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Costs of childhood asthma due to traffic-related pollution in two California communities

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ABSTRACT: Recent research suggests the burden of childhood asthma that is attributable to air pollution has been underestimated in traditional risk assessments, and there are no estimates of these associated costs. We aimed to estimate the yearly childhood asthma-related costs attributable to air pollution for Riverside and Long Beach, CA, USA, including: 1) the indirect and direct costs of healthcare utilisation due to asthma exacerbations linked with traffic-related pollution (TRP); and 2) the costs of health care for asthma cases attributable to local TRP exposure.

We calculated costs using estimates from peer-reviewed literature and the authors' analysis of surveys (Medical Expenditure Panel Survey, California Health Interview Survey, National Household Travel Survey, and Health Care Utilization Project). A lower-bound estimate of the asthma burden attributable to air pollution was US$18 million yearly. Asthma cases attributable to TRP exposure accounted for almost half of this cost. The cost of bronchitic episodes was a major proportion of both the annual cost of asthma cases attributable to TRP and of pollution-linked exacerbations.

Traditional risk assessment methods underestimate both the burden of disease and cost of asthma associated with air pollution, and these costs are borne disproportionately by communities with higher than average TRP.

KEYWORDS: **Air pollution, asthma burden, burden of disease, children, economic costs, vehicle emissions**

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Ambient regional air pollution levels are known to exacerbate asthma [1]. In addition, emerging evidence indicates that traffic-related pollution (TRP) also causes asthma in children living in close proximity to major roadways [2–4]. Traditional risk assessments have not estimated either the burden or economic cost of asthma caused by TRP [5]. In addition, most regional air pollution risk assessments have estimated the burden of disease over large populations with a wide range of air pollution exposure, and these results are not very useful for the development of local policy. Previously, we used new methods [5] to examine the burden of asthma outcomes due to regional air pollution and TRP in two communities in Southern California, Riverside and Long Beach, CA, USA [6]. In these communities, vehicular traffic is the primary source for high levels of regional air pollution, and there are heavy traffic corridors in close proximity to residential neighbourhoods.

For the present study, we estimated the economic impact of the air pollution-related burden of asthma that was reported in Long Beach and Riverside in a study by Perez *et al.* [6]. We used a novel approach to estimate costs of two important outcomes associated with TRP, bronchitic symptoms and the annual cost of care for a child with asthma. First, we characterised the annual frequency of asthma outcomes (including bronchitic symptoms) associated with an asthma case; we then estimated the direct cost of each of these outcomes, and estimated the indirect cost of a parent's/caretaker's time due to these outcomes. Secondly, we multiplied this cost of a typical case of asthma by the number of asthma cases that were attributable to TRP. Thirdly, we estimated

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the cost of asthma exacerbations due to representative regional pollutants (nitogen dioxide (NO_2) and ozone (O_3)) for children with asthma not caused by TRP. Fourthly, to obtain the total asthma-related cost of pollution, we summed the cost of TRP-attributable asthma cases and the cost of regional air pollution-related exacerbations among children with asthma not caused by TRP. Thus, we estimated the cost of the burden of TRP-attributable asthma cases not included in previous estimates of the economic impact of air pollution, yet we avoided double counting of asthma exacerbations among the two groups of asthmatics. This new approach to air pollution risk assessment and cost estimation, accounting for the full impact of TRP exposure, is likely to be widely applicable to urban areas with regional air pollution and residential developments near busy roadways.

METHODS

Overview

In the analysis by PEREZ *et al.* [6], the baseline concentrations for Long Beach and Riverside were the observed 8-yr mean concentrations (1996–2004) for NO_2 (33 ppb and 26 ppb, respectively) and O_3 (29 ppb and 57 ppb, respectively) measured at continuously operating Children's Health Study monitoring stations in each community. This baseline was then contrasted to the levels observed in comparison communities, which implies a decrease in NO_2 of 18 ppb and 11 ppb in Long Beach and Riverside and a decrease in O_3 of 27 ppb in Riverside. Our scenarios cover a concentration range for which there is no evidence for nonlinear effects. We considered five outcomes associated with regional air pollution-attributable asthma exacerbations: bronchitic episodes, emergency room visits, hospitalisations, asthma-specific office visits and school day absences [6]. We then considered the number of TRP-attributable asthma cases [6].

The total cost of an air pollution-attributable asthma outcome equals the cost (direct cost plus indirect cost) for a single asthma-related outcome (*e.g.* an emergency room visit) multiplied by the quantity of that outcome that is attributable to air pollution. Using secondary datasets, we estimated the direct and indirect cost of a single healthcare utilisation as the charge for that service and the opportunity cost (foregone income) of a parent's/caretaker's time. In all cases, we used charges that were for the paediatric population, and when possible, we used estimates for our geographical area and specific diagnostic code.

A sensitive indicator of air pollution-related asthma exacerbation in children is bronchitic symptoms, measured as daily cough, congestion or phlegm, or bronchitis for 3 months in a row [7]. There is no peer-reviewed literature on the aggregate cost of a bronchitic episode, because unlike the other outcomes, a bronchitic episode is not itself a final end-point. Instead, a bronchitic episode is a composite of several types of healthcare utilisations. Our approach was to describe a bronchitic episode using the frequency of each outcome that the peer-reviewed literature suggests is associated with a bronchitic episode. The cost of a bronchitic episode was the sum over each bronchitic-related outcome of the cost (direct and indirect cost) of that outcome multiplied by the frequency of that outcome during an episode.

Like a bronchitic episode, an asthma case has many associated outcomes. Furthermore, there is no published estimate of the annual cost of an asthma case that was appropriate for our population. Nor was there a single database or study that described all outcomes of interest for an asthma case. Consequently, we estimated the frequency of these outcomes for a typical asthma case as the means reported in peer-reviewed literature and the California Health Interview Survey [8]. We selected the peer-reviewed literature with samples that best represented our population, prioritising the following attributes: outcomes measured, mean age of children studied, urban setting, date of study (preference given to most recent) and consistency of estimates with other published studies.

Advantages of our approach are that it is transparent and highlights the drivers of costs (the quantity of and cost for each outcome) for policy makers and clinicians. We believe that these advantages outweigh the disadvantage that our estimates rely on multiple sources. Table 1 specifies the sources (peer-reviewed literature or secondary database) for the quantity and cost of each outcome, and table 2 specifies the sources and time associations.

Asthma exacerbations attributable to regional pollution

The number of regional air pollution-attributable outcomes (bronchitic episodes, emergency room visits, hospitalisations, asthma-specific office visits and school day absences) among children with asthma due to other causes was based on our previous estimates [6]. Five outcomes are associated with bronchitic episodes: school absences, antibiotic prescriptions, office visit to a medical doctor, emergency room visit and in-patient hospital stay. The bronchitis-related frequency of school absences was reported by OEFFINGER *et al.* [14]. Although antibiotics are not effective for the majority of cases of childhood bronchitis, they are frequently used. We estimated the rate of antibiotic prescriptions as the mean rate of antibiotic prescriptions across four published studies [15–18]. We also estimated the number of medical office visits, emergency room visits and in-patient hospitalisations for children as the mean frequency for each outcome for children aged <18 yrs with current asthma and an International Classification of Disease (ICD)-9 diagnosis code of 490 or 491 in the 2007 Medical Expenditure Panel Survey (MEPS) Condition files [33]. These rates were then adjusted to reflect the sampling used in MEPS [34]. The frequencies of episodes of bronchitis are summarised in table 3.

Outcomes for asthma cases attributable to traffic proximity

We used our previous estimates of TRP-attributable asthma cases [6]. Seven outcomes were associated with an asthma case: office visits, emergency room visits, hospitalisations, school absences, comorbidities (ear or sinus infections), bronchitic episodes and medication use (rescue inhalers and control inhalers). In this analysis, we quantified the outcomes associated with an asthma case by estimating how frequently each outcome occurred in the paediatric asthma population (table 4). Frequencies of in-patient hospitalisations and emergency room visits among children (aged 0–17 yrs) were calculated using the California Health Interview Survey [8]. We used published estimates of the annual mean number of asthma-specific visits to medical doctors and albuterol inhalers

TABLE 1 Source for frequency and costs of outcomes

	Source of frequency of outcome	Source of cost estimates
Exacerbations due to regional pollution		
Outcome		
Emergency room visits	PEREZ [6]	HCUP [9] for ICD-9 493 and APA [10]
Hospitalisations	PEREZ [6]	HCUP [9] for ICD-9 493 and APA [10]
Asthma office visits	PEREZ [6]	MEPS [11]
School days absent	PEREZ [6]	US Census Bureau [12, 13]
Bronchitis episodes	PEREZ [6]	
Office visits	MEPS [11] for ICD-9 490/491	MEPS [11]
Emergency room visits	MEPS [11] for ICD-9 490/491	HCUP [9] for ICD-9 490/491 and APA [10]
Hospitalisations	MEPS [11] for ICD-9 490/491	HCUP [9] for ICD-9 490/491 and APA [10]
School absences	OEFFINGER [14]	US Census Bureau [12, 13]
Antibiotics	Mean of frequency of antibiotic prescription for bronchitis: COCO [15], EVERTSEN [16], GONZALES [17], and NYQUIST [18]; frequency of use of each antibiotic types for respiratory infection: STEINMAN [19]	Epocrates [20]
Cases due to traffic proximity		
Attributable to TRP	PEREZ [6]	Complied based on frequency and costs of outcomes for representative case as described below
Outcome per case per year		
Office visit	KATTAN [21]	MEPS [11]
Emergency room visits	CHIS [8]	HCUP [9] for ICD-9 493 and APA [10]
Hospitalisations	CHIS [8]	HCUP [9] for ICD-9 493 and APA [10]
School days missed	Mean of days: TINKELMAN [22], DEAN [23], FLORES [24], WOLSTEIN [25], MAGZAMEN [26] and MOORE [27]	US Census Bureau [12, 13]
Asthma medication per case per year		
Controller inhalers	Mean number of controller inhalers used: CHIS [8]; frequency of types of controllers: KATTAN [21]	Epocrates [20]
Rescue inhalers	Mean number of inhalers used: KATTAN [21]	Epocrates [20]
Comorbidities per case per year		
Non-urgent office visits	Frequency of comorbidities among asthmatics and frequency of outcomes due to comorbidity from GRUPP-PHELAN [28]	MEPS [11]
Antibiotics		EPOCRATES [20]
Urgent care visits		MEPS [11]
In-patient days		HCUP [9] and APA [10]
Bronchitic episodes per case per year	Frequency of bronchitic episodes per asthma case from PEREZ [6]; frequency of outcomes due to bronchitis as described below	
Office visits	MEPS [11] for ICD-9 490/491	MEPS [11]
Emergency room visits	MEPS [11] for ICD-9 490/491	HCUP [9] for ICD-9 490/491 and APA [10]
Hospitalisations	MEPS [11] for ICD-9 490/491	HCUP [9] for ICD-9 490/491 and APA [10]
School absences	OEFFINGER [14]	US Census Bureau [12, 13]
Antibiotics	Mean of frequency of antibiotic prescription for bronchitis: COCO [15], EVERTSEN [16], GONZALES [17] and NYQUIST [18]; frequency of use of each antibiotic type for respiratory infection: STEINMAN [19]	Epocrates [20]

For asthma cases, the number of outcomes is the mean annual number of outcomes per asthma case (case per year). TRP: traffic-related pollution; HCUP: Healthcare Cost and Utilization Project; ICD: International Classifiaction of Diseases; APA: American Pediatric Association; MEPS: Medical Expenditure Panel Survey; CHIS: California Health Interview Survey.

purchased [21]. As all children with asthma should have an albuterol inhaler, we multiplied the mean number of inhalers per person by the number of asthma cases. In contrast, not all children with asthma have control inhalers. Therefore, we took the mean number of control inhalers (cromolyn inhalers and corticosteroid inhalers) used each year [21] and weighted this

TABLE 2 Sources of times associated with outcomes

Time category	Source of travel time	Time on site#
Office visit: all causes	NHTS [29]	GREEK [30] and CABANA [31]
Emergency room: all causes	NHTS [29]	PITTS [32]
Hospital asthma-specific	NHTS [29]	HCUP [9] for ICD-9 493
Hospital bronchitis-specific	NHTS [29]	HCUP [9] for ICD-9 490/491

NHTS: National Household Travel Survey; HCUP: Healthcare Cost and Utilization Project; ICD: International Classifiaction of Diseases. #: wait plus service time.

by the proportion of children with asthma who used controller medication. This proportion was approximated by the proportion of Californian children with current asthma who were either taking a controller medication or should have been taking a controller medication based on symptom frequency [8]. We estimated the number of school absences per year due to asthma as the mean number of school absences due to asthma as reported in six studies [22–27].

We included the healthcare utilisation of children with asthma for sinusitis, allergic rhinitis and otitis media [28]. Given that not all children with asthma experience these comorbidities, we weighted the additional healthcare utilisation by the prevalence of the comorbidities in children with asthma in excess over the prevalence in children without asthma [28]. Similarly, not every asthma case had a bronchitic episode annually. Therefore, we multiplied the mean annual prevalence of bronchitic episodes among children with asthma in the study communities (reported as 0.387 [6]) by the mean number of each outcome associated with a bronchitic episode (table 4).

Cost per outcome

All costs were converted to 2010 US$ rates. Costs of in-patient hospitalisation and emergency room visits for children were based on data from the Healthcare Cost and Utilization Project of the Agency for Healthcare Research and Quality [9]. We approximated the typical cost of an emergency room visit as the difference between the national mean charge for an in-patient stay and the national mean total charge for the emergency room visit and hospital stay for those admitted through the emergency room [9]. The total direct cost of an emergency room visit and hospitalisation was the sum of the facility and physician charges [10]. We used the charge code for moderate complexity (Current Procedural Terminology [CPT] code 99283 for an emergency room visit and CPT codes 99222, 99232 and 99238 for hospitalisation). We used the national mean charge for an office-based physician visit derived from the 2004 MEPS [11]. We approximated the cost of an urgent care visit for a comorbidity as the cost of a typical office visit.

We calculated the mean price for each drug category from an online database of prices [20]. The cost of an antibiotic treatment was the weighted mean of the average cost of the named brand and generic prescription of amoxicillin clavulanate and the cost of a treatment pack of azithromycin, where the weights were the relative frequency of use when a broad-spectrum antibiotic was used to treat paediatric nonspecific respiratory infections [19]. The costs of asthma inhalers (rescue and controller medications) were the average of the prices for each inhaler category and were weighted by the typical utilisation of each drug category [21].

An indirect cost associated with each of these utilisations is the value of the time of the parent/caregiver. The mean round-trip travel time for a medical purpose in an urban area in California in 2009 was 46.6 min [29]. The mean time spent waiting for an office visit for asthma was ~23 min [30]. We used 24 min for the time in the examining room [31]. Thus the total time for a physician office visit was 1.56 h. We calculated the typical length of time for an emergency room visit using the sum of the median wait time and time receiving care [32]. The total of the mean travel time and median time at the emergency room was 3.89 h. We used the mean length of hospital stay (2.2 days for an asthma admission and 3.3 days for a bronchitis

TABLE 3 Mean annual frequency and related direct and indirect costs of a typical bronchitic episode

Outcome	Mean encounter frequency	Direct cost per encounter US$	Indirect cost per encounter US$		Annual cost US$	
			Riverside	Long Beach	Riverside	Long Beach
Office visits	1.15	113	45	40	182	176
Emergency room visits	0.06	844	112	100	57	57
In-patient hospitalisations	0.01	16625	759	677	174	173
School absences	2	NA	230	205	460	410
Antibiotics	1.16	85	NA	NA	99	99
Total cost per case US$					972	915

All costs are rounded to the nearest US$ 2010 rate. NA: not available.

TABLE 4 Mean annual frequency and direct and indirect costs of care for a typical asthma case

	Outcome frequency mean per yr	Direct cost per outcome per yr US$	Indirect costs per outcome per yr US$		Total annual cost US$	
			Riverside	Long Beach	Riverside	Long Beach
Outcome						
Asthma-specific office visit	1.5	113	45	40	239	231
Emergency room visits	0.2	844	112	100	172	170
In-patient hospitalisations	0.04	12776	506	451	531	529
School days missed	5.9	NA	230	205	1362	1214
Medication						
Inhaled corticosteroid	2.2	125	NA	NA	273	273
Cromolyn	1.1	95	NA	NA	102	102
Albuterol	6.8	55	NA	NA	374	374
Comorbidities						
Non-urgent office visits	0.9	113	45	40	134	130
Mean cost of antibiotics	2.2	85	NA	NA	189	189
Urgent care visits	0.2	113	112	100	50	47
In-patient days	0.03	6646	230	205	206	206
Bronchitic episodes						
Office visits	0.5	113	45	40	71	69
Emergency room visits	0.02	844	112	100	22	22
In-patient hospitalisations	0.004	16625	759	677	67	67
School absences	0.8	NA	230	205	178	159
Antibiotics	0.5	85	NA	NA	38	38
Annual total cost per asthma case US$					4008	3819

All costs are rounded to the nearest US$ 2010 rate. NA: not available.

admission) as a measure of the time costs of a hospital admission. We used one standard workday (8 h) as the time associated with a school absence. School absences are an important economic consequence, because they often lead to parents or caregivers missing work. We based the value of an hour on the median household income for Riverside and Long Beach and the typical number of hours worked per year (US$28.75 and US$25.63, respectively) [12, 13].

The project was exempt from review by an institutional review board.

RESULTS

We estimated that a single episode of bronchitic symptoms costs on average US$972 in Riverside and US$915 in Long Beach (table 3). The total annual cost for a typical asthma case was US$4,008 in Riverside and US$3,819 in Long Beach (table 4). The largest share of the cost of an asthma case was the indirect cost of asthma-related school absences (38% for Riverside and 36% for Long Beach). The costs that a child with asthma incurred due to related conditions (sinus and ear infections and bronchitic symptoms) totalled US$955 in Riverside and US$926 in Long Beach and accounted for ~25% of the typical annual costs in both communities.

The average annual costs of the TRP-attributable cases were US$2,765,520 in Riverside and US$6,110,400 in Long Beach (table 5). The total annual cost in these two communities of asthma-related outcomes due to TRP (table 5), compared with communities with background regional air pollution concentrations and with no homes within 75 m of a major roadway, was ~US$18 million.

If we were to consider the exacerbations regardless of cause of asthma onset, as is customary in usual approaches to risk assessment, then the total costs were approximately US$9.8 million a year, or only 54% of the true asthma costs from air pollution exposure (table 6).

DISCUSSION

The scale of the total annual economic impact of asthma cases and asthma exacerbations attributable to air pollution was remarkable (~US$18 million per year), almost half of which was due to TRP-attributable cases of asthma. The cost of these cases is not included in traditional risk assessments. The results are relevant to clinical practice, as much of these costs are borne by the families of children with asthma. The total annual cost associated with a case of asthma (US$3,800–4,000) was 7% of the median household income in Riverside and 8% in Long Beach [12, 13]. These results are troublesome because the sustainable healthcare expenditure of an entire family is considered to be 5% of income.

At least some of these costs could be prevented if the ambient air quality in Riverside and Long Beach were improved to resemble those with comparatively cleaner air in Southern Californian

TABLE 5 Cost of outcomes attributable to pollution exposure for children in Riverside and Long Beach

	Riverside		Long Beach		Total cost per year US$
	Count	Cost per outcome US$	Count	Cost per outcome US$	
Attributable asthma cases	690 (630–750)	4008	1600 (1500–1800)	3819	8875920
NO_2-attributable exacerbations of other-cause asthma					
Emergency room visits	40 (5–70)	956	150 (19–280)	944	179840
In-patient hospitalisations	8 (6–10)	13282	27 (22–32)	13227	463385
Office visits	190 (38–340)	158	440 (80–780)	153	97340
Bronchitic episodes	1500 (440–2300)	975	3100 (1000–4400)	918	4308300
O_3-attributable exacerbations of other-cause asthma					
Emergency room visits	230 (150–310)	956			219880
In-patient hospitalisations	12 (9–15)	13282			159384
Office visits	190 (25–360)	158			30020
Bronchitic episodes	2900 (160–3900)	975			2827500
School days absent	2966 (2223–4685)	230	626 (43–1114)	205	810510
Total annual cost US$					17972079

The 95% confidence intervals are reported in parentheses. All costs are rounded to the nearest US$ 2010 rate. NO_2: nitorigen dioxide; O_3: ozone.

communities. Land-use policies to discourage building homes near major roads, vehicular fleet conversion to very low or zero-emission vehicles, and increased use of public transportation and reductions in vehicle miles travelled would decrease the rates of asthma associated with traffic pollution. To put the potential benefits of reducing these costs in context, the pollution-attributable direct and indirect asthma-related costs in Riverside correspond to 6% of the county's total 2010 budget for health and welfare (US$131 million) [35]. The costs in Long Beach are 21% of the city's direct 2010 expenditures of the Department of Health and Human Services (US$46.5 million) [36].

There are assumptions and limitations inherent in any study of healthcare costs. Our approach was to start with identifiable pollution-attributable outcomes, then calculate the associated costs using data that best represented our population of interest. At each step we selected the option that would produce the most conservative estimate of the cost of the encounter. We identified three areas in which additional research on the economics of asthma is needed: 1) describing the distribution of healthcare utilisation over the population of children with asthma; 2) valuing the impact of asthma on the quality of life; and 3) calculating the indirect cost of caregiving.

TABLE 6 Air pollution related exacerbations and costs of all asthmatics

	Riverside		Long Beach		Total cost per year US$
	Count	Cost per outcome US$	Count	Cost per outcome US$	
NO_2-attributable					
Emergency room visits	42	956	160	944	191192
In-patient hospitalisations	8	13282	30	13227	503066
Office visits	200	158	500	153	108100
Bronchitic episodes	1600	975	3400	918	4681200
O_3-attributable					
Emergency room visits	250	956			239000
In-patient hospitalisations	12	13282			159384
Office visits	220	158			34760
Bronchitic episodes	3100	975			3022500
School days absent	2966	230	626	205	810510
Total annual cost US$					9749712

All costs are rounded to the nearest US$ 2010 rate. NO_2: nitorigen dioxide; O_3: ozone.

We relied on a variety of sources to describe a single ''typical'' asthma case and a ''typical'' bronchitic episode in terms of healthcare utilisation and school absences. Ideally, we would like to describe the entire distribution of these costs over the population using a single comprehensive database; however, these data are not available. We assumed that a TRP-attributable asthma case and bronchitic episode had rates of outcomes equal to those with asthma due to other causes. We estimated the cost of an asthma case by assuming that without exposure to TRP, the child would not have developed asthma. While the evidence for a causal role of air pollution in the development of asthma is increasingly strong [1–4], it does not necessarily follow that none of these children would develop asthma in the absence of TRP exposure.

The estimates of the cost of an asthma case and the cost of each pollution-attributable outcome are lower bound estimates as they included the direct and some indirect costs of each outcome, but did not include the value of the impacts on the quality of life, which can be substantial.

We assigned a value to the time investment required of family members due to a child's asthma, at the current labour value in each community. Previous studies have generally ''discounted'' the value of the time by the proportion of households in which all adult caregivers are employed, implicitly assuming that the value of the caregiver's time who is not employed outside the home is zero. There are three methodological problems with this standard approach. First, the caregiver's time has value to the family and society even if he/she is not employed in the external labour market. Secondly, weighting the value of time by the employment rate produces biased estimates because it ignores the cost of self-selection out of the labour market, as caregivers who have a child with recurring asthma symptoms are more likely to leave the labour force to provide care. Thirdly, it could be argued that because there is disutility associated with time spent procuring healthcare (who enjoys waiting in the emergency room with a sick child?), the market wage we have assigned may actually be an underestimation of the true cost of that time.

Conclusions

There is growing epidemiological and toxicological evidence that exposure to air pollution is both a cause of asthma and a trigger for exacerbations. We estimated that the annual cost of a case of asthma is ~US$3,800–4,000. The total additional asthma-specific cost in Riverside and Long Beach each year that is due to TRP is ~US$18 million, of which almost 50% is due to the cost of asthma cases attributable to residential traffic proximity and 50% is due to regional air pollution-attributable exacerbations among children with asthma due to other causes. The fact that together these two communities account for only 2% of the population of California [12, 13] suggests that the state-wide costs are truly substantial. While these estimates are specific to Southern California, the approach is applicable and relevant to urban and transportation planning beyond this setting. Indeed, >50% of the population is estimated to live within 150 m of major roads in 10 European cities recently studied (Barcelona, Valencia, Bilbao, Seville and Granada, Spain; Brussels, Belgium; Vienna, Austria; Ljubljana, Slovenia; Rome, Italy; and Stockholm, Sweden) [37].

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STATEMENT OF INTEREST

A statement of interest for F. Lurman can be found at www.erj.ersjournals.com/site/misc/statements.xhtml

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