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Air quality influence on chronic obstructive pulmonary disease (COPD) patients' quality of life

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Abstract:

Chronic obstructive pulmonary disease (COPD) is one of the leading causes of death. The relationship between urban air pollution and its short-term health effects on patients suffering from COPD is confirmed. However, information about the impact of air pollutants upon the quality of life (QOL) in patients with COPD is lacking. Through a cross-sectional survey, this study investigates such impact in terms of the scores of the (Chinese) chronic respiratory questionnaire (CCRQ) and the measurements of indoor air quality (IAQ), lung function and Moser's activities of daily living (ADL). Using Yule's Q statistic with a cut-off $|Q|>0.7$ to identify the strong relationships between environmental parameters and CRQ sub-scores, this study reveals that patient emotion is strongly associated with indoor environmental quality although the evidence of a causal relationship between them needs further research.

Keywords: quality of life (QOL), chronic obstructive pulmonary disease (COPD), indoor air pollutants, chronic respiratory questionnaire (CRQ)

Practical Implications:
As QOL in patients with COPD and indoor environmental parameters are strongly associated, indoor air pollutants must be monitored for related studies in the future.

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Introduction:

Chronic obstructive pulmonary disease (COPD) is the fifth leading cause of death in Hong Kong. Investigators are eager to explore the environmental risk factors for COPD such as air pollution and occupational exposure. Despite the finding that urban air pollution (mainly the particulate matter) is associated with increased mortality and hospital admission rates in patients with COPD (Ko *et al.* 2007; Sunyer 2001), the impact of indoor air pollution upon quality of life (QOL) for COPD patients is still lacking.

In a long-term study of the relationship between five major air pollutants (i.e. sulphur dioxide (SO_2), respirable suspended particulates (PM_{10}), nitrogen dioxide (NO_2), carbon dioxide (CO) and ozone (O_3)) and hospital admissions for COPD in a tropical city (Kaohsiung, Taiwan), statistically significant positive results were found in all pollutants with only one exception - SO_2 on warm days ($\geq 25^oC$) (Lee *et al.* 2007). Similarly in Hong Kong, multivariate analysis showed that SO_2, NO_2 and O_3 had a greater effect on COPD admissions in the cold season (December to March) than in the warm season (Ko *et al.* 2007). These findings provide evidence that higher levels of ambient pollutants increase the risk of hospital admission for COPD during winter season in tropical and subtropical cities.

Moreover, QOL was demonstrated strongly related to the number of yearly and past exacerbations in COPD patients, although there was no relation between hospital admission and exacerbation frequency because not all of the exacerbations required hospital admission (Donaldson *et al.* 2002; Ko *et al.* 2007; Seemungal *et al.* 1998). As the chronic respiratory questionnaire (CRQ) developed by Guyatt *et al.* (1987) is one of the most prevalent health-related quality of life (HRQOL) instruments for pulmonary rehabilitation programme (PRP) (Lacasse *et al.* 2002) and has advantages over some of the other outcome variables or QOL questionnaires which are more responsive to the effect of pulmonary rehabilitation (de Torres *et al.* 2002; Singh *et al.* 2001), it is the preferred QOL assessment tool and its Chinese version (CCRQ) was employed in this study (Chan *et al.* 2006).

Methodology:

Target participants

In a cross-sectional study, data was collected from patient interviews via home visits. 41 patients with COPD were recruited by convenience sampling, a method which is most useful for pilot testing. For a good coverage of the local environmental conditions, the samples were taken from 16 districts (out of a total of 19) in Hong Kong geometrically. Invitations, together with the study objectives and survey details, were sent to five selected self-help groups for people with COPD. Prior to commencement of the study, which was carried out in accordance with the principles of the Declaration of Helsinki, all participants provided written informed consent. Ethical approval was also sought from The Hong Kong Polytechnic University (Reference: HSEAR20070308001). Each participating patient was interviewed twice through two seasonal surveys - the first (Measurement A) was conducted in a summer while the second (Measurement B) the winter of the same year, 6 months apart. Participant dropout did not occur between the surveys. Each interview lasted for about 3 hours. A target-oriented questionnaire was employed to assess the influence of indoor air quality (IAQ) parameters on patient QOL. Patients with other lung diseases including active tuberculosis, lung cancer and cardiac complications such as ischemic heart disease were excluded.

Measurement of indoor air quality (IAQ)

The personal interview method was developed based on some earlier residential survey studies done in Hong Kong (Wong 2003; Mui *et al.* 2007; Tu 2005). During the interview, information of the patient and the tenement, including occupant load patterns, time budget for activities, usage patterns of various home appliances and home cleaning practice, was surveyed. For each apartment, the furniture used, window locations and sizes, and potential indoor air pollutant sources (e.g. pets, plants, moldy wall surfaces, places under renovation, etc) were recorded. Surroundings of the apartment were also observed to set down the nearby major pollution sources such as vehicle traffic routes, construction sites, noticeable building exhaust, and vegetation.

ISO 7708 defines sampling conventions for particle size fractions for use in assessing possible health effects of airborne particles in the workplace and ambient environment. Three fundamental conventions, namely inhalable, thoracic and respirable, are defined; and from them, extrathoracic and tracheobronchial conventions may be calculated. The size fractions are expressed in terms of aerodynamic diameter of a particle which is a measure of its behavior in air. Reportedly, 50% of the total airborne particles are in the thoracic (aerodynamic diameter ≤10 μm; PM_{10}) and respirable (aerodynamic diameter ≤2.5 μm; $PM_{2.5}$) fractions (ISO 1995).

IAQ measurements made both inside and outside the apartment covered airborne fungi counts (AFC) and a number of environmental parameters: airborne particulates from 0.3 to >10.0 μm and PM_{10}, air temperature (T), relative humidity (RH), carbon dioxide (CO_2), carbon monoxide (CO), and total volatile organic compounds (TVOC). The sampling interval was set to 1 minute throughout the site survey period which was about 3 hours for each survey. The airborne particulates were denoted as $SP_{0.3}$, $SP_{0.5}$, SP_1, SP_2, SP_5 and SP_{10} and enumerated using a particle counter with size detection ranges of 0.3-0.5 μm, 0.5-1 μm, 1-2 μm, 2-5 μm, 5-10 μm and >10 μm respectively. To evaluate AFC, 500-L air samples collected with the aid of a Reuter Centrifugal Sampler (Biotest; with Malt Extract Agar supplemented with Rose Bengal) were incubated for 7 days at a constant temperature of 25°C and quantified as colony forming units per liter (CFU L^{-1}) of air. All selected measurement locations were 1 m above ground and at least 1 m away from any obstruction. Other measurement equipment details can be found in an earlier study (Wong *et al.* 2006).

It was noted that the patient's response to the Chronic Respiratory Questionnaire (CRQ) was referenced to air quality parameters in the past two weeks immediately preceding the interview. A short-term measurement of IAQ parameters is considered practical for the stated short term period in CRQ. It was also noted for studying the yearly exposure level of common IAQ parameters, a short-term sampling of 4 hours would lead to an error up to 50% (Mui *et al.* 2004).

Measurement of quality of life (QOL)

Chronic Respiratory Questionnaire (CRQ)

Reproducible and sensitive to change, this questionnaire is an established measure of health status for COPD patients in four dimensions, namely dyspnoea, fatigue, emotion, and mastery (Guyatt *et al.* 1987; Siafakas *et al.* 1995). Via a list of validated questions, patient QOL can be assessed on a 7-point Likert-type scale ranging from 1 for 'maximum impairment' to 7 for 'no impairment'. In this study, a Chinese version of the questionnaire was administered as a structured interview performed by a registered occupational therapist.

Measurement of physiological responses

Lung Function Tests

Lung function values including mainly the forced expiratory volume in one second (FEV_1) of 2 standard deviations below the predicted score, which is a diagnostic test for COPD, and the ratio of it to forced vital capacity (FEV_1/ FVC), and peak expiratory flow (PEF; for suspected asthma) were chosen for this study since they are the most common figures showing airflow limitation and provide useful quantitative criteria of health status for patients with COPD (Sunyer 2001). Previous literature has shown that a small respiratory infection will lead to a decline in FEV_1 (Fletcher and Peto 1977). Furthermore, arterial oxygen saturation (SaO_2) values during specified indoor activities (i.e. at rest $SaO_{2,rest}$; after walking on level ground for 2 minutes $SaO_{2,indoor}$; after sitting and standing repeatedly for 2 minutes $SaO_{2,sit}$) were measured. SaO_2 measurement is an initial assessment tool for moderate to severe COPD (van Dijk *et al.* 2004).

Moser's activities of daily living (ADL) class

A classification system of functions developed in an attempt to classify COPD patients according to their functional pulmonary disability into 5 levels: level 1 indicates patients with no substantial restriction of instrumental activities of daily living tasks and level 5 indicates those who are confined to bed or chair most of the day (Moser *et al.* 1980). It has been used quite commonly with the COPD Disability Scale established by the American Thoracic Society in most of the pulmonary rehabilitation programs in Hong Kong. In this study, the therapist rated the patient activities by asking all of the patients to grade their respective actual ADL performances over a 2-week period immediately preceding the interview.

Tests of significance

Under the assumptions that the paired differences were independent and identically normally distributed, paired t-test was performed to test the null hypothesis of no difference between Measurements A and B. Shapiro-Wilk's test was also applied to test the normality at a significance level of 0.01.

Under the null hypothesis of zero correlation, regression line can be tested using Equation (1), a t-distribution with N−2 degrees of freedom, where R is the sample correlation coefficient and N is the total number of data pairs for the regression line,

$$t = \frac{R\sqrt{N-2}}{\sqrt{1-R^2}} \qquad \dots (1)$$

Results and Discussions:

Table 1 shows the characteristics of the 41 COPD patients surveyed. With a mean age of 69.3 years (18 females and 23 males; aged from 40 to 89), this patient group had a mean ADL score of 1.98 and a standard deviation (SD) of 0.85. The number of patients observed in the ADL scale levels 1, 2, 3, 4 and 5 were 14, 15, 11, 1 and 0 respectively. The mean of FEV was 45% (SD=24%) while that of PEF was 50% (SD=27%). As the mean of lung function impairment in terms of FEV1/ FVC was 61% with SD=20%, most of the surveyed patients were having moderate COPD. Reportedly, all patients stayed home at least 16 hours per day, with an average daily indoor time of 21 hours (SD=2.6h).

8 of the 41 patients were on oxygen therapy. The mean levels for $SaO_{2,rest}$, $SaO_{2,indoor}$ and $SaO_{2,sit}$ were 96% (SD=2%), 92% (SD=4%) and 93% (SD=4%) respectively. No significant differences between the collective averages were found in the two measurements ($p \geq 0.1$, paired t-test). The average CRQ sub-scores for the patients were 5.27, 4.26, 5.39 and 5.65 regarding dyspnoea, fatigue, emotion and mastery respectively. In both Measurements A and B, no significant differences were detected between the collective results ($p \geq 0.1$, paired t-test). All lung function indicators and CRQ sub-scores were assumed normally distributed ($p \geq 0.01$, Shapiro-Wilk's test); except for the FEV_1/FVC and PEF scores measured in winter ($p \leq 0.01$, Shapiro-Wilk's test).

Table 1: Characteristics of 41 patients with COPD$^+$

Patient characteristics	Measurement A (Summer)	Measurement B (Winter)
Basic information		
Age	69.3 (11.9) 73*	
Gender: M/F	23/18	
Daily indoor time (h)	21.0 (2.6) 21.5*	
Moser's ADL class	1.98 (0.85) 2*	
Lung Function		
FEV_1 (%)	44 (24) 38*	46 (24) 48*
FEV_1/FVC (%)	62 (21) 61*	60 (19) 58*
PEF (%)	48 (28) 39*	52 (27) 46*
$SaO_{2,rest}$ (%)	96 (2) 96*	96 (2) 97*
$SaO_{2,indoor}$ (%)	92 (5) 94*	91 (5) 93*
$SaO_{2,sit}$ (%)	93 (4) 94*	93 (4) 94*
CRQ sub-scores		
Dyspnoea	5.16 (1.46)	5.41 (1.12)
Fatigue	4.08 (1.21)	4.46 (1.07)
Emotion	5.37 (1.25)	5.41 (1.16)
Mastery	5.67 (1.18)	5.62 (1.03)

$^+$Values shown: average; standard deviation in brackets; median with an asterisk

Table 2: Environmental characteristics

Measured parameter	Measurement A		Measurement B	
	Indoor Average (SD)	Outdoor Average (SD)	Indoor Average (SD)	Outdoor Average (SD)
At patient apartments				
PM_{10} (μgm^{-3})	99.6 (64)	116 (70.2)	105 (56)	101 (62.6)
CO_2 (ppm)	517 (302)	352 (26.5)	523 (326)	360 (28.9)
CO (μgm^{-3})	3124 (5155)	2664 (1279)	2259 (752)	2330 (763)
T (°C)	26.8 (2.9)	28.3 (3.7)	23.2 (3.1)	23.5 (4.2)
RH (%)	58 (12)	59 (12)	66 (13)	64 (16)
TVOC (μgm^{-3})	107 (170)	36.7 (13.5)	93 (238)	41.6 (14.6)
$SP_{0.3}$ (L^{-1})	130006 (72590)	144308 (67159)	161075 (47373)	15733 (42943)
$SP_{0.5}$ (L^{-1})	23218 (23864)	27969 (25646)	39227 (34180)	35441 (26923)
SP_1 (L^{-1})	1949 (2007)	2527 (2512)	4146 (7203)	3300 (2607)
SP_2 (L^{-1})	893 (659)	1243 (734)	1482 (958)	1614 (995)
SP_5 (L^{-1})	64.2 (58.1)	97.0 (66.3)	102 (199)	92.0 (70.4)
SP_{10} (L^{-1})	7.67 (7.89)	10.4 (10.0)	7.85 (7.98)	8.49 (7.99)
AFC (CFU L^{-1})	95.4 (67.4)	151 (182)	120 (111)	151 (183)
Aspergillus (CFU L^{-1})	12.4 (17.0)	12.5 (13.3)	18.7 (22.9)	10.5 (13.7)
Cladosporium (CFU L^{-1})	49.3 (55.6)	106 (191)	55.4 (52.6)	66.4 (101)
Penicillium (CFU L^{-1})	11.6 (16.0)	8.46 (12.2)	18.1 (22.9)	24.4 (22.6)
IAQI	0.42 (0.20)	-	0.42 (0.28)	-
At Hong Kong Observatory stations				
API	-	47.6 (17.7)	-	47.0 (16.8)
(Station) SO_2 (μgm^{-3})	-	24.5 (19.1)	-	19.4 (18.6)
(Station) PM_{10} (μgm^{-3})	-	68.9 (38.1)	-	58.7 (33.4)
(Station) NO (μgm^{-3})	-	119 (68.2)	-	146 (86.2)
(Station) NO_2 (μgm^{-3})	-	62.7 (22.7)	-	70.5 (29.4)
(Station) O_3 (μgm^{-3})	-	58.4 (40.3)	-	36.7 (30.8)
(Station) CO (μgm^{-3})	-	1144 (227)	-	781 (507)

-=not measured; PM_{10}=respirable suspended particulates; CO_2=carbon dioxide; CO=carbon monoxide; T=air temperature; RH=relative humidity; TVOC=total volatile organic compounds; SP=airborne particle count in the specified size range; AFC=airborne fungi count; IAQI=IAQ index; API=Air Pollution Index; SO_2=sulfur dioxide; NO=nitrogen monoxide; NO_2=nitrogen dioxide; O_3=ozone

Table 2 shows the environmental characteristics obtained in this study. PM_{10} mass concentrations did not indicate any seasonal variation ($p \geq 0.3$, paired t-test). Likewise, there were no significant differences between other indoor and outdoor readings when comparing Measurements A and B ($p>0.05$, paired t-test), except for: indoor and outdoor temperatures ($p<0.001$, paired t-test); indoor RH ($p<0.05$, paired t-test); indoor particles in the size range 0.5-5 μm ($p \leq 0.05$, paired t-test); and outdoor *Penicillium* sp. ($p<0.0005$, paired t-test). The IAQ index, which is the average fractional dose within the 8-h exposure limits of indoor PM_{10}, CO_2 and TVOC in the workplace and a screening indicator for unsatisfactory IAQ, also suggested insignificant seasonal variation ($p>0.05$, paired t-test).

The corresponding data of Air Pollution Index (API) and its six contributing air pollutants, viz. SO_2, PM_{10}, NO, NO_2, O_3 and CO, gauged at Hong Kong Observatory stations is shown for reference. API is calculated by taking the maximum of subindices of scale extending from 0 to 500 among all the parameters measured to indicate the overall pollution level: a subindex level ≤100 corresponds to no adverse acute health effect to human while a level of 500 corresponds to significant harm to human health (Yau and Pun 2008). From the station data, the exposure levels of SO_2, CO and O_3 were significantly different between Measurements A and B ($p \leq 0.01$, paired t-test). As more than half of the station CO concentrations were noted below detection limits, CO exposure level was not used in the QOL evaluation.

Although indoor $PM_{2.5}$ was not a monitoring parameter in this study, its particle counts were measured for comparison. By assuming that average particle density is the same for all particle sizes (Chao and Wong 2002), mass concentrations for particles that fall within the size range of 2.5 to 10 μm were approximated from the measured particle counts. For there were no significant differences detected between the weighted-average densities of particle size ranges <2.5 μm and 2.5-10 μm ($p \geq 0.2$, t-test), the assumption should be applicable. This study revealed that under the assumption, the weight contribution of larger particles SP_2 and SP_5 (i.e. 2-10 μm) was 70 to 80% while that of fine particles $SP_{0.3}$ (i.e. 0.3-0.5 μm) was only 4 to 8%.

A number of studies reported that outdoor particle mass concentrations of PM_{10} and $PM_{2.5}$ had influences on COPD admission rate (Ko *et al.* 2007). If COPD patients spend long time indoors, then indoor-to-outdoor (I/O) pollutant correlations will be important in a residential environment. Based on the air pollutant particle counts measured from the surveyed apartments in this study, there were significant I/O correlations ($R \geq 0.74$, $p<0.0001$, t-test). Except for $SP_{0.3}$, correlations were significant among particle counts of different sizes both outdoors ($R \geq 0.5$, $p \leq 0.0001$, t-test) and indoors ($R \geq 0.6$, $p \leq 0.0001$, t-test). PM_{10} mass concentrations correlated with particle counts for all sizes ($R \geq 0.3$, $p \leq 0.05$, t-test) except SP_5. As it was noted that there would be some correlations between indoor PM_{10} level and SP_5 ($p=0.097$, t-test), PM_{10} concentration can be a valid surrogate indicator for monitoring environmental quality in the surveyed apartments if fine particles are a concern. The relationship between outdoor ϕ_1 and indoor ϕ_2 particle concentrations can be expressed by Equation (2), where i=1-7 are the parameters for PM_{10}, $SP_{0.3}$, $SP_{0.5}$, SP_1, SP_2, SP_5 and SP_{10} respectively, C_1 is the regression constant, and ε is the zero mean error term approximated by a normal distribution with a standard error C_2,

$$\phi_{2,i} = C_{1,i}\phi_{1,i} + \varepsilon\left(C_{2,i}\right) \quad \ldots (2)$$

The constants C_1 and C_2 for Equation (2) are exhibited in Table 3. Indoor particle concentrations were found generally lower than the outdoor levels by 67 to 99.8%. This percentage indicated that the outdoor-indoor penetration was closer to unity for finer particles. A significant correlation was reported between the particle size and the I/O particle count ratio (R=−0.868, p<0.05, t-test). Moreover, the average I/O ratio of PM_{10} (i.e. C_1=0.9085) was within the range of PM_{10} I/O ratios (0.88-1.04) resulted from an earlier measurement for Hong Kong apartments (Chao and Wong 2002).

Table 3: Constants for Equation (2)

Pollutants	PM_{10}	$SP_{0.3}$	$SP_{0.5}$	SP_1	SP_2	SP_5	SP_{10}
Constants	i=1	2	3	4	5	6	7
C_1	0.9085	0.9977	0.9015	0.8272	0.8135	0.7338	0.6710
C_2	0.0252	0.017	0.0319	0.0304	0.0346	0.0356	0.0462

PM_{10}= respirable suspended particulates; SP=airborne particle count in the specified size range

This study assumed that a change of the environmental exposure level in a patient's apartment would associate with a change in the patient's CRQ sub-scores. To further analyze the data on an individual basis, 2×2 contingency tables were employed to compute for: concordant positive (CP) and concordant negative (CN) - the number of increment and decrement cases respectively in which both the environmental parametric value and CRQ sub-score increase; discordant positive (DP) - the number of cases in which the environmental parametric value increases while the CRQ sub-score decreases; and discordant negative (DN) - the number of cases in which both the environmental parametric value and CRQ sub-score decrease. A total of 21×4=84 cases were considered, i.e. 21 environmental parameters (including 14 indoor parameters, viz. PM_{10}, CO_2, CO, T, RH, TVOC, $SP_{0.3}$, $SP_{0.5}$, SP_1, SP_2, SP_5, SP_{10}, AFC, IAQI; and 7 outdoor parameters, viz. API, SO_2, PM_{10}, NO, NO_2, O_3, CO) times 4 CRQ sub-scores (for dyspnoea, fatigue, emotion and mastery). Association between a CRQ sub-score and an environmental parameter for each of the 84 cases can be measured by Yule's Q statistic given by Equation (3) below; where cases of Q<0.5, 0.75>Q≥0.5 and Q≥0.75 suggest weak, moderate and strong relationships respectively (Knoke *et al.* 2002; Mui *et al.* 2009).

$$Q = \frac{CP \times CN - DP \times DN}{CP \times CN + DP \times DN} \quad \ldots (3)$$

Table 4: Influence of air quality on QOL in COPD patients

Parameter	Maximum change	Q-statistics	Unit increment δ	Likelihood ratio L_r	Proportion	$\theta_{0.5}$	$\theta_{0.8}$
Dyspnoea							
AFC	252 (CFU L^{-1})	0.71	27.2	2.7	9.27	0.9	1.6
Fatigue							
$SP_{0.5}$	91287 (L^{-1})	−0.73	−56627	1.9	−1.61	0.7	3.8
SP_2	3483 (L^{-1})	−0.75	−788	1.8	−4.42	0.6	2.4
SP_5	294 (L^{-1})	−0.73	−36.7	1.9	−8.01	0.4	0.6
Emotion							
PM_{10}	222 (μgm^{-3})	−0.89	−506	6.7	−0.44	2.5	4.6
CO	3960 (μgm^{-3})	−0.86	−2756	6.8	−1.44	2.1	10
T	13.6 (°C)	0.96	67.5	5.8	0.20	2.3	3.3
RH	41 (%)	0.82	145	5.7	0.28	2.1	4.5
$SP_{0.3}$	197032 (L^{-1})	−0.80	−891418	4.2	−0.22	2.5	6.0

$SP_{0.5}$	91287 (L^{-1})	−0.98	−278640	14	−0.33	2.3	3.3
SP_1	6164 (L^{-1})	−0.99	−19697	16	−0.31	2.4	3.5
SP_2	3483 (L^{-1})	−0.81	−6514	3.1	−0.53	2.1	2.7
SP_5	294 (L^{-1})	−0.91	−473	6.4	−0.62	2.0	3.8
SP_{10}	30 (L^{-1})	−0.96	−48.7	12	−0.61	3.2	4.0
AFC	252 (CFU L^{-1})	0.89	221	8.3	1.14	2.1	5.3
(Station) SO_2	28 (μgm^{-3})	−0.76	−16.7	4.3	−1.70	1.7	3.8
(Station) PM_{10}	145 (μgm^{-3})	−0.89	−220	7.5	−0.66	3.6	4.8
(Station) NO	139 (μgm^{-3})	−0.87	−421	6.0	−0.33	7.0	7.0
(Station) NO_2	90 (μgm^{-3})	−0.75	−173	3.4	−0.52	3.6	6.7
(Station) API	57 (-)	−0.89	−141	7.6	−0.40	2.1	3.4
IAQI	1.31 (-)	−0.77	−1.24	4.2	−1.06	2.8	6.7
Mastery							
(Station) PM_{10}	145 (μgm^{-3})	−0.72	−417	3.9	−0.35	2.0	4.0
(Station) NO_2	90 (μgm^{-3})	−0.71	−217	3.5	−0.41	5.0	8.0

θ=odds ratio for the specified limit; AFC=airborne fungi count; SP=airborne particle count in the specified size range; PM_{10}= respirable suspended particulates; CO=carbon monoxide; T=air temperature; RH=relative humidity; SO_2=sulfur dioxide; NO=nitrogen monoxide; NO_2=nitrogen dioxide; API=Air Pollution Index; IAQI=IAQ index

Table 4 presents 23 cases (out of 84) of moderate to strong correlations based on a cut-off $|Q|>0.7$ regarding the four CRQ sub-scores. A negative Q value indicated that a degraded environment attributed to an increased pollutant level would lead to a drop in the CRQ sub-score. It was noted that three parameters namely AFC, T and RH had positive Q values; a result of Hong Kong winter weather - lower temperature and lower RH. Reportedly, COPD admission rate during the winter in Hong Kong is higher (Ko *et al.* 2007). It was also noted that in the same range of environmental conditions, increased indoor airborne fungi counts were related to a warmer and more humid environment (Wong *et al.* 2008).

From the table, the CRQ emotion domain score and most (17 out of 21) environmental parameters were sufficiently correlated. In other words, patient emotion was the most sensitive indicator for tracing environmental changes.

On the basis that an environmental change is a suggestion of probable QOL degradation, the likelihood ratios L_r (of the selected environmental parameters as shown in Table 4) were determined for the positive indications of the CRQ sub-score decrement and are expressed by,

$$L_r = \begin{cases} \dfrac{P_s}{1-P_f} & ;Q>0 \\ \dfrac{1-P_f}{P_s} & ;Q<0 \end{cases} ;\ P_s = \frac{CP}{CP+DN};\ P_f = \frac{CN}{CN+DP} \qquad \ldots (4)$$

P_s and P_f, the sensitivity and specificity indicators according to the changes of an environmental parameter, refer to the ability of an indication to identify an environment that does and does not have a degraded QOL, respectively.

Alternatively, L_r can be determined from all patient cases N_p by counting the number of correctly identified patients who are suffering with the degraded environment as indicated by the monitored environmental parameter, with $N_{p,0}$ symbolizing those incorrectly identified patient cases,

$$L_r = \frac{N_p - N_{p,0}}{N_{p,0}} \quad \text{... (5)}$$

As the likelihood ratios for the CRQ emotion domain score were generally larger than 3, with some larger than 10, this study revealed that at least 75% of the surveyed patients (i.e. 3:1) would suffer emotionally in a degraded environment. For the CRQ mastery domain score, the likelihood ratios with respect to the station PM_{10} and NO_2 values were about 4 and that suggested poor outdoor air quality would affect patient activity. Comparatively, the influence of air quality on dyspnoea and fatigue was less significant.

The corresponding maximum changes of environmental exposure levels are also shown in Table 4. The average unit increment δ_{ij} in terms of the environmental parameter ϕ_i and the unit change of corresponding CRQ sub-score ϕ_j is,

$$\delta_{ij} = \frac{1}{N_p} \sum_{k=1}^{N_p} \left(\frac{\phi_{i,2} - \phi_{i,1}}{\phi_{j,2} - \phi_{j,1}} \right)_k \quad \text{... (6)}$$

Proportion is a hypothetical ratio of the maximum change to the average unit increment δ for indicating the sensitivity of an environmental parameter to the CRQ sub-score. As the proportion values displayed in Table 4 were evaluated via linear extrapolation without examining a threshold value, they did not indicate any maximum change in the CRQ sub-scores surveyed.

To evaluate the use of δ_{ij}, goodness-of-fit was examined applying the odds ratio θ as given by Equation (7) below, where $N_{p,1}$ is the number of correctly indicated patient cases with the predicted CRQ sub-score ϕ_p lying within the chosen acceptable error limits ϕ^* as compared with the observed CRQ sub-score ϕ_o, while $N_{p,2}$ is the number of correctly indicated patient cases with ϕ_p lying outside ϕ^*. It should be noted that $N_{p,0}$ is the number of all incorrectly indicated patient cases (in which patients with an increased CRQ sub-score were found in a degraded environment and vice versa) and thus is excluded from the equation.

$$\theta = \frac{N_{p,1}}{N_{p,2}} \; ; \; \begin{cases} N_{p,1} : \left|\phi_o - \phi_p\right| \le \phi^* \\ N_{p,2} : \left|\phi_o - \phi_p\right| > \phi^* \end{cases} ; \; N_p = N_{p,0} + N_{p,1} + N_{p,2} \quad \text{... (7)}$$

The odds ratios $\theta_{0.5}$ and $\theta_{0.8}$ determined for two chosen error limits ϕ^*=0.5 and 0.8 respectively in order to show the prediction sensitivity are exhibited in Table 4.

As the results of $\theta_{0.5}$ for the CRQ dyspnoea and fatigue domain scores were low (<1), the predictions did not fit the survey data well, and that was consistent with the likelihood ratio test. With respect to the CRQ emotion domain score, the values of $\theta_{0.5}$ ranged from 1.7 to 7 for the station parameters: 7 for NO; 3.6 for both PM_{10} and NO_2; and 2.1 for API. The differences revealed that the overall API level is not adequate for emotion evaluation. Furthermore, the odds ratios were found higher for finer particles. It was reported that the concentration level of both fine and coarse particles had a significant impact on patient emotion (i.e. $\theta_{0.5}$>2). In the size range below 10 µm, more patients would be emotionally affected by high concentrations of fine particles. IAQI, as an indicator which addresses basic IAQ issues including dilution, filtration and emission control, showed a good correlation with patient response. As $\theta_{0.5}$ for IAQI was slightly higher than $\theta_{0.5}$ for PM_{10} (i.e. 2.8 vs. 2.5), the other two contributors of IAQI, viz. TVOC and CO_2, might have some indications for patient QOL.

Conclusions:

Chronic obstructive pulmonary disease (COPD) is one of the leading causes of death in Hong Kong. This study investigated the impact of some common air pollutants upon the quality of life (QOL) in patients with COPD. Through a cross-sectional survey, 41 COPD patients were interviewed in the summer and winter seasons of the same year. No significant differences were found between the assessment results in the two periods regarding lung function measurements and CRQ scores. There were no significant differences between indoor and outdoor environmental parametric levels ($p>0.05$, paired t-test), except for ($p\leq0.05$, paired t-test): indoor and outdoor temperatures; indoor RH; indoor particles in the size range 0.5-5 μm; and outdoor *Penicillium* sp. For the data recorded from the regional environmental monitoring stations, the exposure levels of sulfur dioxide (SO_2), carbon monoxide (CO) and ozone (O_3) showed significant seasonal variations ($p\leq0.01$, paired t-test).

The results also indicated that the IAQ index had good correlations with its contributors CO_2, PM_{10} and TVOC in an indoor space ($p\leq0.0001$, t-test). Correlations were significant among particle counts of different sizes both indoors and outdoors, except for particle size 0.3-0.5 μm. If fine particles are a concern, then PM_{10} mass concentration can be a surrogate indicator for monitoring environmental quality in the surveyed apartments. Moreover, the COPD patients surveyed were found staying predominantly at home. Using Yule's Q statistic with a cut-off $|Q|>0.7$ to identify the strong relationships between environmental parameters and CRQ sub-scores, this study revealed that patient emotion was strongly associated with indoor environmental parameters although the evidence of a causal relationship between them necessitated further research.

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