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Original Research

COVID-19 transport restrictions in Ireland: impact on air quality and respiratory hospital admissions

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ABSTRACT

Aim: Exposure to poor air quality is a well-established factor for exacerbation of respiratory system diseases (RSDs); whether air pollutants are a cause of the development of RSD, however, remains unclear. This study aimed to examine the relationship between COVID-19 transport restrictions and hospital admissions because of RSD in Dublin city and county for 2020.
Study design: This was a retrospective population-based cohort.
Methods: Admission data were collected from the Health Service Executive Hospital In-patient Enquiry. Daily count of hospital admissions with Dublin city and county address with primary diagnosis of RSD was performed. The daily air nitrogen dioxide (NO_2) data were obtained from the Environmental Protection Agency (EPA).
Results: During the period of transport restrictions, there was a reduction in the annual mean NO_2 from 25 μg/m^3 to 17 μg/m^3 ($P < 0.001$), and decreases in hospital admissions for RSD were observed. Among the 9934 patient episodes included in this study, the mean age at admission was 61.5 years, 57.8% were female (n = 5744), and mean (standard deviation) length of stay was 7.5 (13.52) days.
Conclusion: This study, using routinely gathered data, suggests that decreases in ambient NO_2 as related to COVID-19 transport restrictions were significantly associated with lower asthma and chronic obstructive pulmonary disease admissions.

Introduction

Globally, outdoor air pollution has been recognised as a major public health concern.[1,2] There are reports of up to 7 million premature deaths annually, with a larger number of related hospital admissions.[3] The health burden from ambient air pollution in Ireland is substantial, with the European Environmental Agency estimating annual mortality of more than 1300.[4] In addition, some Irish studies have also highlighted the impact of day-to-day fluctuations in air pollution levels and acute hospitalisations and further confirmed the extent of the impact of the healthcare and social care systems.[1,3,5]

There is growing evidence that respiratory system diseases (RSDs) such as asthma and chronic obstructive pulmonary disease (COPD) can be aggravated or triggered by exposure to nitrogen dioxide (NO_2).[6–8] Furthermore, research has highlighted that short-term exposure (i.e. <24 h), even for annual mean NO_2 values of <50 μg/m3, has increased both respiratory hospital admissions and mortality.[9,10] It has also been reported that long-term (i.e. >24 h) exposure to NO_2 levels below the World Health Organization (WHO) recommended air quality annual mean guideline of 40 μg/m^3 can be associated with unfavourable health outcomes (including respiratory symptoms/disease, hospital admission and mortality).[9,10]

Vehicular traffic is a large cause of air pollution and a major source of outdoor NO_2 in Ireland.[4] Recently, there has been increasing attention about traffic-related air pollution (TRAP) as an exposure variable of interest for policy-makers; this shift has occurred and will help with tackling the impact on human health and meet the international commitment to air quality directives. These would see Ireland committing to European Union standards to deliver expected benefit in terms of reduction in emissions of

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NO_2 particularly from diesel vehicles. The health effects associated with NO_2 are therefore also heavily policy relevant.

In February 2020, the WHO declared a global pandemic for a contagious disease caused by severe acute respiratory syndrome coronavirus 2.[11] The pathogen is responsible for causing COVID-19. As part of the Irish pandemic control measures to mitigate for contagion, COVID-19 transport restrictions were introduced from March 2020. These strategies recommended that residents in Ireland reduce transport through the closure of non-essential services; encouragement of where possible for employees to work remotely; and only allow individuals to movements within limited distance of their places of residence (initially 2 km, then 5 km).[12] As the pandemic progressed and levels of COVID-19 in community reduced, these travel restrictions were relaxed from May 2020, with the proviso that all non-essential travel was kept to a minimum to reduce congregation and propagation of infection.[12] In September 2020, Dublin saw the return travel restrictions, which limited residents in Dublin from leaving the county.[12] This was followed in October 2020 with re-introduction of full lockdown for Ireland due to the rise in COVID-19 cases.[12] Gradual relaxation of travel restrictions started in early December 2020, but due to rapid rise in cases was short-lived and resulted in full travel restrictions returning in late December 2020.[12] Reports on compliance with government advice and guidelines of COVID-19 varied from 60% to 80% from April to November 2020.[13]

This study was designed to take advantage of secular trends in NO_2 brought out due to transport restrictions introduced during the COVID-19 pandemic. It would explore the relationship between ambient levels NO_2 and acute hospital admissions for specific RSD for residents of Dublin city and county between 2018 and 2021. This would allow the authors of the study to add to the body of evidence about the effect of ambient NO_2 on human health in Ireland by looking at the potential reversibility of the effect of NO_2 on RSD admissions at low levels of exposure associated with changes in transport and could support policy decisions on reducing TRAP. It will focus on RSD as the health outcomes because it is a leading cause and ill-health in Ireland, and all are clinical and public health priorities for the Health Service Executive (HSE).

Methods

This study used routinely gathered hospitalisation data collected from the HSE Hospital In-Patient Enquiry (HIPE) system.[14] This repository is a well-established, quality-assured, national hospital care information system that uses ICD-10-AM/ACHI/ACS coding to capture demographic, clinical and care data at discharge on all episodes of emergency and elective care across publicly funded hospitals in Ireland. Each HIPE record represents one episode of care, and individuals may have been admitted to more than one hospital with the same or different diagnoses. In the absence of a Unique Patient Identifier, the records therefore facilitate analyses of hospital activity rather than incidence of disease. Daily counts of all hospital admissions for residents (all ages) with an address in Dublin city and county admitted on the same day. These admissions were individuals with primary diagnoses of asthma (ICD-10-AM codes J45, J46) and COPD (ICD-10-AM codes J43, J44) for January 2018 to February 2021.

The NO_2 data collected from the monitoring station network in Dublin city and council were obtained from the Environmental Protection Agency (EPA). The daily average results from each station were provided, and these were all combined to an overall daily average for Dublin city, and council was generated. Two further strategies were used: the first involved using equal cutoff points (i.e. quartiles) by ordering the distribution to review the impact of high versus low levels of NO_2. The second involved calculated daily variations in the overall daily mean NO_2 for Dublin city and county, but subtracting the overall daily average from the preceding day; this would allow for reviewing the impact of $+5$ μg/m^3 and $+10$ μg/m^3 on hospital admissions for RSD.

To identify the impact on the acute hospital services, the following variables were examined: number of admissions, average age on admission (years), average length of stay (days) and gender. To take account for potential differences in age profile of cases, data for asthma-related admissions were stratified according to the following age groups: 0–17 years, 18–64 years and ≥65 years. This was not used for COPD, as the majority of cases were all over aged >65 years.

Raw and calculated data were collated and entered into Excel (Microsoft 2016) and exported into IBM SPSS Statistics for Windows, Version 26.0 (Armonk, NY). We analysed the data by applying descriptive statistics. All results were considered significant at $P < 0.05$ (two tailed). For correlation of metric variables, Spearman rank order (rho), and for correlations of nominal variables, the chi-squared test, and for small sample sizes, the Fisher's exact test was used. All results of various statistical tests are of an explorative nature.

Results

The overall daily average NO_2 data are shown in Fig. 1 and highlighted the overall decreases in ambient NO_2 levels noted since the start of the COVID-19 transport restrictions (indicated by green arrow). It also reveals a statistically significant reduction in the overall average annual NO_2 levels for Dublin city and county comparing 2018 to 2020 ($P < 0.001$). It also showed that the number of episodes above the WHO annual mean guideline of 40 μg/m^3 reduced with the introduction of pandemic control measures.

The daily hospital admission data are displayed in Fig. 2 and shows that overall decreasing numbers of admissions for the 3-year period. It revealed a statistically significant reduction in the overall respiratory admissions in 2020 when compared with 2018, which corresponds to decreases in annual mean NO_2 levels ($P < 0.001$).

The characteristics of the 9934 patient hospital admission episodes included in this study are described in Table 1. It has shown that mean (standard deviation) age on admission, 61.5 (19.61) years; 57.8% female (n = 5744); and mean (standard deviation) length of stay, 7.5 (13.52) days.

The characteristics for hospital patient episodes with asthma were comparable for non-pandemic and pandemic episodes, whereas with COPD, there was reduction in a mean age and length of stay observed.

The impact of changes in ambient daily mean NO_2 levels on hospital admissions stratified by RSD are shown in Table 2. It highlighted statistically significant increases in mean number of daily hospital admissions for patients with asthma between the ages of 0 and 17 years for changes in $NO_2 \geq 5$ μg/m^3 and ≥10 μg/m^3 (i.e. $P = 0.017$ and $P = 0.041$, respectively).

The impact of different levels of ambient daily mean NO_2 levels on hospital admissions stratified by RSD is described in Table 3. It has shown that there are increases in mean number of daily admissions for patients with asthma and COPD.

Discussion

The main findings of this study using routinely gathered information were as follows: the introduction of COVID-19 travel restrictions contributed to the reduction in ambient NO_2 levels in Dublin, decreased number of hospital admissions with asthma and COPD (with comparable characteristic profiles between non-

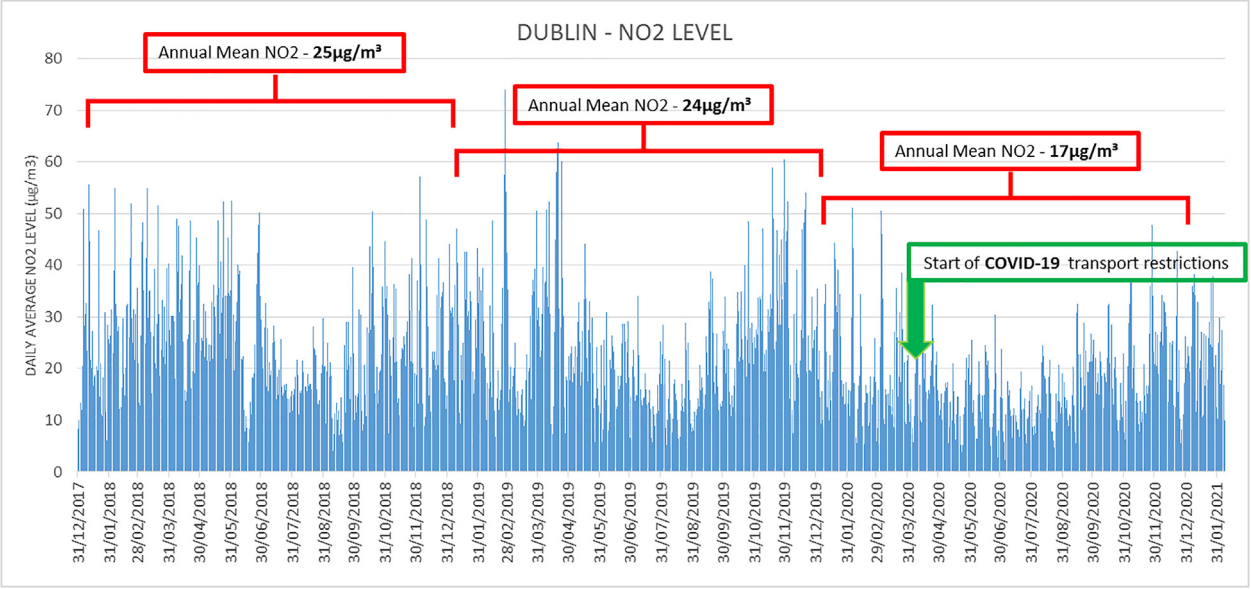

Fig. 1. Daily mean NO_2 levels in Dublin between 2018 and 2021. Data provided from HIPE from 2020 to present is provisional and subject to final validation.

pandemic and pandemic episodes), increases in daily ambient NO_2 levels (i.e. ≥5 µg/m^3 and ≥10 µg/m) were associated with increases in asthma admissions particularly in the 0–17 years of age; with high daily ambient NO_2 levels (i.e. ≥46 µg/m^3) were associated with increases in asthma and COPD admissions.

The impact of COVID-19 transport restrictions with observed reductions in ambient NO_2 levels is a finding that is consistent with newly published reports. These have highlighted falls of 23–37% of ambient NO_2 levels being observed with the introduction of pandemic controls and were 32% from this study (i.e. 25 µg/m^3 to 17 µg/m^3).[15–17] The decreases in hospitalisations for persons with asthma and COPD have been reported consistently, with children with asthma being impacted most commonly (i.e. responsible for at least 15%–24% of exacerbations) as a result of this reduction in ambient NO_2 levels has also be documented in new publications on the area.[1,7–9,18–20] In addition, some reports have also highlighted overall falls in admissions of 40–64% for asthma and 50–85% for COPD and were 79% (i.e. 2813–585) for asthma admissions and 78% (i.e. 5335–1201) for COPD admissions in this study. The other results are also concordant with findings in the literature.[15,16,21,22]

The decreases in hospital admissions for RSD and ambient NO_2 levels after the introduction of the COVID-19 travel restrictions coincided with overall reduction in acute hospital admissions because of the pressure of the acute hospital from COVID-19. This was not controlled for in this study, as it would require differential calculations on all diseases and requirements for acute and emergency admissions. Furthermore, the limited demographic profiles reviewed for patient episodes for RSD showed similar characteristics, suggesting that although numbers had reduced, there was consistency in the patient population. Furthermore, to offer validity for the ascribing changes in hospital admission figures to NO_2, this study has demonstrated the statistically significant correlation and

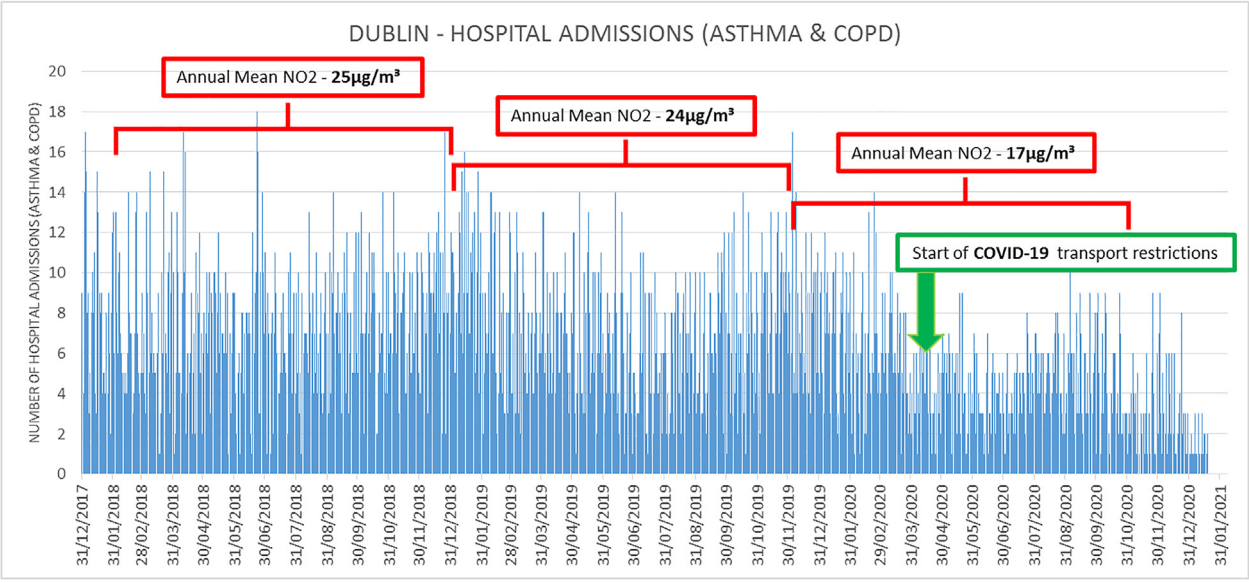

Fig. 2. Daily numbers of respiratory system disease in-patient admission to hospitals between 2018 and 2021. Data provided from HIPE from 2020 to present is provisional and subject to final validation.

Table 1
Distribution of hospital admissions for residents of Dublin from 2018 to 2021.

Characteristics	All patient episodes (31/12/2017 to 07/02/2021)	Non-pandemic episodes (31/12/2017 to 11/03/2020)	Pandemic episodes (12/03/2020 to 07/02/2021)
Asthma			
Number of episodes	3398	2813	585
Age on admission (years), mean (SD)	47.2 (22.50)	47.2 (22.78)	47.5 (21.13)
Sex			
Male	1347 (40%)	1111 (39%)	236 (40%)
Female	2051 (60%)	1702 (61%)	349 (60%)
Length of admission, mean (SD) days	3.1 (4.57)	3.1 (4.78)	3.2 (3.29)
Chronic obstructive pulmonary disease			
Number of episodes	6536	5335	1201
Age on admission (years), mean (SD)	68.9 (12.72)	69.2 (12.62)	67.7 (13.12)
Sex			
Male	2843 (43%)	2344 (44%)	499 (42%)
Female	3693 (57%)	2991 (56%)	702 (58%)
Length of admission (days), mean (SD)	8.5 (14.63)	8.9 (15.61)	6.9 (9.32)

Data provided from HIPE from 2020 to present are provisional and subject to final validation.

Table 2
Distribution of hospital admissions for residents of Dublin stratified by change in NO_2 from 2018 to 2021.

Characteristics	Mean number of daily hospital admissions		Chi-squared test
	<5 μg/m^3	≥5 μg/m^3	
Asthma			
All ages	1.32	1.33	0.883
0–17 years	2.63	3.01	0.017
18–64 years	1.69	1.71	0.887
≥65 years	3.52	4.07	0.008
Chronic obstructive pulmonary disease (COPD)			
All ages	5.83	6.12	0.158
	Mean number of daily hospital admissions		
	<10 μg/m^3	≥10 μg/m^3	
Asthma			
All ages	1.31	1.42	0.196
0–17 years	2.69	3.13	0.041
18–64 years	1.72	1.56	0.232
≥65 years	3.63	4.05	0.123
Chronic obstructive pulmonary disease (COPD)			
All ages	5.87	6.20	0.246

Data provided from HIPE from 2020 to present are provisional and subject to final validation.

the impact that NO_2 levels on hospital admissions for RSD in Ireland (i.e. showing that both sharps increases in daily ambient NO_2 and high overall ambient levels of NO_2 above the WHO threshold are associated with increases in hospital admissions). These findings are consistent with findings in the literature.[6,7,18,19]

We must acknowledge that we cannot truly quantify to what extent the reduced numbers of admissions of RSD are because of decreased exposure to poor ambient air quality, improvements on control of these diseases or avoidance of healthcare settings. However, based on the results, it is reasonable to say that the ambient NO_2 levels have some short-term impact on acute hospitalisations for RSD. It has different degrees of impact on respiratory human health, with individuals with asthma being more affected than those with COPD. These findings have been already well documented within the literature.[6,15,16,21,22] It has also been shown that changes in NO_2 levels have differential impact on RSD, with younger persons with asthma being consistently impacted. This finding is consistent with published reports.[6,22]

It was also noted that the number of episodes of ambient NO_2 levels exceeding the WHO annual mean guideline of 40 μg/m^3 has reduced with the introduction of transport restriction measures. Given the transport is the major source of ambient NO_2 in Ireland, it is reasonable to assume that there is no other explanation for the change in this ambient air pollutant. These findings have been replicated in other countries with comparable infrastructure and vehicular patterns to Ireland that introduced transport restrictions as part of pandemic control measures.[15–17,20]

A caveat that must be acknowledged is that the ambient air quality monitoring network in Dublin may not have historically been sufficient to accurately characterise the spatial patterns for ambient NO_2 around Dublin city and county. This can potentially lead to underestimates in this daily ambient air pollutant. These may occur because the ambient air quality network has a limited number of stations, some of which might not be next to the busiest road networks that might be more used during the transport restrictions. A number of statistical approaches have been used to alleviate this shortcoming, including modelling and development of forecasting frameworks.[3,23] However, these approaches are not a substitute for improved data collection, and the EPA is currently and continually upgrading and expanding the ambient air quality

Table 3
Distribution of hospital admissions for residents of Dublin stratified by level of NO_2 from 2018 to 2021.

Characteristics	Mean number of daily hospital admissions				Chi-squared test
	≤15 μg/m^3	16–30 μg/m^3	31–45 μg/m^3	≥46 μg/m^3	
Asthma					
All ages	1.24	1.31	1.43	1.44	0.140
0–17 years	2.63	2.75	2.75	3.28	0.072
18–64 years	1.66	1.69	1.68	1.87	0.338
≥65 years	3.56	3.68	3.67	4.48	0.046
Chronic obstructive pulmonary disease (COPD)					
All ages	5.34	5.97	6.46	6.96	<0.001

Data provided from HIPE from 2020 to present are provisional and subject to final validation.

network. In addition, as a reference, the NO_2 monitoring network had three stations at the start of 2018, and this was expanded to 13 stations by the start of 2021, as part of the expansion under the National Ambient Air Quality Monitoring Programme.

There are a series of limitations associated with this work. The first limitation is that there are relatively low levels of day-to-day variation in ambient NO_2, which might lend to impact on the statistical power when considering human health outcomes. However, given that Ireland is committed to European and WHO strategies to improve ambient air quality, it is unfavourable and undesirable to see marked variations/deteriorations in levels of ambient NO_2 levels. The second limitation is related to the lack of individual-level information on medical comorbidities and smoking status. This might have to further quantify the level of impact on persons at high risk for the impact of high levels of NO_2. Access to this level of information would be useful and relevant but would require ethical approval, which was not necessary to undertake this current piece of work. A third limitation is related to the reduction in overall hospital admissions during the COVID-19 pandemic. It is however a reasonable assumption that persons with illnesses where breathing difficulties might be experienced would have still sought hospital-delivered care, as part of their treatment pathway. In addition, the fourth limitation noted was that some of the individuals with RSD included might have impact from poor air quality episodes, which do not result in hospital admissions. Ambulatory care in general practice, outpatient settings, emergency room visits that do not conclude in hospital admission, and pharmacy attendances (i.e. using prescriptions for corticosteroids as a surrogate marker for activity) are not traditionally captured by the HIPE system. Given that there is no consistent and equitable way to gather any of the aforementioned healthcare interactions, the hospital admissions is the best surrogate for capturing morbidity related to poor ambient NO_2 levels for this piece of work.

This study introduces empiric evidence that in Dublin city and county, where ambient NO_2 levels are predominantly compliant with WHO annual mean guideline of 40 $\mu g/m^3$ that the introduction of COVID-19 transport restrictions has led to overall reduction of ambient levels of NO_2. It was also shown that reduction in ambient NO_2 levels following the transport restrictions was associated with reduction in admissions of RSD. Although these findings are related to pandemic control, this study might serve as support for policy development to reduce ambient NO_2 levels in Dublin city and county and across Ireland. It should help to inform the targeting of public health strategy to minimise any adverse effects of TRAP, as well as capture any positive elements, which could be harnessed to reduce hospital admissions in vulnerable groups over the long term.

Author statements

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Ethical approval

This research uses routinely collected data at the population level rather than the individual level; it conforms to the Helsinki Declaration and does not require approval from a research ethics committee.

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Competing interests

The authors declare no conflict of interest.

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