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Research Article

Evaluation of Air-Borne Trace Metals in Orthopaedic Sections of Health Care Facilities

Afzal Nimra[1], Zulfiqar Ali[1*], Safdar Sidra [2], Rida Ahmad[1]

[1]Environmental Health and Wildlife, Department of Zoology, University of the Punjab, 54600, Lahore, Pakistan
[2]Wildlife and Ecology, University of Veterinary and Animal Sciences, Lahore, Pakistan

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Authors' Contributions
AN carried out the research work, and wrote the manuscript. ZA supervised the research work and improved the research design. SS helped with the statistical analysis. RA helped in field sampling and analysis.

Keywords
Trace metals, Hospital, Air quality, Indoor air, Pakistan, I/O ratio

Abstract | The airborne levels of carcinogenic trace metals lead (Pb), cadmium (Cd), arsenic (As) and nickel (Ni) were evaluated in the Orthopaedic Operation Theater (OOT), Orthopaedic Wards (OW) and Orthopaedic Emergency Rooms (OER) of six hospitals, in Lahore, Pakistan. Overall, the average levels of Cd, As and Ni (31, 20, and 37 ng/m^3) were lower indoors as compared to outdoors (39, 21, and 51 ng/m^3) except Pb. The high indoor levels of Pb (113 ng/m^3) as compared to outdoors (85 ng/m^3) suggested pronounced indoor sources. The average indoor-outdoor (I/O) ratio for the Pb, Cd, As and Ni were 1.34, 0.94, 0.99 and 0.79 respectively. The results showed that indoor air in the hospitals were affected by the common effects of indoor (wall paints, indoor equipment, environmental tobacco smoke) and outdoor (dust, soil and fuel combustion) sources. The hospitals were located on busy roads, where high vehicular emissions probably emit trace metal pollutants.

Novelty Statement | This study discusses the concentration and possible sources of airborne trace metals in sensitive areas of hospitals, which is to our knowledge, is the first study contributed from Pakistan and its understanding is important in order to improve law enforcement against causative factors.

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Introduction

Poor air quality in health care facilities is one of the major detrimental factors that can compromise the health of the patients. It is hence essential to maintain a healthy pollution-free environment in hospitals with regular monitoring to exclude any potential contamination from multiple sources. While these sources may be located both indoors and outdoors, ventilation plays a major role apart from various routine activities within the hospitals. Among the major classes of pollutants identified in hospitals, particulate matter and bioaerosols are considered more harmful while gaseous pollutants are also present to some extent. Another major physical pollutant of concern is the presence of trace metals in the air released from different sources. The trace metals are the essential constituent of airborne total suspended particulate matter (TSPM) (Aziakpono *et al*., 2013). The TSPM consist of broad range of particles including super coarse (PM>10), coarse (PM2.5-10) and fine (PM2.5) fractions (Thomson *et al*., 2016). As a component of airborne particulate matter, the most concerning metals related to toxicity in humans include arsenic (As), antimony (Sb), chromium (Cr), cadmium (Cd), mercury (Hg), zinc (Zn), cobalt (Co), copper (Cr) and lead (Pb). These metals are mostly used as stabilizers in vinyl-based plastic materials, roof resilient flooring, and wall coverings. The trace elements such as cadmium (Cd), lead (Pb) and zinc (Zn) are mainly

Corresponding author: Dr. Zulfiqar Ali
zali.zool@pu.edu.pk

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contributed by anthropogenic sources than natural sources (Shah and Shaheen, 2008; Okuda *et al*., 2008). The main anthropogenic sources include vehicular emissions (Cd, Pb, Cr, Ba), construction and industrial emissions (Mn, Al, Si) and combustion processes (Ni, Cr,) (Fang *et al*., 2010; Okuda *et al*., 2008; Susaya *et al*., 2010). Indoors, the abundance of trace metals are attributed to infiltration from outdoor sources (Habil *et al*., 2013) and various indoor sources such as paints, equipment, and tobacco smoke (Chattopadhyay *et al*., 2003; Paoletti *et al*., 2006; Taner *et al*., 2013). The trace metals mostly occur in the solid particle phase in the atmosphere and are ubiquitous in both coarse ($PM_{2.5-10}$) and fine ($PM_{2.5}$) fractions (Hu *et al*., 2012).

The trace metals associated to particulate matter such as Pb, Cd, Cr, Ni and As can be severely toxic and carcinogenic upon inhalation in higher quantities (Panne *et al*., 2001; Valavanidis *et al*., 2008; Pandey *et al*., 2013; Lawrence and Khan, 2020). According to International Agency for Research on Cancer (IARC) classification, arsenic (As), nickel (Ni) and cadmium (Cd) are carcinogenic to humans (IARC, 2012), whereas the inorganic lead (Pb) is classified as a probable carcinogen (IARC, 2006). Even in the minor levels, the existence of PM metals may significantly contribute to PM induced severe health implications (Dreher *et al*., 1997; Xia *et al*., 2007).

Hospitals are the buildings where these trace metals can be found throughout (IARC, 1972) and particle emission processes are the main drivers of many elements in the atmosphere. Although the airborne concentration of the trace metals in the urban environments have been reported in several countries such as Brazil (Sella *et al*., 2004), Denmark (Yang *et al*., 2002) and India (Khillare *et al*., 2004), limited studies are available on the elemental composition of PM in hospitals (Wang *et al*., 2006b; Brown *et al*., 2012; Loupa *et al*., 2016; Li *et al*., 2017; Slezakova *et al*., 2012, 2014). The current study aims to determine the airborne concentration of carcinogenic trace metals in the orthopaedic sections of hospitals of Lahore, Pakistan.

Materials and Methods

Sampling sites

Lahore is the capital of Punjab and the second largest city of Pakistan with respect to population i.e. 7,684,000 inhabitants (Shirazi and Kazim, 2014). According to the Punjab Specialized Health Care and Medical Education Department, there are 11 teaching, 2 district headquarters, 4 tehsil headquarters, 6 rural health centers and 37 basic health units working in the vicinity of district Lahore.

The health care sector in Pakistan can be divided into different categories depending on the governing bodies i.e. public hospitals run by the government, privately owned hospitals, and trust hospitals being run by different welfare trusts for the benefit of the general public. For the current study, six hospitals were selected, two from each category. Following a preliminary study in different operation theatres of two hospitals (Nimra *et al*., 2015), orthopaedic sections (orthopaedic operation theater, orthopaedic ward, and emergency room: where airborne injuries are treated initially) of each hospital were further selected owing to the reportedly higher levels of dust and infections in these areas. The selected hospitals were categorized and labeled as follows:

Category A= Government Hospitals (H1 and H2)
Category B= Trust Hospitals (H3 and H4)
Category C= Private Hospitals (H5 and H6)

From each hospital, the following sites were selected and labeled thus:

1. Orthopaedic Operation Theatre (OOT)
2. Orthopaedic Ward (OW)
3. Orthopaedic Emergency Room (OER)
4. Outdoor (OD)

Brief information on the characteristics of the hospitals is described in Table 1 composed with the help of hospital administrative staff and hospital's official websites. All of the studied hospitals were located in urbanized areas of Lahore near main roads where the traffic influx was very high.

Air sampling

Air sampling was conducted to collect TSPM using a high-volume air sampler fitted with pre-weighed glass fiber microfilters (EPM 2000-Whatman England) at a rate of 35 l/min for 8 hours at each site. The sampling campaigns were organized at an interval of three months for a year to determine the airborne levels of Pb, Ni, Cd and As. After sampling, the filters were carefully removed and stored in sterilized Petri plates for further analysis.

Metal extraction

For the extraction of trace metals, each filter was heated at 50°C with 5ml HNO_3 and 5ml of $HCLO_4$ for 30 minutes and then heated in a digestion block Teckam PTC-2 under a fume hood at 170 °C for 4 hours to solubilize the metals in ionic form. After digestion, the samples were cooled down and 5ml of deionized H_2O was added to wash out a residual solution. The solution was filtered and the final solution was made up to 25ml with deionized water and was analyzed by ICP-AES (Arcous model, Germany) (Kermani *et al*., 2016). Filter blanks were also digested and analyzed in a similar way to test samples. The filter blanks were subtracted from the exposed filters to get the actual trace metal concentration in the TSPM.

Data analysis

The following formula was used to calculate metal concentration (US EPA, 2011).

Table 1: Brief profile of selected hospitals.

Type	Category A		Category B		Category C	
	H 1	H 2	H 3	H 4	H5	H6
	Teaching	Teaching	Teaching	Teaching	Non-teaching	Non-teaching
Building year	1943	1958	1991	1974	1992	2000
Building age	74	59	26	43	25	17
Patient visit /month	60000	75000	45000	39000	9000	31830
Number of beds	534	1096	580	350	40	260
Location	Main road	Main road	Main road	Main road	Main road	Main road
Average surgeries/annum	119000	159000	59,500	25,000	900	10,000

$$C = ((\mu g\ /\mathrm{mL} * \mathrm{VF} * \mathrm{A} * \mathrm{D}))/\mathrm{VS}$$

Where, C= Concentration in µg/m^3; µg/mL= metal concentration in solution; VF=Total extraction solution volume; A= Area correction; D= Dilution factor if required; VS= Volume of air sampled.

The data analysis was done using IBM SPSS statistics 21. Kolmogorov- Simonov and Levene test confirmed data to be non-parametric, which was normalized for further analysis. Repeated measure One Way ANOVA with one factor was applied to compare indoor and outdoor value sets for each metal irrespective of sampling sites. A spearmen correlation test was applied to test the correlation between different trace metals. The average I/O ratio for each metal was calculated and graphically presented using Microsoft Excel (version, 2013). The I/O ratio > 1 indicates indoor sources of pollutants whereas, I/O ratio < 1 suggests the outdoor origin of indoor pollutants (Lomboy *et al*., 2015).

Results and Discussion

Trace metal concentration in the total suspended particulate matter (TSPM) collected at the different indoor and their respective outdoor (ambient) sites are represented in Table 2.

The average concentration of Pb, Cd, As, and Ni in indoor sites were 113 (± 32), 31 (± 15), 20 (± 10) and 37 (± 11) respectively. For outdoor environments, the recorded levels of Pb, Cd, As, and Ni were 85 (± 23), 39 (± 18), 21(± 08) and 51 (± 20) respectively (Table 2). The average levels of Pb were higher in indoor sites, while the Cd, As and Ni levels were comparatively high in outdoor environments.

Slezakova *et al*. (2012) have reported high levels of trace elements in hospital air while enrichment factor analysis revealed most of the carcinogenic metals (including Pb, Ni, As) to be anthropogenic rather from natural sources. Okuda *et al*. (2008) and Li *et al*. (2017) have also reported a majority of toxic metals to be anthropogenic. In the current study, the concentration of trace metals was found to be variable but still higher and observed to be in the following order for both indoor and ambient samples: Pb > Ni > Cd > As.

Table 2: Mean airborne trace metal composition of total suspended particulate matter sampled from indoor and outdoor sites of selected hospitals.

*N=216		Indoor sites (ng/m^3)				Outdoor sites (ng/m^3)			
		Pb	Cd	As	Ni	Pb	Cd	As	Ni
Orthopaedic operation theatre (OOT)	OOT$_1$	149	17	19	39	77	62	18	82
	OOT$_2$	130	43	15	42	90	21	20	53
	OOT$_3$	106	24	55	24	91	57	19	32
	OOT$_4$	163	72	10	28	77	32	18	35
	OOT$_5$	151	38	11	31	85	39	20	32
	OOT$_6$	123	24	23	32	89	43	28	45
Orthopaedic wards (OW)	OW$_1$	162	52	13	51	149	69	18	94
	OW$_2$	90	27	12	12	84	19	17	45
	OW$_3$	99	25	17	32	96	59	17	41
	OW$_4$	82	24	17	39	77	20	13	53
	OW$_5$	85	40	27	32	72	45	25	70
	OW$_6$	75	26	23	37	54	21	21	48
Orthopaedic emergency rooms (OER)	OER$_1$	149	45	25	63	131	67	20	89
	OER$_2$	139	26	26	46	90	21	34	55
	OER$_3$	87	20	14	33	78	49	23	37
	OER$_4$	84	19	22	53	76	20	43	35
	OER$_5$	89	29	18	51	65	42	21	32
	OER$_6$	71	11	13	25	56	21	10	36
Mean		113	31	20	37	85	39	21	51
Max		163	72	55	63	149	69	43	94
Min		71	11	10	12	54	19	10	32
Standard deviation		32	15	10	11	23	18	08	20

*N, total number of samples from the hospitals during four sampling campaigns.

The Pb concentrations were specifically higher in the OOT's as compared to the OW's and OER's (Figure 1a). Moreover, the levels were specifically higher in the hospitals indoors as compared to outdoors. Whereas, most of the studies have reported high levels of Pb outdoors (Wang *et al*., 2006a; Loupa *et al*., 2016). This was probably due to

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more pronounced sources of Pb in the current study e.g. tobacco smoke. The hospitals in the current study were not ETS free, as smoking indoors was not strictly controlled. Although according to the health ordinance 2002 of Pakistan smoking and other tobacco use in public areas specifically hospitals is prohibited (Tobacco Control Cell, Ministry of Health, GoP, 2010), but the implementation over the ban has been reported to be poor (Khan *et al*., 2016). A considerable number of doctors and paramedic staff in hospitals has been reported to be active smokers (Malik *et al*., 2010). Moreover, doctors have been observed to smoke during working hours, probably contributing to increase Pb levels (Piryani and Rizvi, 2004). The other indoor sources include timeworn lead-based paints which upon improper removal by sanding or dry scratching can cause harmful exposures, medical waste incinerators and dust infiltrating from outdoors (Yaffe *et al*., 1983). Indoor activities involving use of lead such as use of lead aprons and electrocautery in the operating rooms during surgeries can also be a potential source. The use of electrocautery has been reported to produce metal fumes during orthopaedic surgeries by Harkavy and Novak (2014) and Sah *et al.* (2017). Moreover, a recent study has reported the use of lead aprons during surgical procedures to be a major contributor towards indoor lead levels in hospitals with sixty-three percent on the tested aprons having quantifiable levels of lead dust on them which is consequently an occupational safety hazard (Burns *et al*., 2017). Outdoor Pb commonly originate from coal and diesel emissions, waste incineration and construction material (Janssen *et al*., 1997).

The monitored levels of Cd in ambient air (19- 69 ng/m^3) were also higher and more than the reported levels in Iranian hospitals (5.97- 33.26 ng/m^3) by Kermani *et al.* (2016). The higher concentration of Cd in outdoor environments (Figure 1b) is probably attributable to industrial and vehicular emissions, fertilizers, and combustion processes. The possible indoor sources of Cd within the hospital are medical waste incinerators. The bottom and fly ashes from hospital's incinerators release heavy metal-laden solid particles along with inorganic and organic salts (Alvim-Ferraz and Afonso, 2003; Ibanez *et al*., 2000). Another source indoors is the ETS, which either in form of first or second hand smoke can be a potential threat to occupants specifically patients in hospitals (Willemsen *et al*., 2004). The people smoking in the corridors, outdoor entrances, cafeterias and parking lots of hospitals were observed signifying frequent policy breaching. Contrary, smoking is banned in European hospitals since 2000 with an effective compliance over the years. The enforcement of smoke free policies have been reported to decrease indoor air pollution (Connolly *et al*., 2009).

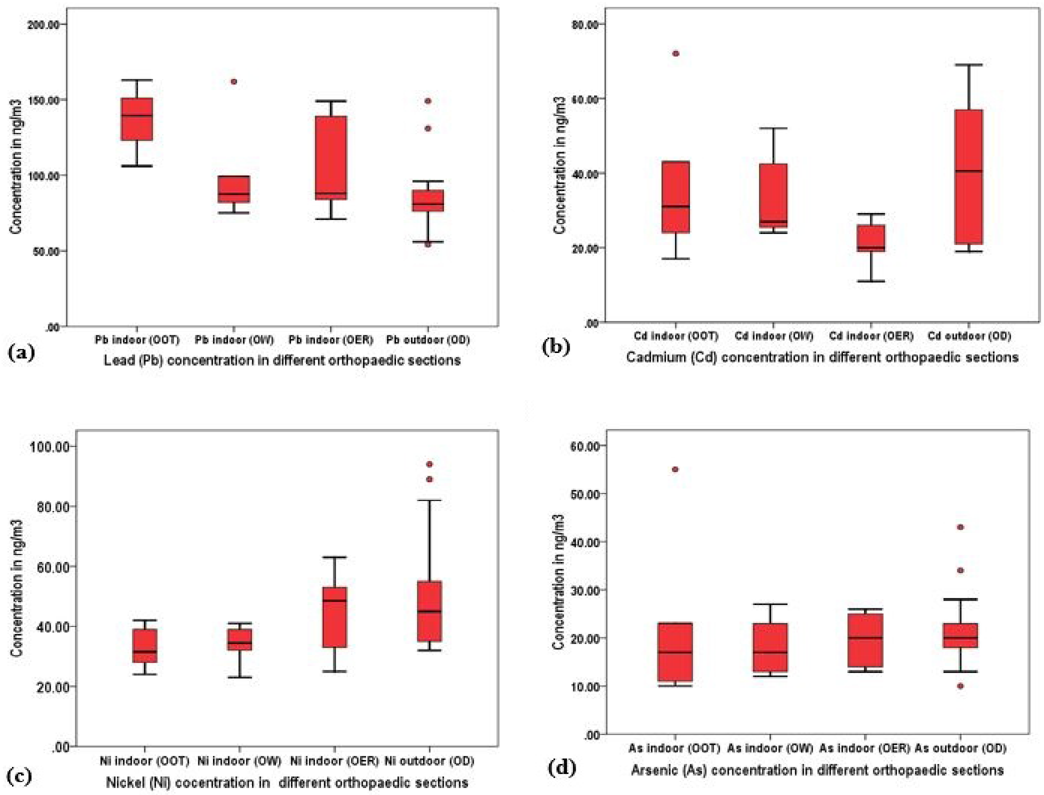

Figure 1: Average concentration (ng/m^3) of heavy metals in the different orthopaedic sections: (OOT) orthopaedic operation theatre; (OW) orthopaedic ward; (OER) orthopaedic emergency room and (OD) uutdoor (a) lead (Pb); (b) cadmium (Cd); (c) nickel (Ni) and (d) arsenic (As).

Error bars are the 95% confidence interval, the bottom and top of the box are the 25th and 75th percentiles, the line inside the box is the 50th percentile (median), and any outliers are shown as filled red circles

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While Pb was found to be higher in concentration indoors, Ni levels were higher in ambient samples (Figure 1a, 1b). This in agreement with Wang *et al.* (2006b) who reported higher levels of Ni in the PM fractions outdoors (28-52 ng/m^3) as compared to indoors (23-39 ng/m^3) of hospitals. This is understandable, as Ni is majorly contributed to ambient air by combustion processes and sewage and waste incineration processes (Radulescu *et al.*, 2015). However, the indoor sources in hospitals could be medical waste incinerators and ETS. As concentrations (10-55 ng/m^3) however, remained almost the same in all samples. Still, these levels were significantly higher (0.12-3.65 ng/m^3) than those reported by Kermani *et al.* (2016). However, another study related to the elemental composition of hospital air reported As levels between 49 -126 ng/m^3 in PM_{10} and between 40-140 ng/m^3 in $PM_{2.5}$ size fractions (Slezakova *et al.*, 2012). However, it is necessary to be careful while comparing the trace metals levels with other studies because of different sampling equipment, filter types and PM fraction. As is generally not an indoor pollutant but can be found in the indoor areas with tobacco smoking (Slezakova *et al.*, 2009). Ambient levels of As are generally related to metal industries combined with the combustion of fossil fuels (Tanner *et al.*, 2008) and since Lahore is a highly urbanized and industrialized metropolis, these sources cannot be neglected. Overall, the metal concentration indoors and outdoors dust were significantly different for Pb (p=0.000) and Ni (p=0.005) but not for the Cd (p=0.124) and As (p=0.608) respectively.

Indoor-outdoor ratio (I/O) is an important indicator to differentiate between the indoor and outdoor concentrations of pollutants. The mean I/O ratio of Pb (1.34) was indicative of indoor sources of Pb (Figure 2). Similarly, I/O ratio of 0.99 and 0.94 for As and Cd respectively indicate almost similar contributions from both indoor and outdoor sources. In addition, for Ni, a strong influence of ambient sources was identified with a mean I/O ratio of 0.79. According to Hassan (2012) and Habil *et al.* (2013), two major sources of toxic metals in indoor air is infiltration from ambient sources along with indoor sources including wall paint and different types of equipment (Paoletti *et al.*, 2006; Kefeni and Okonkwo, 2013; Tanner *et al.*, 2008). Moreover, as discussed earlier, the use of lead aprons in orthopaedic surgeries is also a contributing factor (Burns *et al.*, 2017).

It is noteworthy that while Pb levels were comparatively elevated at all sites, they are still within the threshold limits defined by WHO and European Commission for 1-year as seen in Table 4; while levels of Cd, Ni and As were above the suggested limits of 5, 20 and 6 ng/m^3 respectively at all sites. Such high levels reflect the importance of identifying the contributing agents in health care facilities and to replace or eliminate them for a safe environment for the patients and staff.

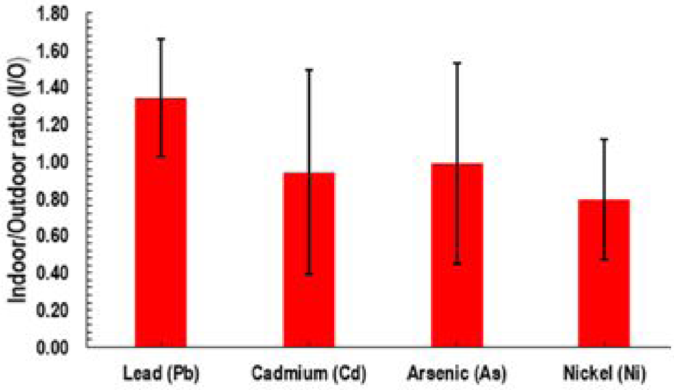

Figure 2: Indoor/Outdoor ratio of airborne metals in the indoor and outdoor environment.
*Error bars represent standard deviation.

The airborne metals recovered from particulate matter PM indicated a positive correlation between Pb and Cd (r = 0.64) while correlation among other metals was statistically insignificant (Table 3). These results suggest that Pb and Cd probably originated from similar sources, while other metals probably had a different origin. Pb and Cd have been reported to be released in the environment simultaneously (Brender *et al.*, 2006; Walker *et al.*, 2007).

Table 3: Spearmen correlation coefficient matrix(r) between selected airborne trace metals.

	Pb	Cd	As	Ni
Pb	1	**.646****	-.131	.281
Cd	**.646****	1	-.228	.160
As	-.131	-.228	1	.009
Ni	.281	.160	.009	1

Values in bold with ** Correlation is significant at the 0.01 level (2-tailed).

Table 4: Guidelines for the vinyl-based trace metals by WHO and European commission.

Trace metal	Proposed limits	Averaging period	Source
Lead (Pb)	0.5 µg/m^3	1-year	WHO, European commission, 2000
Cadmium (Cd)	5 ng/m^3	1-year	WHO, European commission, 2000
Nickel (Ni)	20 ng/m^3	1-year	WHO, European commission, 2000
Arsenic (As)	6 ng/m^3	1-year	WHO, European commission, 2000

Conclusion

The mean indoor levels of trace metals (Cd, As, Ni) were less than those monitored outdoors, suggesting more pronounced outdoor emission sources. Whereas,

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the higher levels of Pb indoors suggests an indoor origin of the pollutant. The Cd, As and Ni levels were almost 3-8 times higher than the recommended limits of 5,6 and 20 ng/m^3 respectively by WHO, European commission. However, the Pb concentration remain within the recommended levels. Based on the findings, it can be concluded that indoor air of hospitals is not satisfactory. The use of environmental tobacco smoke (ETS), different equipment such as lead aprons and electrocautery poses a health risk as prolonged exposure to trace metals, most of which are carcinogenic in nature, and may result in adverse health effects especially in immune-compromised patients and health care workers. The regional and national laws of European countries implements complete ban over smoking in the hospital premises for twenty years. Whereas, the hospitals in Pakistan are still not ETS free and struggling for the compliance of tobacco control policy. This probably also results in increased levels of trace metals indoors. This calls for strict implementation of the ETS free hospital policy in Pakistan. Moreover, the long-term potential exposure risk to trace metals is required when assessing health risks in hospitals.

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Conflict of interest

The authors have declared no conflict of interest.

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