Original Article

Poor Rhinitis and Asthma Control Is Associated With Decreased Health-Related Quality of Life and Utilities: A MASK-air Study

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What is already known about this topic? National estimates of patients' quality of life based on the control of asthma or allergic rhinitis are lacking. Real-world data may provide insights into the quality of life of patients with asthma or allergic rhinitis and improve the ability to provide care for these patients.

What does this article add to our knowledge? This study provides country-specific estimates (per disease control level) for quality of life in patients with allergic rhinitis or asthma across multiple European countries, using EuroQoL five-dimension utility index scores and the EuroQoL five-dimension visual analog scale.

How does this study impact current management guidelines? This study points to the importance of achieving good rhinitis and asthma control. It also provides insights into patients' preferences regarding different control levels and comorbid status, which are essential for developing guidelines.

BACKGROUND: Allergic rhinitis (AR) and asthma may affect health-related quality of life. However, national estimates on the quality of life of patients with AR or asthma are lacking.
OBJECTIVE: To provide estimates for utility scores and EuroQoL five-dimension (EQ-5D) visual analog scale (VAS) for patients with AR or asthma.
METHODS: We conducted a cross-sectional study using direct patient data from the MASK-air app on European MASK-air users with self-reported AR or asthma. We used a multi-attribute instrument (EQ-5D) to measure quality of life (as utility scores and EQ-5D VAS values). Mean scores were calculated per country and disease control level using multilevel regression models with poststratification, accounting for age and sex biases.
RESULTS: We assessed data from 7905 MASK-air users reporting a total of up to 82,737 days. For AR, utilities ranged from 0.86 to 0.99 for good control versus 0.72 to 0.85 for poor control; EQ-5D VAS levels ranged from 78.9 to 87.9 for good control versus 55.3 to 64.2 for poor control. For asthma, utilities

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Abbreviations used
AR- Allergic rhinitis
CSMS- Combined Symptom-Medication Score
e-DASTHMA- Electronic Daily Control Score for Asthma
HRQoL- Health-related quality of life
MID- Minimal important difference
OECD- Organization of Economic Cooperation and Development
QoL- Quality of life
VAS- Visual analog scale

ranged from 0.84 to 0.97 for good control versus 0.73 to 0.87 for poor control; EQ-5D VAS levels ranged from 68.4 to 81.5 for good control versus 51.4 to 64.2 for poor control. Poor disease control was associated with a mean loss of 0.14 utilities for both AR and asthma. For the same control levels, AR and asthma were associated with similar utilities and EQ-5D VAS levels. However, lower values were observed for asthma plus AR compared with AR alone.

CONCLUSIONS: Poor AR or asthma control are associated with reduced quality of life. The estimates obtained from mobile health data may provide valuable insights for health technology assessment studies. **(J Allergy Clin Immunol Pract 2024;12:1530-8)**

Key words: *Allergic rhinitis; Asthma; EQ-5D-5L; Health-related quality of life; Mobile health; Quality of life; Real-world data; Utilities*

INTRODUCTION

Allergic rhinitis (AR) and asthma can affect quality of life (QoL).[1] Quantifying the impact of AR and asthma on health-related QoL (HRQoL) is important for many purposes including health technology assessment studies that enable cost-utility assessments of interventions for AR or asthma.[2,3] However, national estimates of the HRQoL of patients with AR or asthma per level of disease control are not available.

Health-related QoL can be assessed using different methods. The EuroQoL five-dimension (EQ-5D) questionnaire is the most widely used multi-attribute utility instrument.[4] It assesses five HRQoL domains and produces a five-digit health state profile that can be converted into a single index value (utilities), quantifying the preferences of the population on the respective health states. The EQ-5D questionnaire is also composed of a visual analog scale (VAS) to enable patients to self-assess their health status. The utilities and EQ-5D VAS may both be relevant to policymakers because they provide different and complementary information.[5]

One source of information on QoL may come from real-world data obtained from mobile apps. For example, the EQ-5D−five-level (5L) questionnaire is included in MASK-air (www.mask-air.com; freely available on the Google Play and Apple App Stores of 29 countries), a mobile app for asthma and rhinitis. In its review

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of MASK-air, the Organisation of Economic Cooperation and Development (OECD) stressed the importance of providing data on HRQoL and utilities based on MASK-air real-world data. A previous MASK-air study found that worse AR control is associated with higher EQ-5D-5L levels, with a distinct impact on different EQ-5D-5L domains.[6] However, that independent study did not provide generalizable utilities and EQ-5D VAS estimates for these populations.

Therefore, in this study, we aimed to examine how HRQoL varies with AR or asthma control and to provide populational estimates for the mean utility index score and EQ-5D VAS for these diseases.

METHODS

Study design

We performed a cross-sectional study based on direct patient data from MASK-air. We first used multinomial regression models to assess whether the level of AR or asthma control was associated with differences in the utility index score and the EQ-5D VAS. Then, we calculated estimates computed for the mean utility index score and the mean EQ-5D VAS in European patients with AR or asthma (by country and level of disease control). Furthermore, we applied multivariable models with poststratification to correct for biases in the age and sex distribution of MASK-air users.

Setting and participants

MASK-air is a Good Practice of (i) the Directorate-General for Health and Food Safety (European Commission) for digitally enabled, patient-centered care in rhinitis and asthma multimorbidity[7-9] and (ii) OECD for Public Health on integrated care for chronic diseases.[10]

We assessed European MASK-air users who (1) were aged between 15 or 16 years (depending on the age of digital consent in the country[11]) and 74 years, (2) had self-reported AR or asthma, and (3) had filled-in the full EQ-5D-5L questionnaire (allowing for the computation of utilities) or the EQ-5D VAS alone. We analyzed utilities and EQ-5D VAS data, because they provide complementary information, with utilities being regarded as a societal valuation and the VAS as an individual valuation of the respondent's health state.[5]

We analyzed data (May 2016 to December 2022) from European countries (1) with at least 20 users reporting EQ-5D-5L, and (2) for which a national value set was available to compute utilities based on the EQ-5D-5L. We excluded countries in which data on the mean utilities for the general population were unavailable. For Denmark and Belgium, we were unable to analyze data on asthma due to limitations in the sample size.

Data sources and variables

MASK-air includes a daily monitoring questionnaire in which users report (1) the daily impact of asthma and AR symptoms through a score of 0 to 100 on the VAS (in which higher scores correspond to a higher impact of allergy symptoms), (2) the EQ-5D VAS (on a scale of 0 to 100, in which the higher the value, the better the patient is feeling that day), and (3) the daily use of asthma and rhinitis medication (using a scroll list of prescribed and over-the-counter medications customized for each country).[7] Data collected from daily symptoms and medication use allow for the computation of the Allergic Rhinitis and its Impact on Asthma-EAACI Combined Symptom-Medication Score (CSMS) and the electronic daily control score for asthma (e-DASTHMA)[12,13] (see Table E1 in this article's Online Repository at www.jaci-inpractice.org). In addition, MASK-air users can optionally answer the EQ-5D-5L questionnaire, a multi-attribute instrument that assesses an individual's health status through a VAS and a descriptive system covering five dimensions (see Supplement Methods in this article's Online Repository at www.jaci-inpractice.org).[4] Health states can be converted into utility index scores based on available country-specific standard value sets for the EQ-5D-5L.[14-23]

Data analysis

When responding to the MASK-air daily monitoring questionnaire, it is not possible to skip questions and data are saved only after the final answer. This precludes missing data within each questionnaire.

All analyses were performed using R software (R Foundation for Statistical Computing Platform, Vienna, Austria). Categorical variables are described using absolute and relative frequencies whereas continuous variables are described as means and SDs.

To study whether AR or asthma control is associated with differences in mean utility index scores and EQ-5D VAS levels, we built multilevel mixed-effects models considering the clustering of observations by user and country (ie, they were set as random effects). We selected the level of disease control (ie, CSMS categories for AR and e-DASTHMA score categories for asthma) as a fixed effect and included age and sex as covariates in the models (see Supplemental Methods).

Subsequently, in our main analyses, we estimated the mean utility index scores and mean EQ-5D VAS separately for patients with AR and patients with asthma. Therefore, we assessed four samples per country and per level of disease control: (1) utility index scores in patients with AR, (2) utility index scores in patients with asthma, (3) EQ-5D VAS in patients with AR, and (4) EQ-5D VAS in patients with asthma. To correct for biases in the sex and age representativeness of MASK-air users, we computed multilevel models with poststratification. This method has been previously described elsewhere.[24] It enabled an estimation of the expected nationwide mean utility index scores and EQ-5D VAS levels (by country and level of disease control), and considered the populational sex and age distribution of patients with AR and asthma in the respective countries. We assessed uncertainty by performing 1000 simulations and computing the mean of the coefficients of the multilevel models with poststratification of these 1000 random samples.

Figure 1 represents our method. A more detailed report is available in the Supplemental Methods and in Tables E2 through E4 (in this article's Online Repository at www.jaci-inpractice.org).

We performed sensitivity analyses on (1) users with AR and no asthma, and (2) users with AR and asthma. We were unable to perform additional analyses on patients with only asthma due to limitations in the sample size.

We assessed differences between groups by comparison with the minimal important difference (MID) (determined using 0.5 × SD), corresponding to 10 points for EQ-5D VAS[11] and 0.09 for utilities. The MID may vary according to target population, so a difference of less than 10 points on the EQ-5D VAS or less than 0.09 in the utility score would not be deemed clinically relevant.

Ethics

MASK-air is registered with *Conformité Européene* and follows the European Union General Data Protection Regulation. An independent review board approval was not required for this specific study because (1) the use of MASK-air secondary data was approved by an independent review board (Köln-Bonn, Germany; reference no. 17−069), (2) all data were anonymized before the study using k-

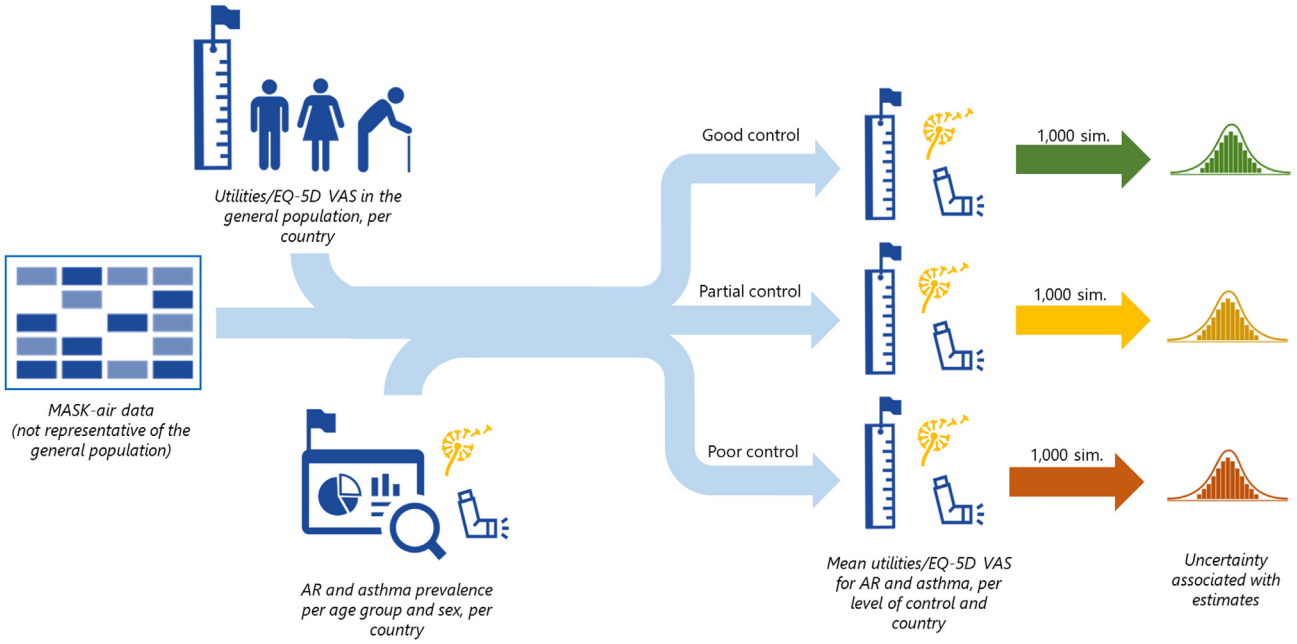

FIGURE 1. Graphical summary of data analysis methodology. Individual data were obtained from the MASK-air mobile app (eg, sex, age, disease control, and utilities/EuroQoL five-dimension [EQ-5D] visual analog scale [VAS]) and combined with contextual information on the quality of life of the general population as well as on the prevalence of allergic rhinitis (AR) and asthma to compute mean utilities/EQ-5D VAS for AR and asthma per level of disease control and country. Uncertainty in estimates was assessed by means of 1000 simulations.

anonymity, and (3) users agreed to the analysis of their data for research purposes in the terms of use (translated into all languages and customized according to the legislation of each country).

RESULTS

Descriptive results

The utility index score was estimated in 2424 users for AR (4008 observations [ie, days]; 63.2% females; mean age ± SD, 36.3 ± 13.1 years) and in 1032 users for asthma (1936 observations; 66.6% females; mean age ± SD, 37.2 ± 13.2 years) (Table I; see Figure E1 in this article's Online Repository at www.jaci-inpractice.org).

The EQ-5D VAS was estimated in 7905 users for AR (82,737 observations; 57.4% females; mean age ± SD, 36.4 ± 13.1 years), and in 2821 users for asthma (36,046 observations; 61.1% females; mean age ± SD, 36.4 ± 13.5 years) (Table 1 and Figure E1).

Impact of disease control on HRQoL

In multivariable mixed-effects regression models, both partial and poor disease control (compared to good disease control) were associated with decreased utilities for asthma and for AR (Table II). Having partial disease control was associated with a decrease of 0.03 to 0.04 units in utilities whereas for poor disease control, the range of decrease was 0.10 to 0.14 units (Table II). Regarding EQ-5D VAS, having partial disease control was associated with a mean decrease of 9.2 to 9.7 units in VAS for AR patients and a 5.5 to 5.6 decrease for asthma patients. However, poor disease control was associated with a mean decrease of 15.5 to 15.6 in patients with asthma and 20.6 in patients with AR (Table II).

Utility index score per country

Table III and Figure E2 (in this article's Online Repository at www.jaci-inpractice.org) show mean utility scores per country and per level of disease control.

In all countries, we observed that worse AR or asthma control was associated with lower utilities. We found that good AR control was associated with a utility score ranging from 0.86 (Belgium) to 0.99 (Poland) and partial AR control from 0.83 (Belgium) to 0.96 (Poland), whereas poor AR control was associated with a utility score ranging from 0.72 (Belgium) to 0.85 (Poland). On average, moving from good to partial control led to a loss of 0.03 utilities, whereas moving from partial to poor control of disease led to a mean loss of 0.11 utilities (higher than the MID). Thus, moving from good to poor disease control led to a mean loss of 0.14 utilities (higher than the MID).

For asthma, we found good control to be associated with a utility score ranging from 0.84 (Netherlands) to 0.97 (Poland), partial control from 0.80 (Netherlands) to 0.94 (Poland), and poor control from 0.73 (Netherlands) to 0.87 (Poland). Moving from good to partial disease control led to an average loss of 0.03 utilities, whereas moving from partial to poor disease control led to an average loss of 0.08 utilities. Thus, moving from good to poor disease control led to a mean loss of 0.11 utilities (higher than the MID).

Between-country differences were smaller than the MID for both asthma and AR, except between Belgium versus Portugal or Poland and between the Netherlands versus Poland.

EQ-5D VAS per country

Table IV and Figure E2 show mean EQ-5D VAS levels per country and per level of disease control.

TABLE I. Characteristics of MASK-air sample used to estimate nationwide utility index score and EQ-5D visual analog scale for AR and asthma

	Utility index score*		EQ-5D VAS†	
Variable	**AR**	**Asthma**	**AR**	**Asthma**
Users (observations), n	2,424 (4,008)	1,032 (1,936)	7,905 (82,737)	2,821 (36,046)
Belgium	39 (45)	NA	72 (339)	NA
Denmark	24 (35)	NA	37 (67)	NA
France	510 (744)	177 (263)	2,146 (25,963)	613 (7,653)
Germany	324 (808)	141 (498)	833 (19,847)	308 (10,650)
Italy	417 (709)	177 (254)	2,667 (9,042)	836 (3,007)
Netherlands	190 (280)	72 (105)	278 (1,504)	109 (301)
Poland	211 (294)	90 (191)	402 (6,683)	155 (2,952)
Portugal	388 (614)	224 (378)	765 (11,311)	469 (8,485)
Spain	181 (274)	91 (154)	450 (6,567)	227 (2,464)
United Kingdom	140 (205)	60 (93)	255 (1,414)	104 (534)
Females, n (%)	1,534 (63.2)	687 (66.6)	4,540 (57.4)	1,725 (61.1)
Age (mean [SD])	36.3 (13.1)	37.2 (13.2)	36.4 (13.1)	36.4 (13.5)
AR plus asthma, n (%)	14,54 (60.0)	944 (91.5)	5,388 (68.2)	2,473 (91.2)
Disease control, n (%)‡				
Days of good control	1,465 (36.6)	875 (45.2)	47,562 (57.5)	22,561 (62.6)
Days of partial control	1,019 (25.4)	326 (16.8)	21,685 (26.2)	6,598 (18.3)
Days of poor control	1,523 (38.0)	735 (40.0)	13,489 (16.3)	6,887 (19.1)
VAS				
Global (median [IQR])	34 (54)	35 (52)	14 (31)	15 (29)
Eye (median [IQR])	16 (49)	17 (59)	6 (21)	8 (21)
Nose (median [IQR])	33 (56)	31 (54)	15 (33)	15 (30)
Asthma (median [IQR])	5 (30)	23 (47)	3 (14)	11 (26)

AR, allergic rhinitis; *EQ-5D*, EuroQoL five-dimension; *IQR*, interquartile range; *NA*, not available; *VAS*, visual analog scale.
*Characteristics of MASK-air sample used to estimate nationwide EQ-5D VAS scores. The EQ-5D VAS is a scale of 0 to 100 in which higher scores reflect better overall health on that day.
†Characteristics of MASK-air sample used to estimate nationwide utility index scores. Utilities quantify the preferences of the population on the respective health states, in which 1 represents full health and 0 represents death.
‡Allergic rhinitis control was assessed based on the combined symptom-medication score. Asthma control was based on the electronic daily control score for asthma.

TABLE II. Multilevel mixed-effects models assessing association between disease control and utility index score/EQ-5D VAS

Disease control	Utility index score* (coefficient [95% CI]) *P*	EQ-5D VAS† (coefficient [95% CI]) *P*
Allergic rhinitis (all patients)		
Partial vs good control	−0.03 (−0.04 to 0.02) <.001	−9.2 (−9.4 to −9.0) <.001
Poor vs good control	−0.13 (−0.14 to −0.11) <.001	−20.6 (−20.9 to −20.3) <.001
Poor vs partial control	−0.10 (−0.11 to −0.08) <.001	−11.4 (−11.7 to −11.1) <.001
Allergic rhinitis only		
Partial vs good control	−0.03 (−0.04 to −0.02) <.001	−9.7 (−10.0 to −9.4) <.001
Poor vs good control	−0.12 (−0.14 to −0.10) <.001	−20.6 (−20.9 to −20.2) <.001
Poor vs partial control	−0.09 (−0.11 to −0.07) <.001	−10.9 (−11.2 to −10.5) <.001
Asthma (all patients)		
Partial vs good control	−0.03 (−0.05 to −0.01) .003	−5.6 (−6.0 to −5.3) <.001
Poor vs good control	−0.13 (−0.14 to −0.11) <.001	−15.6 (−16.1 to −15.2) <.001
Poor vs partial control	−0.07 (−0.09 to −0.04) <.001	−10.0 (−10.5 to −9.5) <.001
Asthma plus allergic rhinitis		
Partial vs good control	−0.04 (−0.06 to −0.01) .002	−5.5 (−5.9 to −5.1) <.001
Poor vs good control	−0.10 (−0.12 to −0.08) <.001	−15.5 (−16.0 to −15.0) <.001
Poor vs partial control	−0.06 (−0.09 to −0.04) <.001	−10.0 (−10.5 to −9.5) <.001

EQ-5D, EuroQoL five-dimension; *VAS*, visual analog scale.
*The EQ-5D VAS is a scale of 0 to 100 in which higher scores reflect better overall health on that day.
†Utilities quantify the preferences of the population on the respective health states, in which 1 represents full health and 0 represents death.

TABLE III. Mean utility index score* (SE) per country and level of disease control

	Allergic rhinitis control			Asthma control		
Country	Good	Partial	Poor	Good	Partial	Poor
Belgium	0.86 (0.05)	0.83 (0.05)	0.72 (0.05)	NA	NA	NA
Denmark	0.94 (0.05)	0.90 (0.05)	0.80 (0.05)	NA	NA	NA
France	0.96 (0.05)	0.92 (0.05)	0.82 (0.05)	0.91 (0.03)	0.88 (0.03)	0.81 (0.03)
Germany	0.91 (0.05)	0.88 (0.05)	0.77 (0.05)	0.89 (0.03)	0.86 (0.03)	0.79 (0.03)
Italy	0.94 (0.04)	0.91 (0.04)	0.80 (0.04)	0.90 (0.03)	0.87 (0.03)	0.80 (0.03)
Netherlands	0.88 (0.05)	0.85 (0.05)	0.74 (0.05)	0.84 (0.04)	0.80 (0.04)	0.73 (0.04)
Poland	0.99 (0.04)	0.96 (0.04)	0.85 (0.04)	0.97 (0.04)	0.94 (0.04)	0.87 (0.04)
Portugal	0.97 (0.04)	0.94 (0.04)	0.83 (0.04)	0.94 (0.03)	0.91 (0.03)	0.84 (0.03)
Spain	0.92 (0.05)	0.88 (0.05)	0.78 (0.05)	0.87 (0.04)	0.83 (0.04)	0.76 (0.04)
United Kingdom	0.93 (0.05)	0.90 (0.05)	0.79 (0.05)	0.87 (0.04)	0.84 (0.04)	0.77 (0.04)

NA, not available.
*Utilities quantify the preferences of the population regarding the respective health states, in which 1 represents full health and 0 represents death.

In all countries, we observed that worse AR or asthma control was associated with a lower EQ-5D VAS. Good AR control was associated with a mean EQ-5D VAS ranging from 78.9 (Italy) to 87.9 (United Kingdom), partial control from 67.4 (Italy) to 76.3 (United Kingdom), and poor control from 55.3 (Italy) to 64.2 (United Kingdom). Moving from good to partial AR control was associated with an average decrease of 11.6 points on the EQ-5D VAS (higher than the MID), whereas moving from partial to poor AR control was associated with an average decrease of 11.7 points on the EQ-5D VAS (higher than the MID).

For asthma, we found good control to be associated with a mean EQ-5D VAS ranging from 68.4 (Netherlands) to 81.5 (Portugal), partial control from 59.8 (Italy) to 72.8 (Portugal), and poor control from 51.4 (Netherlands) to 64.5 (Portugal). Compared with good disease control, on average, patients with partial disease control showed a decrease of 8.6 points on the EQ-5D VAS (lower than the MID), whereas patients with poor disease control showed a decrease of 16.4 points (higher than the MID).

For both asthma and AR, all between-country differences were lower than the MID.

Comparison of AR alone and AR with asthma

We performed an additional sensitivity analysis, estimating utilities for users with AR alone and for users with both asthma and AR (Figure 2; see Tables E3 and E4 in this article's Online Repository at www.jaci-inpractice.org). Results were similar to those described earlier. We found mean utilities and mean EQ-5D VAS scores for patients with well-controlled or partially controlled disease to be consistently higher in patients with AR alone compared to patients with both AR and asthma, although differences were not higher than the MID. However, for patients with poorly controlled disease, mean utilities were similar in patients with AR alone and in patients with both asthma and AR.

DISCUSSION

To our knowledge, this is the first study (i) to produce utility and EQ-5D VAS estimates per country and per level of control in patients with AR or asthma for several European countries and (ii) to use real-life mobile health (mHealth) data comparing HRQoL in AR and asthma. This study reveals several relevant novel findings: (1) similar utilities were observed in patients with AR versus those with asthma for poorly controlled disease; (2) for patients with controlled or partly controlled AR, those with AR plus asthma had overall lower mean utility estimates compared to patients with AR alone; and (3) a higher discrimination between different control levels was observed for the EQ-5D VAS than for the utility index score. Our results are especially relevant for

TABLE IV. Mean EuroQoL five-dimension visual analog scale* (SE) per country and level of disease control

	Allergic rhinitis control			Asthma control		
Country	Good	Partial	Poor	Good	Partial	Poor
Belgium	84.6 (7.3)	73.0 (7.3)	60.9 (7.3)	NA	NA	NA
Denmark	82.6 (7.6)	71.0 (7.6)	61.7 (7.6)	NA	NA	NA
France	82.4 (7.2)	70.8 (7.2)	59.0 (7.2)	74.4 (5.2)	65.8 (5.2)	57.4 (5.2)
Germany	85.3 (7.7)	73.7 (7.7)	61.7 (7.7)	77.5 (5.2)	68.9 (5.2)	60.5 (5.2)
Italy	78.9 (7.1)	67.4 (7.1)	55.3 (7.1)	68.4 (5.2)	59.8 (5.2)	51.4 (5.2)
Netherlands	83.5 (7.1)	71.9 (7.1)	59.9 (7.1)	75.1 (5.4)	66.5 (5.4)	58.1 (5.4)
Poland	86.3 (7.1)	74.7 (7.1)	62.7 (7.1)	80.5 (5.5)	71.8 (5.5)	63.5 (5.5)
Portugal	87.1 (7.1)	75.5 (7.1)	63.5 (7.1)	81.5 (5.2)	72.8 (5.2)	64.5 (5.2)
Spain	85.6 (7.1)	74.0 (7.1)	62.0 (7.1)	77.5 (5.3)	68.8 (5.3)	60.5 (5.3)
United Kingdom	87.9 (7.1)	76.3 (7.1)	64.2 (7.1)	78.8 (5.4)	70.1 (5.4)	61.8 (5.4)

NA, not available.
*The EuroQoL five-dimension visual analog scale is a scale of 0 to 100 in which higher scores reflect better overall health on that day.

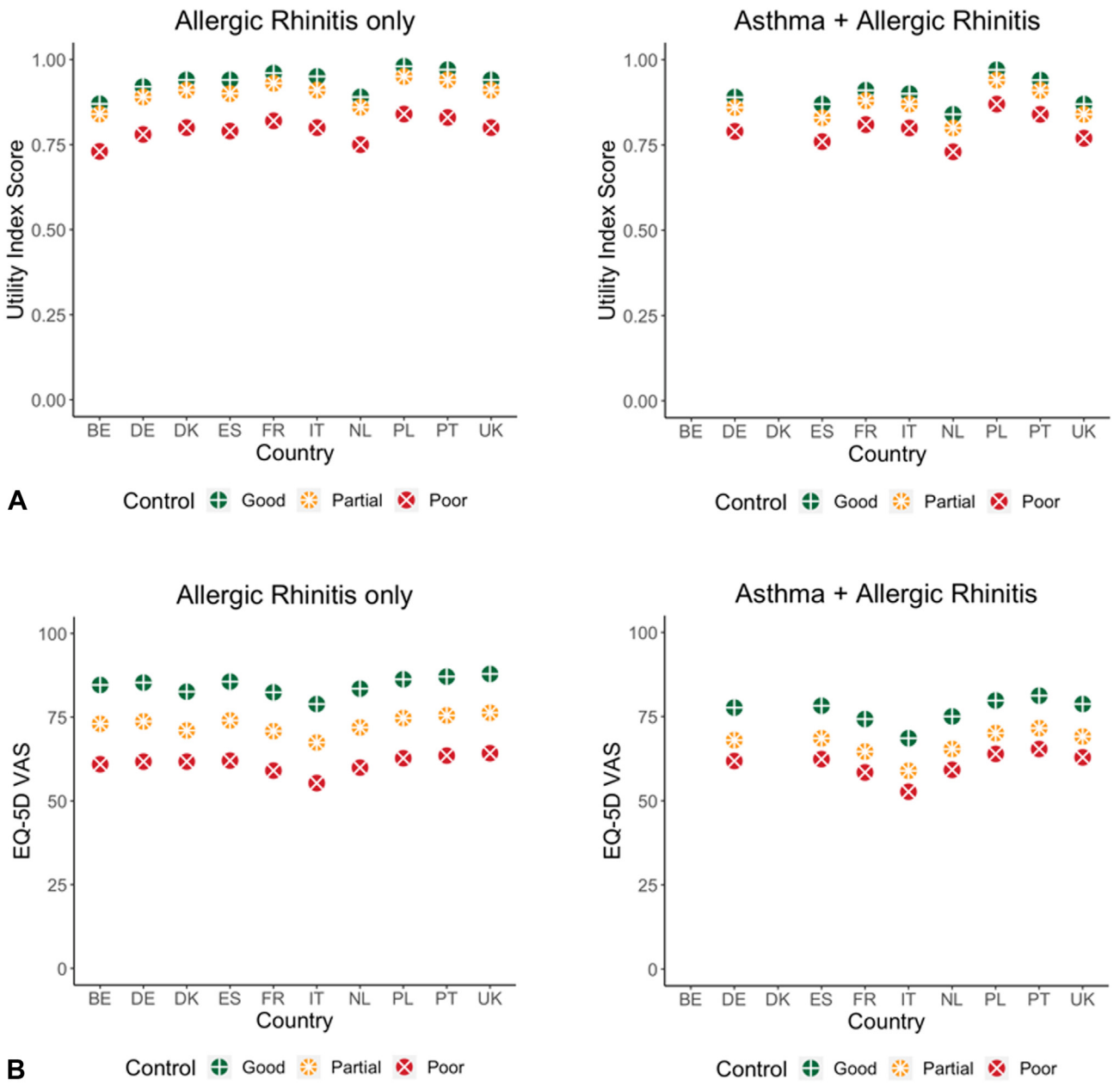

FIGURE 2. (**A**) Utility index score and (**B**) EuroQoL five-dimension (EQ-5D) visual analog scale (VAS) of patients with only allergic rhinitis and patients with both asthma and allergic rhinitis, per country and level of control (according to the Combined Symptom-Medication Score for Allergic Rhinitis and the electronic daily control score for asthma for asthma plus allergic rhinitis). *BE*, Belgium; *DE*, Germany; *DK*, Denmark; *ES*, Spain; *FR*, France; *IT*, Italy; *NL*, Netherlands; *PL*, Poland; *PT*, Portugal; *UK*, United Kingdom.

health technology assessment studies in which national estimates of utilities for AR or asthma may be required.

We found that poorer disease control was associated with decreased HRQoL. This is consistent with previous studies that showed poorer asthma control or increased asthma or AR severity to be associated with decreased QoL.[25-30] In AR, however, many studies using EQ-5D-5L were performed during immunotherapy trials[31] or did not differentiate between controlled and uncontrolled rhinitis.[32] As for asthma, in a meta-analysis published in 2022,[33] seven studies assessed utilities based on ED-5D-5L with observed utilities ranging from 0.83 to 0.88 (results similar to ours). In the two studies assessing uncontrolled asthma, mean EQ-5D-5L utilities were 0.69.[26,34] Studies based on ED-5D-3L also showed that severe asthma impairs utilities.[33]

We computed mean utilities and EQ-5D VAS scores for 10 European countries and three validated control levels.[35] Therefore, we found HRQoL for the same level of control, whether measured through the utility index score or through the EQ-5D VAS, to be similar in patients with AR and in patients with asthma, especially those with poor disease control. This is in line with a previous epidemiologic study in young adults, which suggested a similar impairment in HRQoL for patients with AR

and for patients with asthma, although disease control was not assessed in that study.[36] Importantly, we also found the differences in HRQoL between good and partial disease control to be smaller than those between partial and poor disease control for both AR and asthma. Another relevant finding in our study is that compared with utilities, the EQ-5D VAS could better differentiate AR patients with well-, partly, or poorly controlled disease.

In our study, most patients with asthma also had AR. However, this may reflect real life, because there have been estimates indicating that over 80% of patients with asthma have AR.[37] Importantly, we found mean utility estimates to be consistently lower for comorbid AR plus asthma compared to AR alone. This assessment is particularly important because AR alone and AR plus asthma display relevant genetic, immunologic, epidemiologic, and clinical findings.[38]

Our study showed that rhinitis and asthma may have an important impact on HRQoL, which may be underappreciated. For example, the mean utility value for patients with type 2 diabetes mellitus is 0.79,[39] a value that is similar to the utility values of poorly controlled AR or asthma. The latter are also similar to the utilities estimated for New York Heart Association Classes I and II of heart failure (0.79-0.86 for class I and 0.75-0.81 for class II)[40] and for low disease activity rheumatoid arthritis (0.73).[41] This highlights the need for physicians to assess patients systematically regarding rhinitis and asthma symptoms and to promote good control of allergic diseases (which is of utmost relevance considering that AR is frequently undervalued in the clinical practice).

Finally, this study used an app and showed that EQ-5D and VAS can be monitored using mHealth, as previously reported.[42]

This study had some limitations. First, we relied on self-reported data regarding the diagnosis of AR and asthma. We were unable to calculate national utility and EQ-5D VAS estimates for asthma and AR considering all control levels together, because information on the distribution of AR and asthma severity levels per country were not widely available. For AR, only regional (as opposed to national) estimates of the prevalence of AR were available for Denmark and Poland. For the Netherlands, specific data on the prevalence of AR were unavailable and we had to use data on the prevalence of respiratory allergic disorders. Likewise, for Spain, we considered data on the prevalence of general allergies (excluding asthma), because specific data for the prevalence of AR per sex and age group were unavailable. For some of the included countries, estimates of the prevalence of AR or asthma were unavailable in sufficient detail for all age groups. In these cases, we assumed the prevalence of the disease to be constant throughout each age interval provided in the respective studies. In addition, we were unable to assess nonallergic comorbidities (because these are not collected in the MASK-air app). However, we believe that their frequency and severity are not highly affected by the control of allergic diseases. MASK-air also does not collect user information such as income, education level, and occupation. Collecting such data could present a privacy threat and limit the feasibility of mHealth studies. Importantly, we provide stratified analyses by control level, which limits biases related to disease control (which may be influenced by social determinants). We included Belgium and Denmark in the analysis for AR but not for asthma, because a limited sample was available. However, our methodology relies on data from all countries to allow for the computation of country-specific utilities, and it has been shown to provide reliable estimates with smaller sample sizes than the ones included in this study.[24]

This study also had important strengths. We assessed real-world data from a large set of participants from 10 European countries, with the structure of MASK-air precluding the existence of missing data within each daily questionnaire. The CSMS and the e-DASTHMA were previously assessed regarding their validity, reproducibility, and MID (in which several observed differences were larger than the MID).[12,13] The method we employed (multilevel models with poststratification), although innovative in this field, has been previously validated.[24] We found consistent results in different models in sensitivity analyses, pointing to the robustness of the results. In addition, we found that with both multilevel mixed-effects models and multilevel models with poststratification, AR and asthma control were associated with worse disease control. By providing our estimates per level of disease control, we limit the risk of bias that may arise from mHealth app users displaying higher disease severity. We report utility index scores and EQ-5D VAS for several European countries. This is especially important because the EQ-5D VAS and the utility index scores calculated from EQ-5D-5L profiles are complementary and both may be relevant for decision makers.[43] Finally, we quantify the impact on HRQoL for several European countries for both AR and comorbid AR and asthma.

To the best of our knowledge, this is the first study (1) to estimate HRQoL measures for patients with AR or asthma in several European countries, and (2) to assess AR alone and AR plus asthma. These national estimates may be used in cost-utility studies, decision analysis models, and other health technology assessment studies in which national estimates of utilities for AR or asthma may be required. This allows for an assessment of AR or asthma interventions, considering not only their effectiveness in symptom control but also their expected impact on the HRQoL.

Our study has produced estimates of the mean utility score and EQ-5D VAS for patients with AR or asthma in up to 10 European countries. Importantly, we found differences in utility index scores that may be explained not only by different national standard value sets used to compute utilities but also by differences in HRQoL across countries, as shown by the across-country differences in EQ-5D VAS (which is independent of any country-specific conversion). As such, although these results are generalizable for each country studied, they may not be generalizable for other countries. In addition, our method, especially the use of multilevel regression models with post-stratification, may be employed in other contexts to correct for sampling biases.

Conclusion

Using mHealth data from the MASK-air app, we estimated mean utilities and EQ-5D VAS for AR and asthma per level of disease control. We obtained national estimates for 10 European countries corrected for biases in the age and sex distribution of MASK-air users. We observed consistent results across countries showing that (1) poor AR or asthma control is associated with low HRQoL, and (2) for the same control levels, the HRQoL in AR is similar to that in asthma. This study provides estimates that can be used in future health technology assessment studies (cost-utility analyses) and highlights the importance of achieving good AR and asthma control.

The results of this real-life study can be used to show the impact of AR alone or with asthma to policy makers, as recommended by OECD.[10]

Acknowledgments

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ONLINE REPOSITORY

SUPPLEMENTAL METHODS

Data analysis

We analyzed all data from users who met eligibility criteria and had valid data. No sample size calculation was performed.

Our methodology consisted of three steps. First, we used linear mixed models to estimate separate outcomes for each of the four defined samples: the utility index score and the EuroQoL five-dimension (EQ-5D) visual analog scale (VAS) for patients with allergic rhinitis (AR) and for patients with asthma. To account for between-country variation, allowing us to estimate the outcomes for different countries, we included a random effect that varies over the country of residence of each MASK-air user in the model. In addition, to account for variations between different levels of disease control and enable us to estimate mean utilities and the EQ-5D VAS per level of disease control, the models included a random effect indicating the level of control as assessed by the Combined Symptom-Medication Score (for AR) or by the Electronic Daily Control Score for Asthma score (for asthma). We considered three categories of disease control according to these scores: good, partial, or poor (definitions in Table E1). On the individual level, we included the sex and age group of each MASK-air user through random effects. Nine age groups were considered (15-19 years, 20-24 years, 25-29 years, 30-34 years, 35-39 years, 40-44 years, 45-49 years, 50-59 years, and 60-74 years). To improve our estimates, we added context-level information to the models, namely the mean utilities or mean EQ-5D VAS in the general population of each country. Afterward, we predicted the mean utility index score and mean EQ-5D-VAS for specific ideal types. In this case, we had 18 ideal types (two genders ? nine age groups) for each level of disease control (three) per country (10 for AR and eight for asthma). Finally, we post-stratified the estimates by ideal type, using data on the number of people living with AR and asthma for each country (data sources are available in Table E2). Thus, for each user's age group, sex, and country, the model's estimates were weighted by the number of patients with AR or asthma in each country's population. This enabled the utility index score and the EQ-5D VAS value to be estimated for each country and each level of disease control.

We applied simulation methods to assess the uncertainty associated with the obtained estimates.[E1] Because each user may provide more than 1 day of MASK-air daily monitoring data, we performed 1,000 simulations, selecting for each simulation a random observation per user. We then computed the mean of the coefficients of the multilevel models with post-stratification of these 1,000 random samples.

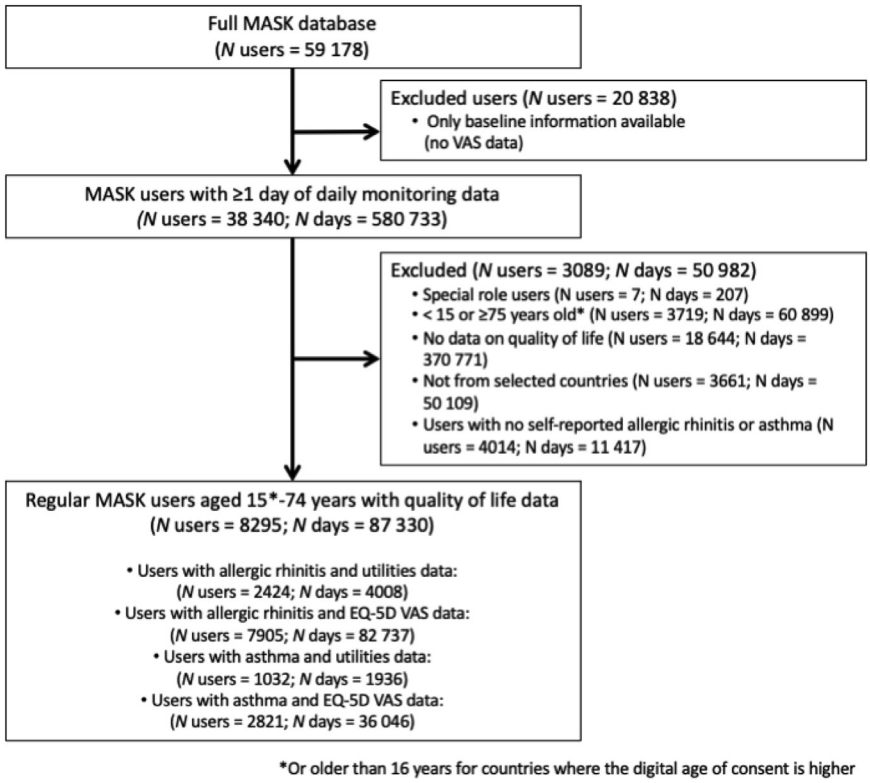

FIGURE E1. Flowchart of participant selection. *EQ-5D*, EuroQoL five-dimension; *VAS*, visual analog scale.

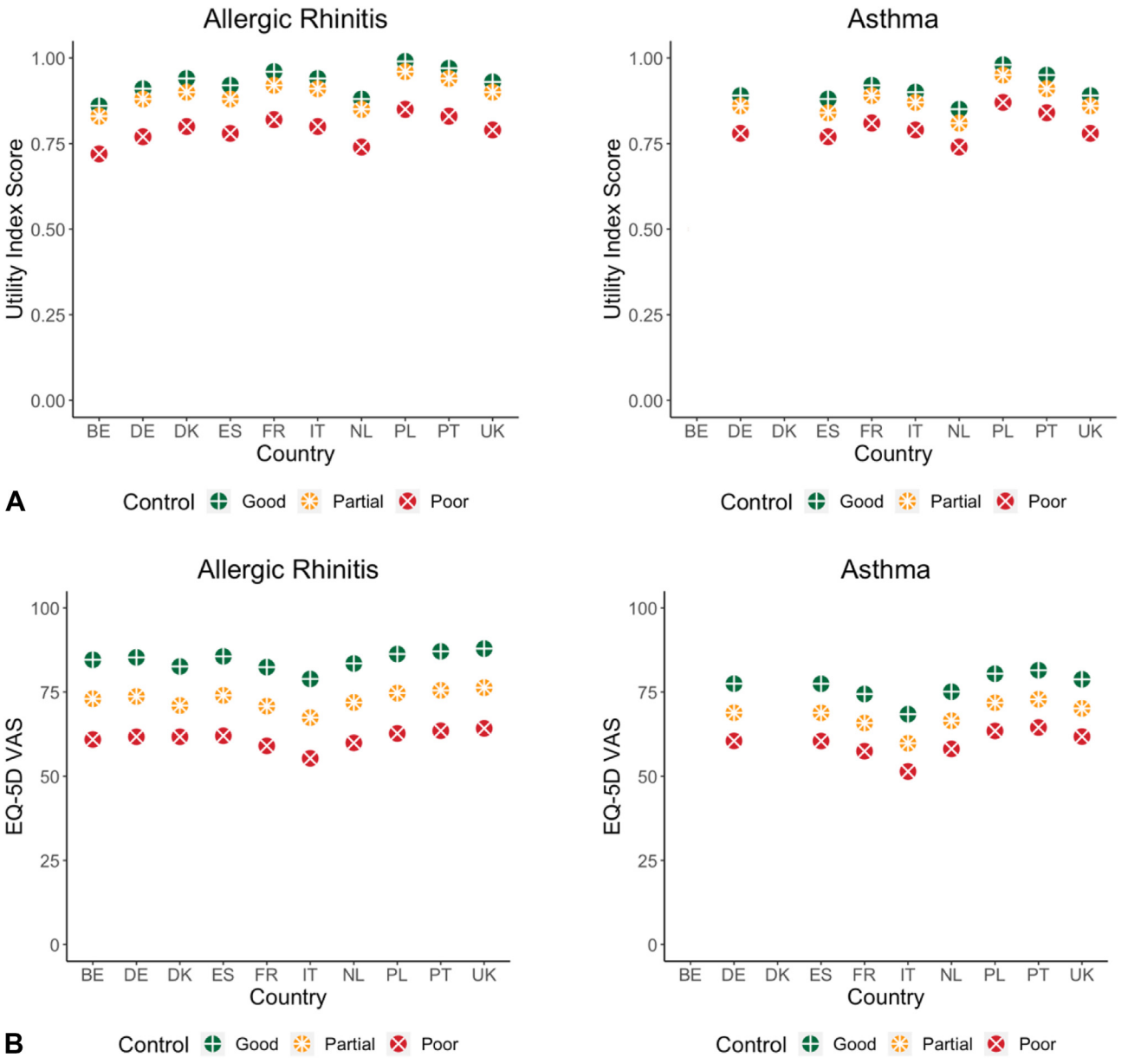

FIGURE E2. (**A**) Utility index score and (**B**) EuroQoL five-dimension (EQ-5D) visual analog scale (VAS) results for patients with allergic rhinitis and patients with asthma per country and level of control. *BE*, Belgium; *DE*, Germany; *DK*, Denmark; *ES*, Spain; *FR*, France; *IT*, Italy; *NL*, Netherlands; *PL*, Poland; *PT*, Portugal; *UK*, United Kingdom.

TABLE E1. Formulas for calculating Combined Symptom-Medication Score and Electronic Daily Control Score for Asthma and respective cutoff values

Score	Formula	Cutoff
Combined Symptom-Medication Score	(0.037 × VAS Global Symptoms) + (0.033 × VAS Eyes) + (0.020 × VAS Nose) + (0.027 × VAS Asthma) + (0.450 if intranasal MP azelastine-fluticasone is used) + (0.424 if nasal steroids are used) + (0.243 if asthma medication is used) + (0.380 if other rhinitis relief medication is used)] × 7.577	Good control: <15.8 Partial control: 15.8-35.3 Poor control: >35.3
Electronic Daily Control Score for Asthma	[(0.086 × VAS Asthma) + (1.756 if ICSs without long-acting β-agonists are used) + (0.859 if ICS with long-acting β-agonists [excluding formoterol] are used) + (1.238 if ICS with formoterol is used) + (0.559 if short-acting β-agonists or short-acting muscarinic antagonists are used) + (4.022 if biologics or long-acting muscarinic antagonists are used)] × 6.695	Good control: <16.4 Partial control: 16.4-28.9 Poor control: >28.9

ICS, intranasal corticosteroid; *VAS*, visual analog scale.

TABLE E2. Data sources for multilevel regression models per country

Country	Demographic data	Prevalence of allergic rhinitis	Prevalence of asthma	Utility index score	EuroQoL five-dimension visual analog scale
Belgium	E2	E3	NA	E4	E4
Denmark	E5	E6†	NA	E7	E7
France	E8	E9	E10	E11	E11
Germany	E12	E13	E13	E14	E14
Italy	E15	E16	E17	E18	E18
Netherlands	E19	E20*,†	E21	E22	E22
Poland	E23	E24	E24	E25	E26
Portugal	E27	E28	E29	E30	E30
Spain	E31	E32‡	E32	E33	E33
United Kingdom	E34	E35	E36	E37	E37

NA, not available.
*Regional data were used because national data were not available.
†Data on the prevalence of allergic respiratory disorders were used because data on the prevalence of allergic rhinitis were not available.
‡Data on the prevalence of general allergies were used because data on the prevalence of allergic rhinitis were not available.

TABLE E3. Mean utility index score* (SE) per country and level of disease control for patients with only allergic rhinitis and for patients with asthma and allergic rhinitis

	Control in allergic rhinitis only† (n = 1,454 users)			Control in asthma and allergic rhinitis‡ (n = 944 users)		
	Good	Partial	Poor	Good	Partial	Poor
Belgium	0.87 (0.05)	0.84 (0.05)	0.73 (0.05)	NA	NA	NA
Denmark	0.94 (0.05)	0.91 (0.05)	0.80 (0.05)	NA	NA	NA
France	0.96 (0.05)	0.93 (0.05)	0.82 (0.05)	0.92 (0.04)	0.89 (0.04)	0.81 (0.04)
Germany	0.92 (0.05)	0.89 (0.05)	0.78 (0.05)	0.89 (0.04)	0.86 (0.04)	0.78 (0.04)
Italy	0.95 (0.05)	0.91 (0.05)	0.80 (0.05)	0.90 (0.04)	0.87 (0.04)	0.79 (0.04)
Netherlands	0.89 (0.05)	0.86 (0.05)	0.75 (0.05)	0.84 (0.04)	0.81 (0.04)	0.73 (0.04)
Poland	0.98 (0.05)	0.95 (0.05)	0.84 (0.05)	0.97 (0.04)	0.94 (0.04)	0.87 (0.04)
Portugal	0.97 (0.05)	0.94 (0.05)	0.83 (0.05)	0.94 (0.04)	0.91 (0.04)	0.84 (0.04)
Spain	0.94 (0.05)	0.90 (0.05)	0.79 (0.05)	0.88 (0.04)	0.85 (0.04)	0.77 (0.04)
United Kingdom	0.94 (0.05)	0.91 (0.05)	0.80 (0.05)	0.88 (0.04)	0.85 (0.04)	0.77 (0.04)

NA, not available.
*Utilities quantify the preferences of the population on the respective health states, in which 1 represents full health and 0 represents death.
†Defined according to the Combined Symptom-Medication Score.
‡Defined according to the Electronic Daily Control Score for Asthma.

TABLE E4. Mean EuroQoL five-dimension visual analog scale* (SE) per country and level of disease control for patients with only allergic rhinitis and for patients with asthma and allergic rhinitis

	Control in only allergic rhinitis† (n = 5,388 users)			Control in asthma and allergic rhinitis‡ (n = 2,473 users)		
	Good	Partial	Poor	Good	Partial	Poor
Belgium	83.6 (7.0)	73.0 (7.0)	61.1 (7.0)	NA	NA	NA
Denmark	80.6 (7.3)	70.0 (7.3)	58.0 (7.3)	NA	NA	NA
France	82.3 (6.8)	71.7 (6.8)	59.8 (6.8)	74.2 (4.9)	64.6 (4.9)	58.4 (4.9)
Germany	84.4 (6.8)	73.8 (6.8)	61.8 (6.8)	77.6 (4.9)	68.0 (4.9)	61.8 (4.9)
Italy	78.2 (6.7)	67.6 (6.7)	55.6 (6.7)	68.5 (4.9)	58.9 (4.9)	52.7 (4.9)
Netherlands	82.9 (6.8)	72.3 (6.8)	60.4 (6.8)	75.0 (5.2)	65.3 (5.2)	59.1 (5.2)
Poland	86.9 (6.8)	76.3 (6.8)	64.4 (6.8)	79.7 (5.2)	70.1 (5.2)	63.9 (5.2)
Portugal	87.6 (6.8)	77.1 (6.8)	65.1 (6.8)	81.2 (4.9)	71.5 (4.9)	65.3 (4.9)
Spain	84.2 (6.9)	73.6 (6.9)	61.6 (6.9)	78.2 (5.0)	68.5 (5.0)	62.3 (5.0)
United Kingdom	86.1 (6.8)	75.5 (6.8)	63.6 (6.8)	78.7 (5.2)	69.0 (5.2)	62.9 (5.2)

NA, not available.
*The EuroQoL five-dimension visual analog scale is a scale of 0 to 100 in which higher scores reflect better overall health on that day.
†Defined according to the Combined Symptom-Medication Score.
‡Defined according to the Electronic Daily Control Score for Asthma.

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