auger 2015(105)	USA	CS	601	NS	5.1	Ter Care	Black, Other	Readmission
Venkat 2015(106)	USA	CS	1,785	59.8	NS	Sec Care	Black, Hispanic	ED Visit, Hosp
Wells 2015(107)	USA	CCS	719	74.1	32.4	Sec Care	Black, Hispanic, Other	ED Visit
Hull 2016(35)	UK	CS	35,864	53.3	NS	Prim Care	Black, Asian	Hosp
Mitchell 2016(26)	USA	CS	273	41.4	7.5	Gen Pop	Black	Hosp, Intu
Franklin 2017(108)	USA	CS	265	42.6	11.5	Hosp Rec	Black	ED Visit, Hosp, Intu
Hughes 2017(109)	USA	CSS	33,201	49.7	NS	Gen Pop	Black, Hispanic, Asian	ED Visit
Parikh 2017(110)	USA	CS	36,906	37.4	5	Ter Care	Black, Hispanic, Other	Readmission
Zhang 2017(111)	USA	CSS	5,535	42.7	11.8	Gen Pop	Black, Hispanic	ED Visit
Deshpande 2018(24)	USA	CSS	5,672	68.3	49.3	Gen Pop	Black, Hispanic	ED Visit
Grunwell 2018(112)	USA	CS	579	41.8	NS	Sec Care	Black, Other	Hosp, Intu
Trent 2018(113)	USA	CS	913	53.3	NS	Hosp Rec	Black, Hispanic	ED Visit, Hosp, Intu
Aratani 2019(114)	USA	CS	47,657	36.0	2.7	Sec Care	Black, Hispanic, Asian, Other	Hosp
Fitzpatrick 2019(8)	USA	CS	631	59.3	38.2	Sec Care	Black	ED Visit, Hosp
Cremer 2020(40)	USA	CSS	4,700	67.3	66.5	Gen Pop	Black, Hispanic	ED Visit, Hosp
Urquhart 2020(115)	USA	CSS	3,336	41.3	NS	Gen Pop	Black, Hispanic	ED Visit
Zein 2020(116)	USA	CS	60,302	62.1	47.5	Sec Care	Black, Asian, Other	Exacerbation

Banta 2021(117)	USA	CSS	61,625	49	NS	Gen pop	Hispanic, Other	ED Visit, Exacerbation
Kraft 2021(27)	USA	CS	5,701	66	49.5	Hosp Rec	Black, Asian, Other	Exacerbation
Sheikh 2021(30)	USA	CS	345	44.6	6.2	Ter Care	Black	ED Visit
Adejare 2022(29)	USA	CS	42,375	67.2	49.6	Hosp Rec	Black	ED Visit
Beuther 2022(31)	USA	CS	1,112	70.5	43.9	Ter Care	Other	Exacerbation
Busby 2022a(37)	UK	CS	3,402	63.6	50.0	Ter Care	Black, Asian, Other	ED Visit, Exacerbation
Busby 2022b(37)	UK	CS	13,936	67.9	55.8	Prim Care	Black, Asian, Other	ED Visit, Exacerbation
Lugogo 2022(28)	USA	CS	1,884	69	54	Ter Care	Black, Hispanic, Other	ED Visit, Hosp, Exacerbation
Redmond 2022(36)	UK	CS	1,140	61.1	50.6	Hosp Record	Other	Exacerbation

NOTE: CS, Cohort Study; CSS, Cross-sectional Study; CCS, Case Control Study; ED, Emergency Department; Gen Pop, General Population (i.e., survey / interview); Hosp, Hospitalisation; Intu, Intubation; NS, Not Specified; PCA, Primary Care Attendance; Prim, Primary; Sec, Secondary; Ter, Tertiary

Table 2 – Pooled effect of ethnicity on asthma-related healthcare utilisation and morbidity

Outcome	All Studies			Good Quality		
	N	OR (95% CI's)	I^2	N	OR (95% CI's)	I^2
Health Care Utilization						
Primary Care Attendance	4	0.72 (0.48, 1.09)	70.5	3	0.61 (0.44, 0.83)	6.9
ED Visit	36	1.74 (1.53, 1.98)	90.3	21	1.74 (1.56, 1.93)	49.8
Hospitalisation	30	1.63 (1.48, 1.79)	43.1	15	1.54 (1.35, 1.77)	29.9
Hospital readmission	6	1.19 (0.90, 1.57)	78.0	5	1.12 (0.84, 1.51)	79.3
Ventilation / Intubation	5	2.67 (1.65, 4.31)	74.2		NS	
Exacerbations						
Exacerbations	7	1.10 (0.94, 1.28)	78.8	5	1.06 (0.91, 1.23)	78.6

NOTE: ED, Emergency Department; NS, Not Specified; ORs reported are Ethnic Minority Groups vs White

Figure Legends

Figure 1: PRISMA flowchart diagram outlining the study search and selection process

Figure 2: Forest plot of odds ratio of asthma-related emergency department visits

Figure 3: Forest plot of odds ratio of asthma-related hospitalisation

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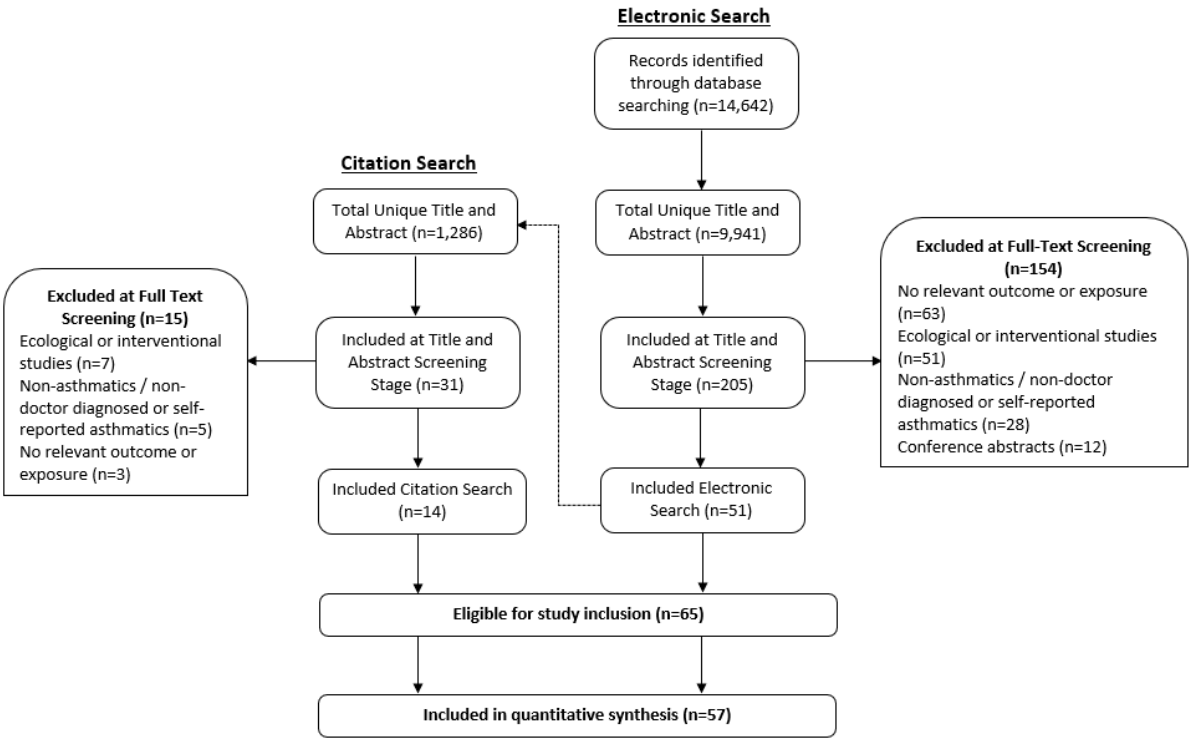
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Citation Search
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Non-asthmatics / non-doctor diagnosed or self-reported asthmatics (n=5)
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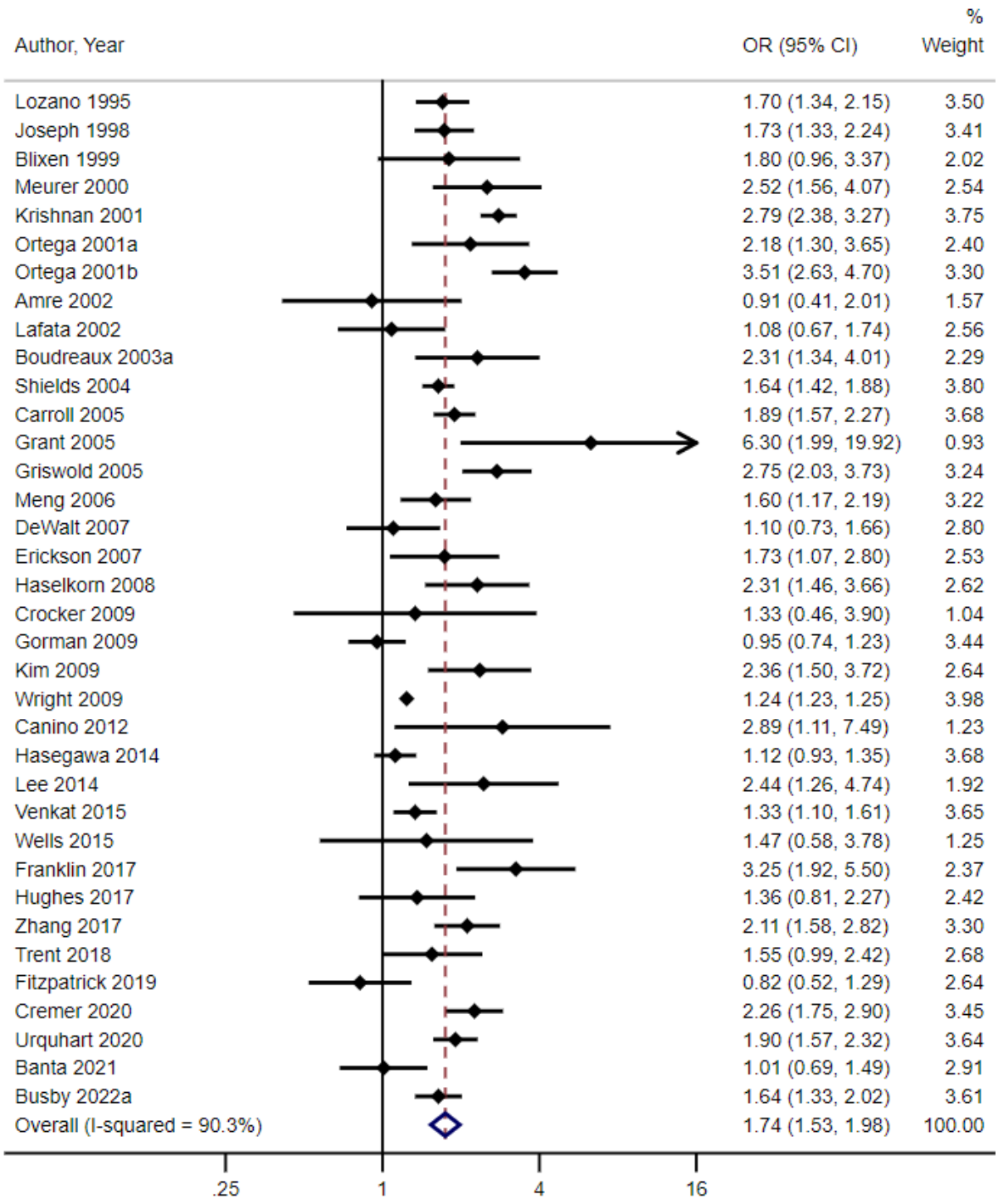
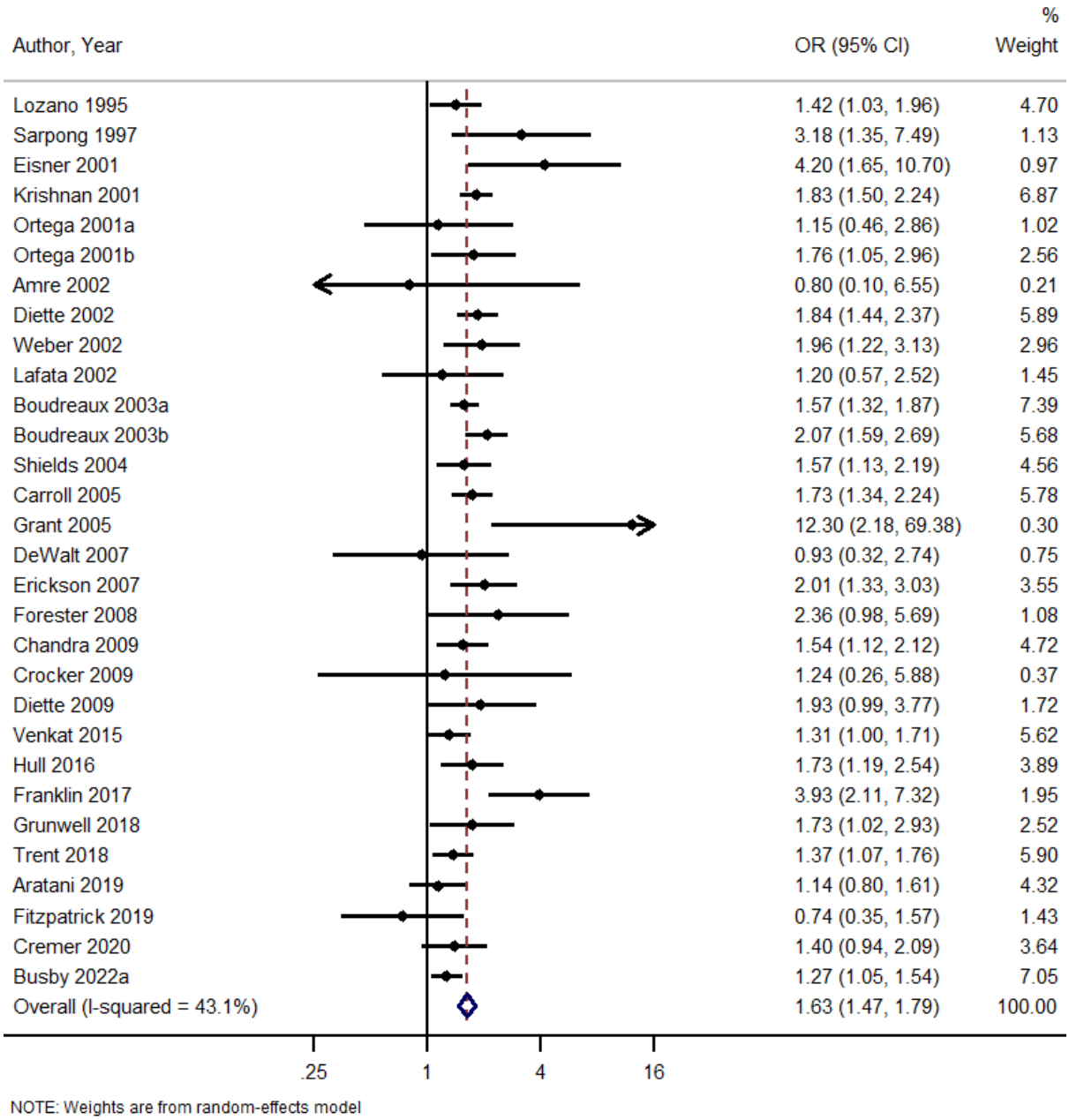


NOTE: Weights are from random-effects model



NOTE: Weights are from random-effects model

Online Data Supplement

Title: Variation in asthma care, exacerbations and mortality by ethnicity: A systematic review and meta-analysis.

Authors: AbdulQadr Akin-Imran, PhD[1,2], Achint Bajpai, BSc[3], Dáire McCartan[1], Liam G Heaney, MD[4], Frank Kee, MD[1], Charlene Redmond, BSc[1], John Busby, PhD[1]

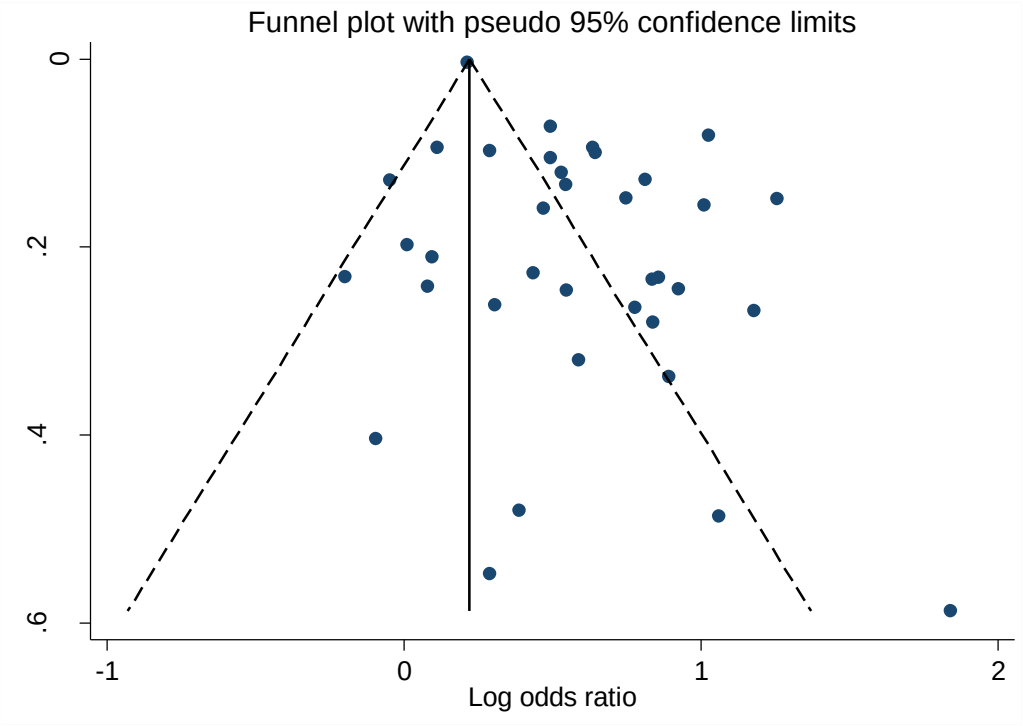


Figure S1: Funnel plot for studies reporting emergency department visits by different ethnic minority groups

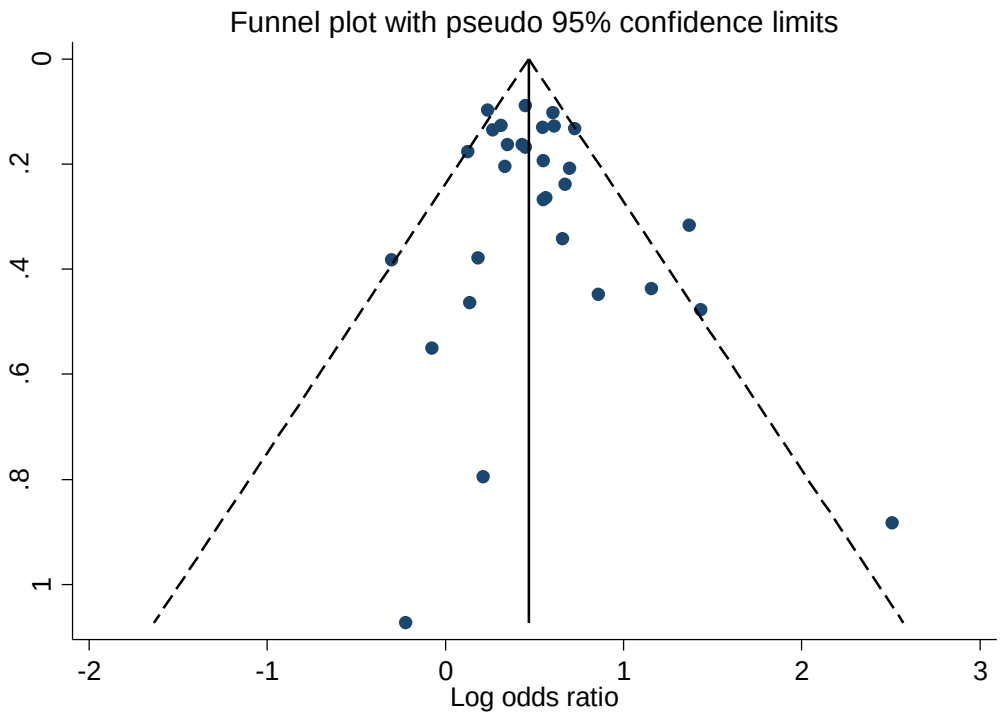


Figure S2: Funnel plot for studies reporting hospitalisations by different ethnic minority groups

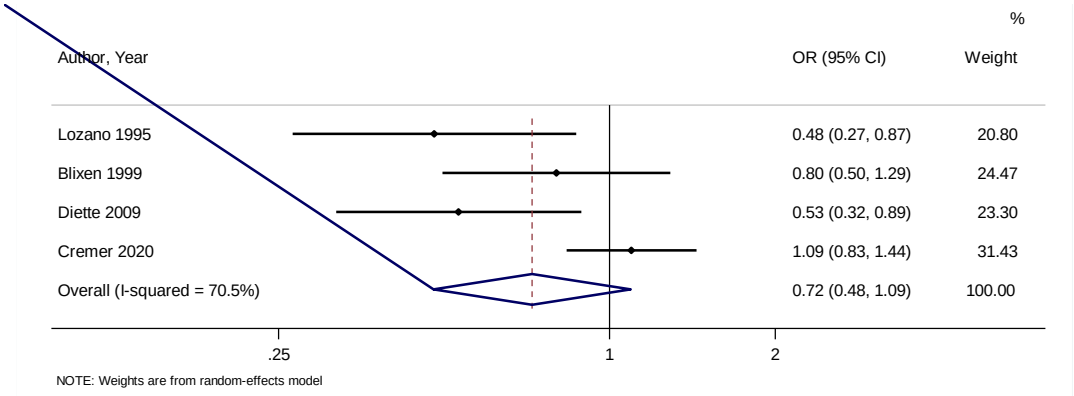


Figure S3: Forest plot of odds ratio of asthma-related primary care attendance

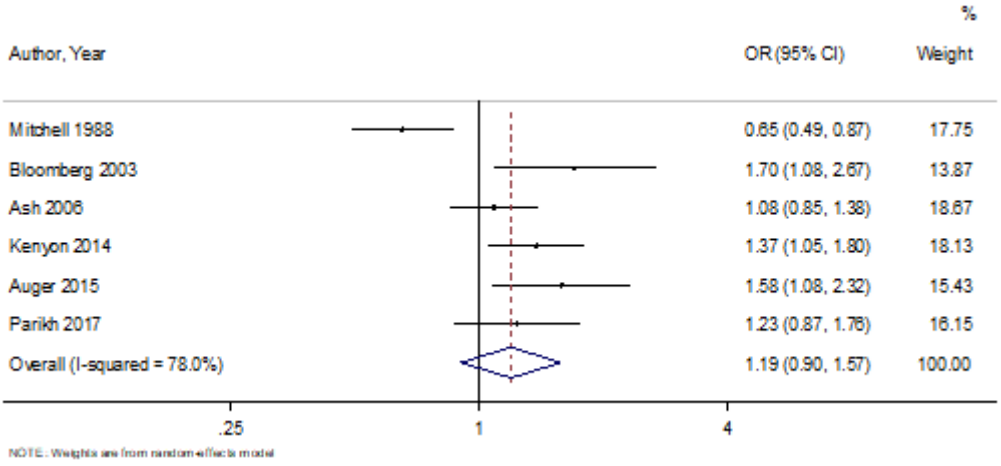


Figure S4: Forest plot of odds ratio of asthma-related hospital readmission

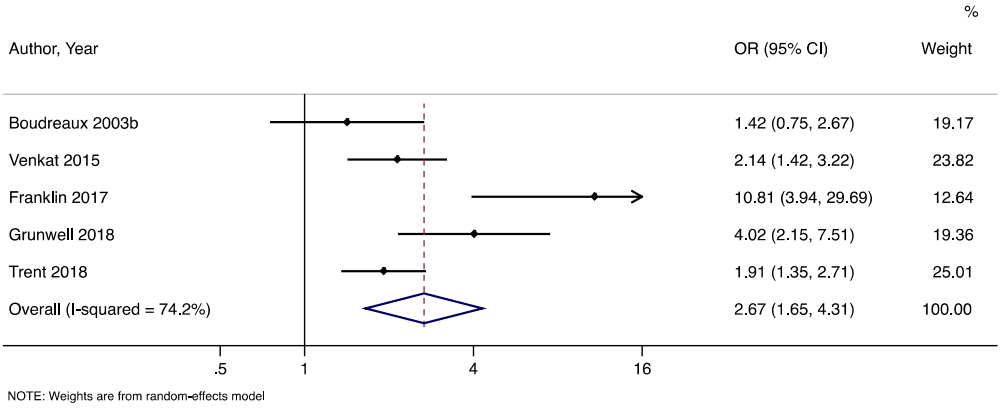


Figure S5: Forest plot of odds ratio of asthma-related ventilation / intubation

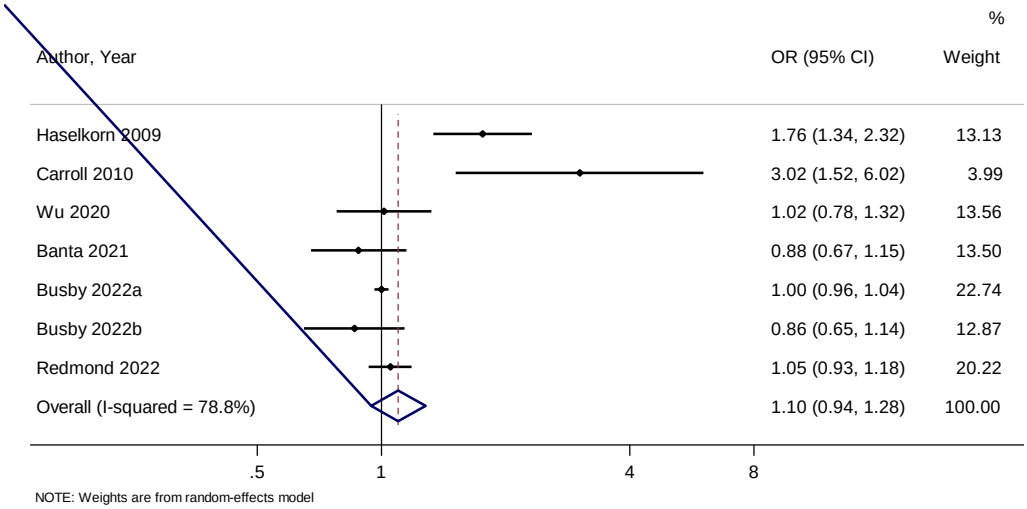


Figure S6: Forest plot of odds ratio of asthma-related exacerbation

Online Data Supplement

Title: Variation in healthcare utilisation, exacerbations and mortality by ethnicity: A systematic review and meta-analysis.

Authors: AbdulQadr Akin-Imran, PhD[1,2], Achint Bajpai, BSc (Hons)[3], Dáire McCartan[1], Liam G Heaney, MD[4], Frank Kee, MD[1], Charlene Redmond, BSc[1], John Busby, PhD[1]

Table S1: Search domains and terms used in MEDLINE and EMBASE database

MEDLINE and EMBASE search strategy: Ovid <inception to July 2020>

Domain	Search Terms
Asthma	Asthma/ or asthma.mp. OR wheeze.mp. **AND**
Ethnic/race	Ethnic Groups/ or ethnic*.mp. OR race*.mp. OR racial group.mp. OR migration.mp. OR emigrant*.mp. OR migrant*.mp. OR "Emigrants and Immigrants"/ or "Emigration and Immigration"/ OR Minority Groups/ or minorit*.mp. OR Minority Health/ OR Refugees/ or refug*.mp. OR Refugee Camps/ OR asylum.mp. OR Indian.mp. OR Pakistani.mp. OR Bangladeshi.mp. OR Asian.mp. OR Black.mp. OR Afro*.mp. OR African Americans/ OR African.mp. OR Chinese.mp. OR BAME.mp. OR Eastern Europe.mp. OR Europe, Eastern/ OR Eastern Europe*.mp. OR Europe, Eastern/ OR Irish.mp. OR Non?White*.mp. OR Arabs.mp. or Arabs/ OR Gyps*.mp. OR Gips*.mp. OR Jews/ OR Jew*.mp. OR Hispanic Americans/ OR Hispanic*.mp. OR Latin America/ or Latin*.mp. OR white.mp. OR mixed.mp. OR Caribbean.mp. OR American Indian.mp. or Indians, North American/ OR Alaska Native.mp. or Alaska Natives/ OR Native Hawaiian.mp. OR Pacific Islander.mp. **AND**
Outcome	Mortality/ or mortality.mp. OR Death/ or death*.mp. OR morbidity.mp. or Morbidity/ OR exacerbat*.mp. OR vent*.mp. OR emergency department.mp. or Emergency Service, Hospital/ OR ED.mp. OR A&E.mp. OR (accident and emergency).mp. OR accident & emergency.mp. OR emergency room.mp. OR emergency ward.mp. OR Patient Readmission/ or readmission*.mp. OR hospitali?ation.mp. OR Patient Admission/ or admission*.mp. OR General Practice/ or general pract*.mp. or Primary Health Care/ or General Practitioners/ OR primary care.mp. OR attend*.mp. OR consult*.mp. OR utili*.mp. OR Intensive Care Units/ or ICU.mp. OR (High Dependency Unit* or HDU).mp. OR critical care.mp. or Critical Care/

Table S2: Search domains and terms used in Web of Science database

Web of Science search strategy: <Inception to July 2020>

Domain	Search Terms
Asthma	TS= (asthma OR wheeze) **AND**
Ethnic/race	TS= (ethnic* OR ethnic groups OR race* OR racial group OR migration OR migrant* OR minorit* OR minority group OR minority health OR emigrant* OR immigrant* OR immigrant OR refug* refugee camp OR asylum OR Indian OR Pakistani OR Bangladeshi OR Asian OR Black OR Afro* OR African OR African American OR Chinese OR BAME OR Eastern Europe* Irish OR Non white* OR arabs/ or gypsies/ or jews* OR Hispanic* OR Latin* OR Gyps* OR Gips*) **AND**
Outcome	TS= (mortality OR death* OR morbidity OR exacerbat* OR vent* OR "emergency department" OR ED OR (accident near/2 emergency) OR A&E OR readmission* OR hospitali?ation OR admission* OR "primary care" OR GP OR "general pract*" OR *attend* or consult* or utili*)

Table S3: List of data fields collected during data extraction

Study details	**Categorical variable options**
Title	
Lead author contact details	
Cohort description	
Country in which the study was conducted	
Study design	Case control, cohort, cross-sectional
Data collection setting	General practice, hospitalization records, ED records, secondary care, tertiary care, insurance database, general population, other
Study year / Data collection period	
Total number of participants	
Mean Age (SD/SE)	
Female (%)	
Age range	
Inhaled Corticosteroid (%)	
Oral Corticosteroid (%)	
Severe asthma (%)	
Asthma severity	Not specified, mild, moderate, severe, other
FEV1 Average	

Study comparison data	**Categorical variable options / examples**
Exposure	Race, Ethnicity, Race/Ethnicity
Group compared	e.g., White vs Hispanic
Reference group summary	i.e., White
Estimate group summary	e.g., Black
How outcomes were compared	e.g., the probability of ED visit (odds ratio) or counting the number of admissions (rate ratio)
Outcomes	primary care attendance, exacerbations, ED visit, hospitalisation, ventilation / intubation, readmission, Mortality
Ratio type	Odds ratio, risk ratio, hazard ratio, chi squared
Ratio	
Lower CI	
Upper CI	
Confidence level (%)	
P value	
Standard error	
Are estimates adjusted?	Yes, no
Variables adjusted for	
Were estimates calculated manually?	Yes, no
Outline how estimate was calculated	

Table S4: Quality assessment criteria, based on Newcastle - Ottawa Quality Assessment Scale Cohort Studies

Note: A study can be awarded a maximum of one star for each numbered item within the Selection and Outcome categories. A maximum of two stars can be given for Comparability

Selection
1) Representativeness of the exposed cohort
a) truly representative of the average **(i.e. ethnic minority asthma patients)** in the community ✵ b) somewhat representative of the average **(i.e. ethnic minority asthma patients)** in the community ✵ c) selected group of users e.g. nurses, volunteers d) no description of the derivation of the cohort
2) Selection of the non exposed cohort
a) drawn from the same community as the exposed cohorts (i.e. **White / Caucasian / non-minority asthma patients)** ✵ b) drawn from a different source c) no description of the derivation of the non exposed cohort
3) Ascertainment of exposure
a) secure record (e.g. **medical, insurance, health records)** ✵ b) structured interview ✵ c) written self report d) no description
4) Demonstration that outcome of interest was not present at start of study
a) yes ✵ b) no
Comparability
1) Comparability of cohorts on the basis of the design or analysis
a) study controls for (**asthma severity**) ✵ b) study controls for any additional factor (**e.g. sex, age, socioeconomic status, comorbidity)** ✵
Outcome
1) Assessment of outcome
a) independent blind assessment (e.g. **health records**) ✵ b) record linkage (e.g. **health records**) ✵ c) self report (i.e. **no reference to original health records or documented source to confirm the outcome**) d) no description
2) Was follow-up long enough for outcomes to occur
a) yes (**3 months and over)** ✵ b) no
3) Adequacy of follow up of cohorts
a) complete follow up - all subjects accounted for ✵ b) subjects lost to follow up unlikely to introduce bias - small number lost **(<5%)** follow up, (or description provided of those lost) ✵ c) follow up rate **< 80%** and no description of those lost

d) no statement

Threshold between good and poor-quality studies

Studies were rated poor-quality if:

- They did not adjust, by design or analysis, any factor
- They had less than 2 stars in the outcome section
- They had less than 3 stars in the selection section
- They had an overall rating of less than 6 stars

NOTE: The above quality assessment criteria were adapted for case-control and cross-sectional studies. However, regarding cross-sectional studies, studies were assigned a single star for ascertainment of the exposure, if they had used a validated tool, or described the measurement tool within the study or in their study protocol.

Table S5: Methodological quality assessment of the included studies using Newcastle-Ottawa Scale

Cohort Study

Study	Selection				Comparability	Outcomes			Quality Rating
	Representativ e-ness	Selection	Exposure Ascertainment	Outcome not present at start of study	Comparability	Outcome Assessment	Sufficient follow-up period	Adequacy of follow-up	
Mitchell 1988[1]	*	*	-	*	*	*	*	*	Good
Lozano 1995[2]	*	*	*	*	*	*	*	*	Good
Sarpong 1997[3]	*	*	-	*	*	*	*	*	Good
Joseph 1998[4]	*	*	*	*	*	*	*	*	Good
Blixen 1999[5]	*	*	*	*	*	*	*	*	Good
Eisner 2001[6]	*	*	-	*	*	-	*	-	Poor
Ortega 2001a[7]	*	*	-	*	-	-	*	*	Poor
Ortega 2001b[8]	*	*	-	*	-	-	*	*	Poor
Amre 2002[9]	*	*	*	*	*	-	*	*	Good
Diette 2002[10]	*	*	-	*	*	-	*	-	Poor
Lafata 2002[11]	*	*	*	*	*	*	*	*	Good
Weber 2002[12]	*	*	*	*	*	-	*	-	Poor
Bloomberg 2003[13]	*	*	*	*	-	*	*	*	Poor
Boudreaux 2003a[14]	*	*	-	*	-	*	*	*	Poor
Boudreaux 2003b[15]	*	*	-	*	*	-	*	-	Poor
Shields 2004[16]	*	*	-	*	*	*	*	*	Good
Carroll 2005[17]	*	*	*	*	*	*	*	*	Good
Griswold 2005[18]	*	*	-	*	*	*	*	*	Good
Ash 2006[19]	-	*	*	*	*	*	*	*	Good
Erickson 2007[20]	*	*	-	*	*	*	*	-	Good
Haselkorn 2008[21]	*	*	-	*	*	-	*	*	Good
Chandra 2009[22]	*	*	*	*	-	*	*	*	Poor
Haselkorn 2009[23]	*	*	-	*	*	-	*	*	Good
Carroll 2010[24]	*	*	*	*	-	*	-	*	Poor
Hasegawa 2014[25]	*	*	*	*	-	*	*	-	Poor

Kenyon 2014[26]	*	*	*	*	*	*	*	-	Good
Auger 2015[27]	*	*	*	*	*	*	*	-	Good
Venkat 2015[28]	*	*	*	*	-	*	-	*	Poor
Hull 2016[29]	*	*	-	*	*	*	*	*	Good
Mitchell 2016[30]	*	*	-	*	-	-	*	*	Poor
Franklin 2017[31]	*	*	-	*	-	*	*	*	Poor
Parikh 2017[32]	*	*	-	*	*	*	*	*	Good
Grunwell 2018[33]	*	*	-	*	*	-	*	*	Good
Trent 2018[34]	*	*	*	*	-	*	*	*	Poor
Aratani 2019[35]	*	*	*	*	*	*	*	*	Good
Fitzpatrick 2019[36]	*	*	-	*	-	*	*	*	Poor
Zein 2020[37]	*	*	*	*	-	*	*	*	Poor
Kraft 2021[38]	*	*	*	*	-	*	*	*	Poor
Sheikh 2021[39]	*	*	-	*	-	-	*	*	Poor
Adejare 2022[40]	*	*	*	*	-	*	*	*	Poor
Beuther 2022[41]	*	*	-	*	*	*	*	*	Good
Busby 2022[42]	*	*	*	*	*	*	*	*	Good
Lugogo 2022[43]	*	*	*	*	-	*	*	*	Poor
Redmond 2022[44]	*	*	*	*	*	*	*	*	Good

Cross-sectional Study

Study	Selection				Comparability	Exposures		Quality Rating
	Representative-ness	Sample size	Response rate	Exposure Ascertainment	Comparability	Outcome Assessment	Statistical test	
Zoratti 1998[45]	*	*	*	*	-	**	*	Poor
Meurer 2000[46]	*	*	-	*	*	*	*	Good
Krishnan 2001[47]	*	*	*	*	-	*	*	Poor
Grant 2005[48]	*	*	*	*	*	*	*	Good

Meng 2006[49]	*	*	-	*	*	*	*	Good
DeWalt 2007[50]	*	*	-	*	*	*	*	Good
Forester 2008[51]	*	*	*	*	-	*	*	Poor
Crocker 2009[52]	*	*	-	*	*	*	*	Good
Diette 2009[53]	*	*	-	*	*	*	*	Good
Gorman 2009[54]	*	*	-	*	-	*	-	Poor
Kim 2009[55]	*	*	-	*	*	*	*	Good
Wright 2009[56]	*	*	*	*	-	*	*	Poor
Canino 2012[57]	*	-	*	-	-	*	*	Poor
Lee 2014[58]	*	*	-	*	*	*	*	Good
Hughes 2017[59]	*	*	*	*	*	*	*	Good
Zhang 2017[60]	*	*	-	*	*	*	*	Good
Deshpande 2018[61]	*	*	-	*	*	*	*	Good
Cremer 2020[62]	*	*	-	*	*	*	*	Good
Urquhart 2020[63]	*	*	-	*	*	*	*	Good
Banta 2021[64]	*	*	*	*	*	*	*	Good

Case control Study

Study	Selection				Comparability	Outcomes			Quality Rating
	Case Definition	Representative-ness	Control Selection	Control Definition	Comparability	Exposure Ascertainment	Consistent between cases and controls	Non-Response rate	
Wells 2015[65]	-	*	-	*	-	*	*	-	Poor

Table S6: Adjustment factors reported from studies reporting asthma-related healthcare use by ethnicity

Study ID	Age	Sex	SES	Income	Insurance	Education	BMI	Asthma severity	Asthma drug	Smoking status	Comorbidity	Health status	Location	Literacy
Mitchell 1988[1]	×	×	✓	×	×	×	×	×	×	×	×	×	×	×
Lozano 1995[2]	✓	✓	×	×	×	×	×	×	×	×	×	×	✓	×
Sarpong 1997[3]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Joseph 1998[4]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Zoratti 1998[45]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Blixen 1999[5]	✓	✓	×	✓	×	×	×	×	×	×	×	×	×	×
Meurer 2000[46]	✓	✓	×	×	×	×	×	✓	×	×	×	×	×	×
Eisner 20011[6]	✓	✓	×	✓	×	✓	×	✓	×	✓	×	✓	×	×
Krishnan 2001[47]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Ortega 2001a[7]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Ortega 2001b[8]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Amre 2002[9]	✓	✓	×	×	×	×	×	×	✓	✓	×	×	×	×
Diette 2002[10]	✓	✓	×	×	×	✓	×	✓	×	✓	✓	✓	×	×
Lafata 2002[11]	✓	✓	×	✓	×	×	×	×	×	×	×	×	×	×
Weber 2002[12]	✓	✓	×	×	×	×	×	✓	✓	×	×	×	×	×
Bloomberg 2003[13]	✓	✓	×	×	✓	×	×	×	×	×	×	×	×	×
Boudreaux 2003a[14]	✓	✓	×	✓	✓	×	×	×	✓	×	×	×	×	×
Boudreaux 2003b[15]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Shields 2004[16]	✓	✓	×	×	✓	×	×	×	×	×	×	×	✓	×
Carroll 2005[17]	✓	×	×	×	×	✓	×	×	×	✓	×	×	✓	×
Grant 2005[48]	✓	✓	×	✓	×	×	×	×	✓	×	×	×	×	×
Griswold 2005[18]	✓	✓	×	×	✓	✓	×	×	✓	×	×	×	×	×
Ash 2006[19]	✓	✓	×	×	×	×	×	×	×	×	✓	×	×	×
Meng 2006[49]	✓	✓	×	✓	✓	✓	×	✓	×	✓	×	✓	✓	×
DeWalt 2007[50]	✓	×	×	✓	×	×	×	✓	✓	✓	×	×	×	✓
Erickson 2007[20]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Forester 2008[51]	✓	×	×	×	×	×	×	×	✓	×	×	×	×	✓
Haselkorn 2008[21]	×	×	×	×	×	×	×	×	×	×	×	×	×	×

Chandra 2009[22]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Crocker 2009[52]	✓	✓	×	✓	✓	×	✓	✓	×	✓	×	×	✓	×
Diette 2009[53]	✓	✓	×	✓	✓	✓	✓	×	×	×	×	×	×	×
Gorman 2009[54]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Haselkorn 2009[23]	✓	✓	×	✓	×	×	✓	×	✓	✓	×	×	×	×
Kim 2009[55]	✓	✓	×	×	×	×	×	×	×	×	×	×	✓	×
Wright 2009[56]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Carroll 2010[24]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Canino 2012[57]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Hasegawa 2014[25]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Kenyon 2014[26]	✓	✓	×	✓	×	×	×	×	✓	×	×	×	×	×
Lee 2014[58]	×	✓	×	×	✓	×	×	✓	✓	✓	×	✓	×	×
Auger 2015[27]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Venkat 2015[28]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Wells 2015[65]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Hull 2016[29]	✓	✓	✓	×	×	×	×	✓	✓	✓	✓	×	×	×
Mitchell 2016[30]	×	×	×	×	×	✓	×	×	×	×	×	×	×	×
Franklin 2017[31]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Hughes 2017[59]	✓	✓	×	✓	×	✓	×	×	×	×	×	×	✓	×
Parikh 2017[32]	✓	×	×	×	✓	×	×	✓	×	×	✓	×	×	×
Zhang 2017[60]	✓	✓	×	✓	✓	✓	×	×	×	✓	×	×	×	×
Deshpande 2018[61]	✓	✓	×	×	×	✓	×	×	✓	×	×	✓	×	×
Grunwell 2018[33]	✓	×	×	✓	×	×	×	✓	×	×	✓	×	×	×
Trent 2018[34]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Aratani 2019[35]	×	✓	×	×	×	×	×	×	×	×	×	×	×	×
Fitzpatrick 2019[36]	×	×	×	✓	×	✓	×	×	×	✓	×	×	×	×
Cremer 2020[62]	×	×	×	×	✓	×	×	×	✓	✓	✓	×	×	×
Urquhart 2020[63]	✓	✓	×	✓	✓	✓	×	×	×	×	×	✓	✓	×
Zein 2020[37]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Banta 2021[64]	✓	✓	×	×	×	×	✓	×	×	×	×	×	×	×
Kraft 2021[38]	×	×	×	×	×	×	×	×	×	×	×	×	×	×

Sheikh 2021[39]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Adejare 2022[40]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Beuther 2022[41]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Busby 2022[42]	✓	✓	×	×	×	×	×	✓	×	×	×	×	×	×
Lugogo 2022[43]	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Redmond 2022[44]	✓	✓	×	×	×	×	×	✓	✓	×	×	×	✓	×

NOTE: SES, socioeconomic status; BMI, body mass index; Smoking; smoking status, exposure, environmental tobacco smoke; Location, urban or rural area of residence; √, Yes; ×, No

TABLE S7 - Subgroup Analyses: pooled effect on asthma-related healthcare utilisation by various factors

Subgroup	ED Visit				Hospitalisation				Hospital Readmission			
	N	OR (95% CI's)	I^2	*P*	N	OR (95% CI's)	I^2	*P*	N	OR (95% CI's)	I^2	*P*
Race				0.001				0.068				<0.001
Black	33	1.86 (1.68, 2.06)	90.6		30	1.69 (1.40, 2.06)	86.1		5	1.76 (1.61, 1.91)	65.4	
Hispanic	22	1.52 (1.35, 1.71)	89.6		13	1.33 (1.09, 1.62)	61.2					
Asian	5	0.97 (0.59, 1.61)	81.8		4	1.42 (0.85, 2.38)	88.8					
Other	8	1.13 (0.86, 1.48)	73.3		6	1.23 (0.88, 1.72)	30.8		4	1.05 (0.97, 1.13)	0.0	
Age				0.942				0.840				
Paediatric	18	1.72 (1.45, 2.04)	89.3		13	1.63 (1.37, 1.94)	36.9					
Other	18	1.79 (1.45, 2.18)	85.8		17	1.62 (1.44, 1.83)	49.1					
Time period				0.745								
Pre-2010	30	1.79 (1.54, 2.08)	90.7									
Post-2010	6	1.58 (1.29, 1.94)	74.2									

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