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Original Article

Community Section

Factors Influencing Particulate Matter 2.5 Levels in Indoor Areas of Rural Houses: A Cross-sectional Study

RAJEEV ROY NEELAKANTA[1], ANUSHA RAJA JAGADEESAN[2], LAKSHMI GOUDHAMAN[3], MERITON STANLY ATHISAYARAJ[4]

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ABSTRACT

Introduction: Almost 3 billion of the world's poorest people still rely on solid fuels, with a concomitant increase in indoor Particulate Matter (PM 2.5) concentration resulting in deaths from respiratory diseases. Increased prevalence of respiratory diseases among never smoking young individuals and fairly among women compared to men point towards a causal relationship between chronic smoke inhalation resulting from the burning of biomass fuels.

Aim: To assess the quantitative exposure levels of PM 2.5 in a rural setting in South India and determine the association between PM 2.5, type of house, ventilation available and fuel used.

Materials and Methods: This community-based cross-sectional study was conducted for three months from September to November 2020 in the rural field practice area of Sri Ramachandra Institute of Higher Education and Research, Chennai, Tamil Nadu, India. The houses were classified into three types Kutcha (roof, walls and floor made of poor quality materials), semi pucca (two components made of good quality material and one component is of poor quality) and pucca (roof, walls and floor made of good quality material) houses according to census of India 1991. The air quality inside 127 houses was assessed by measuring PM 2.5 levels for 24 hours in both kitchen and living rooms. The association between house characteristics, ventilation, type of fuel and indoor air quality was Studied using student t-test and one-way Analysis Of Variance (ANOVA).

Results: Among 323 included residents, 168 were males and 155 females with the mean age 36.99±13.24 years. The difference in average house area and living area between the three types of houses were statistically significant (p-value <0.001). The mean concentrations of PM 2.5 were 290.07 μg/m^3 and mean differences in PM 2.5 levels in living room and kitchen of semi pucca (t=7.32, p-value <0.001) and pucca houses (t=5.47, p-value <0.001) were significant. The association between cross ventilation in kitchen (OR 3.24, p-value=0.042), artificial ventilation (OR 3.23, p=0.026), type of fuel (firewood OR 2.85, p-value=0.042) and PM 2.5 levels is significant at 95% CI limits.

Conclusion: Indoor air pollution is a silent killer responsible for several respiratory problems. Simple cost-effective measures could reduce indoor PM 2.5 levels and thereby indoor air pollution.

Keywords: Biomass, Floor space area, Kutcha house, Pucca house, Semi pucca house

INTRODUCTION

The increase of industries among urban dwellings has made us view the problem of air pollution as being limited to the industrial areas. Air pollution within households as a major cause of morbidity and mortality among women in the rural areas who rely upon biofuels as their primary fuel source has been neglected. The World Health Organisation (WHO) has reported that among the 4.3 million people who die annually from exposure to household air pollutants, 82% die from stroke, ischaemic heart disease and Chronic Obstructive Pulmonary Disease (COPD) while pneumonia and lung cancer account for the remaining 18% of deaths, respectively. Women and young children are particularly vulnerable with more than 50% of pneumonia deaths among children under 5 being linked to household air pollution [1]. The risks posed to human health by indoor air pollution often far outweigh those posed by outdoor air pollution due to increased exposure over prolonged periods. Annually, 2.7 million deaths are caused due to indoor air pollution by incomplete combustion of fossil fuels as per estimates by WHO. Also combined household and ambient air pollution contribute to more than six million deaths annually [2]. Non communicable disease epidemics notable among which include upper and lower airway disease and cancers of the lung, accounting for one-third of the global burden of disease, have air pollution as a major contributory factor [3]. According to World Bank statistics on indoor air pollution among low and middle-income countries in 2013 created a welfare loss of $1.52 trillion, while those due to labor income losses reached $94 billion [4].

Total 52% of the world's population is dependent on fossil fuels, especially solid fuels. Developed countries like Central and Eastern Europe have reduced this usage to 16% but many developing countries including India have a usage of 74% [5]. Dried crop residues, leaves, bushes, chopped wood or agricultural waste and dried dung of domesticated animals such as cows are the principal biomass fuel source. The composition of biomass fuels mainly includes hydrogen, carbon, oxygen, nitrogen and other elements incorporated into complex organic matter in varying amounts. Several end products include substances like polycyclic hydrocarbons which are produced during the combustion of these fossil fuels and are invariably harmful to human health [6]. Thousands of substances that cause damage to human health have been identified in biomass smoke. Those who have been implicated in the causation of health-related problems include Particulate Matter (PM), sulphur oxides, especially with coal, nitrous oxides, carbon monoxide, formaldehyde and carcinogens like benzopyrene [7]. These pollutants exert their effects on the lungs in several ways viz., causing inflammation in the bronchial mucosa, reducing mucociliary clearance mechanism and impairing local immune response [8]. Many air quality studies use PM composed of both solid as well as liquid particles as an indicator for indoor air pollution, which is reliable in terms of measurement standards [9-11]. PM's ability to have an impact on health, especially the respiratory component is determined by the aerodynamic diameter as size plays a critical determinant. The nasal mucosa and the upper airways are unable to filter fine PM 2.5 especially those with less than 2.5 microns aerodynamic diameter. These PM can penetrate deep into the lungs at the level of gaseous exchange and thereby pose detrimental health risks [12].

In developing countries like India, 15 years is the average age when a young girl enters the kitchen and starts cooking. She spends about four to six hours daily in the poorly ventilated kitchen, an enclosed space with fossil fuel as the predominant cooking source. For women, 30-40 years of exposure to solid fuel smoke occurs, which equals exposure to or inhaling a volume of 25 million liters of polluted indoor air for 60,000 hours of their lifetime [13]. India has a high prevalence of chronic cor pulmonale and in turn high mortality rates for the same. Reports show an increased prevalence of this condition among never smoking young individuals and fairly among women compared to men; these findings thereby point towards a causal relationship between chronic smoke inhalation resulting from the burning of biomass fuels. In 1984 Northern and Central India, chronic cor pulmonale accounted for 10-30% of hospital admissions, the highest rates of any non industrial population in the world [14]. The majority of published studies on solid fuel cook stoves and indoor air quality (PM 2.5 measurements employing gravimetric methods which give collected data) were comparative studies between various socio-economic factors and household characteristics [5-9].

The aim of this study was to assess the quantitative exposure levels of PM 2.5 by Light Amplification by Stimulated Emission of Radiation (LASER) method instead of the conventional gravimetric method in a rural setting in Southern India. This study is a part of a larger study which found the association between indoor air pollution, smoking and COPD. The objectives of the current study were to determine the association between PM 2.5 and various parameters such as type of house, ventilation available and the fuel used.

MATERIALS AND METHODS

This cross-sectional study which was community-based was conducted through the Department of Community Medicine, in the field practice area of Rural Health and Training Centre, Sri Ramachandra Institute of Higher Education and Research, Panimalar Medical College Hospital and Research Institute, Chennai, Tamil Nadu, India. The study was conducted for three months from September to November 2020 on non rainy days to obviate the role of temperature and rainfall on indoor air pollution. The area was located in Tiruvallur District about 60 km from Chennai. The area comprised nine panchayats with a total population of 18879 with 4445 houses. Line listing of all houses in each of the nine panchayats was done and was numerically numbered for the sample frame. Institutional Ethics Committee approval was obtained before the start of the study (Ref No CSP-MED/16/NOV/32/197).

Inclusion and Exclusion criteria: Those houses which had residents available for 24 hours for measurement of air quality and those respondents who were residing in the current house for more than 24 months were included in the study. Residents, less than 20 years of age and those with a history of smoking/current smokers were excluded from the study.

Sample size calculation: The sample size was calculated using a prevalence of 80% and a relative precision of seven [10]. A 14 houses per panchayat totaling 127 houses were selected by simple random sampling and included in the study.

Study Procedure

Total 337 respondents who consented to participate in the study were interviewed and informed consent from the members of the household was obtained. The entire family was interviewed regarding the smoking status and duration of cooking.

The houses were classified into three types according to census of India 1991 [11] -

1. Kutcha houses- roof, walls, and floor made of poor quality materials,
2. Semi pucca houses- two components made of good quality material and one component is of poor quality, and
3. Pucca houses- roof, walls, and floor made of good quality material.

Indoor air quality assessment: The air quality inside the house was assessed by measuring Particulate Matter Concentrations 2.5 (PMC 2.5) using Standalone Indoor Air Quality Monitor (SAQM), manufactured by FORBIX SEMICON, model number- FBXDQMG. The monitor was factory calibrated before the day's work using the software provided. The dust monitor has a LASER based sensing mechanism. It can sense PM 1.0/2.5 with an accuracy level of ±10%. Two devices were used for one household to simultaneously measure PMC 2.5 levels in the living room and kitchen. The monitors were placed at a height of 3-3½ feet from the ground and were connected to a 24 hour battery backup. The average PMC 2.5 level measurements for 24 hours were taken for both kitchen and living rooms. The 24 hour PM 2.5 levels of 15 μg/m^3 as per the 2021 air quality guidelines of WHO was taken as the cut-off value [12].

Parameters compared: Based on studies done in other rural parts of India, factors that were found to influence indoor air pollution such as floor space area, type of house (pucca, semi pucca, and kutcha), type of fuel used and ventilation characteristics were taken up for the study [5,10]. House area in terms of living area, kitchen area where available among the different house types was calculated and used for analysis.

STATISTICAL ANALYSIS

Data compilation was done using Epi Info version 7.0 and data analysis was done using IBM software of Statistical Package for Social Sciences (SPSS) version 16.0. Recoding with more than two levels was done for various exposure variables like demographic factors, housing type, household kitchen dimensions, ventilation patterns, and PM 2.5 levels. The association between house characteristics, ventilation, type of fuel and indoor air quality was studied using the Student t-test and one-way Analysis Of Variance (ANOVA) within 95% limits of a confidence interval, and p-value <0.05 was considered significant. Tukey's Honest Significant Difference (HSD) test was done as a follow-up of ANOVA, to assess the significance of differences between pairs of groups.

RESULTS

Total of 127 houses with 337 residents were selected for the study (response rate 95.84), of which 14 did not give consent and were excluded. Among 323 included residents, 168 were males and 155 females and both the sexes were in the 20-70 years of age group. The mean age of the study population was 36.99±13.24 years. The socio-economic classification was based on per capita income and the number of members in the family as per modified B.G Prasad's socio-economic scales 2021 [Table/Fig-1] [13].

Families resided in the current houses which were either owned/rented for periods between 24-144 months with a mean duration of 66 months were considered. The difference in average house area and the living area between the three types of houses were statistically significant [Table/Fig-2].

Cross ventilation was not observed in any of the kutcha houses. Though, cross ventilation was limited among semi pucca houses, it was compensated for by the presence of artificial ventilation [Table/Fig-3].

Liquefied Petroleum Gas (LPG) was the preferred primary fuel in pucca and semi pucca houses whereas, kerosene was the predominant fuel in kutcha houses. While kutcha houses had firewood and kerosene as a secondary fuel source, electricity and firewood were used in semi pucca and pucca houses [Table/Fig-4].

The mean concentrations of PM 2.5 were 290.07 μg/m^3 ranging between 68-840 μg/m^3. The mean PM 2.5 levels for 24 hours recommended by WHO air quality guidelines 2021 is 15.0 μg/m^3, thereby showing that all houses were exposed to harmful levels of

Variables	Frequency (n)	Percentage (%)
Age (in years)		
20-30	132	40.9
31-40	104	32.2
41-50	32	9.9
51-60	27	8.4
>60	28	8.7
Socio-economic class*		
Lower class	63	19.5
Lower middle class	55	17
Middle class	126	39
Upper middle class	69	21.4
Upper class	10	3.1

[Table/Fig-1]: Demographic characteristics of population.
*Modified B.G Prasad's socioeconomic classification; N=323 residents

Variables	Kutcha houses (n=35)	Semi pucca houses (n=65)	Pucca houses (n=27)	Values
Average house area (sq ft)	282.11±31.68	471.27±75.17	582.43±102.52	F=135.74 (p<0.001)*
Average kitchen area (sq ft)	-	37.60±11.23	48.27±15.37	t=3.259 (p=0.0016)**
Average living area (sq ft)	282.11±31.68	433.67±69.761	534.16±91.761	F=110.51 (p<0.0001)*

[Table/Fig-2]: Household characteristics.
*One way ANOVA, **t test for difference of means; N=127 houses

Variables	Semi pucca (65) n (%)	Pucca (27) n (%)
Cross ventilation		
Living room	34 (52.30)	23 (85.19)
Kitchen	22 (33.85)	15 (55.56)
Artificial ventilation		
Absent	34 (52.15)	9 (33.34)
Exhaust fan	22 (33.85)	12 (44.44)
Chimney	8 (12.30)	6 (22.22)

[Table/Fig-3]: Ventilation characteristics of household interiors.

Variables	Kutcha houses (35) n (%)	Semi pucca houses (65) n (%)	Pucca houses (27) n (%)
Primary cooking fuel			
Firewood	8 (22.86)	-	-
Kerosene	22 (62.86)	-	-
Liquified Petroleum Gas (LPG)	5 (14.28)	65 (100)	27 (100)
Secondary cooking fuel			
Electricity	-	8 (12.31)	12 (44.44)
Firewood	13 (37.14)	30 (46.2)	6 (22.22)
Kerosene	3 (8.57)	4 (6.2)	-
None	19 (54.29)	23 (35.4)	9 (33.34)

[Table/Fig-4]: Types of fuel used for cooking.

PMC. Statistical differences in PM 2.5 levels in the living room and kitchen of semi pucca (t=7.32, p<0.001) and pucca houses (t=5.47, p<0.0001) were significant. Post hoc Tukey HSD showed a statistically significant difference between PM 2.5 levels in the kutcha house and semi pucca house (Q=96.51, p<0.0001). A similar statistically significant difference was observed between PM 2.5 levels of kutcha and pucca houses (Q=97.77, p-value <0.0001) [Table/Fig-5].

A negative correlation was seen between floor surface area of both living room (r=-80.8, p=<0.0001) and kitchen (r=-74.5, p=<0.0001) and PM 2.5 concentration levels [Table/Fig-6-8]. However, significant correlation was not observed when stratified based on house type

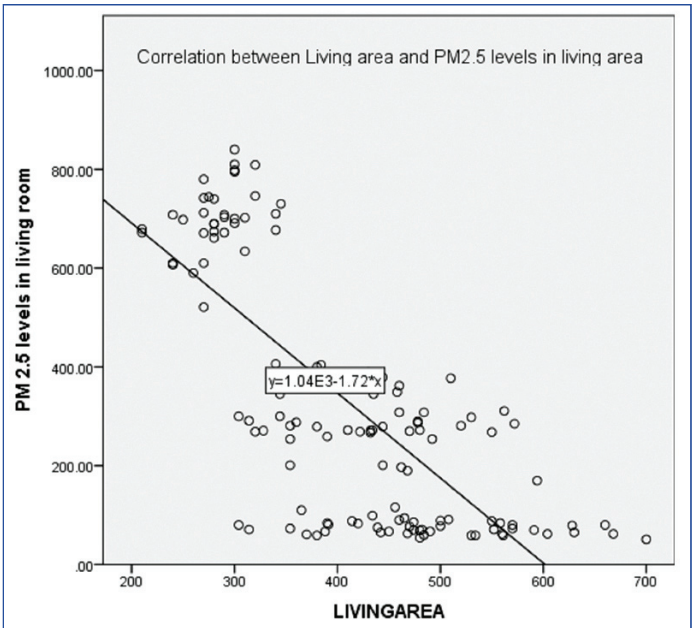
Variables	Kutcha houses	Semi pucca houses	Pucca houses	Values
PMC 2.5 levels				
Living room	700.66±67.85	219.54±111.87	105.78±99.20	F=321.2* p<0.0001
Kitchen		297.82±132.62	140.07±99.05	t=5.56, p<0.00001

[Table/Fig-5]: Indoor particulate matter concentrations 2.5.
*One way ANOVA

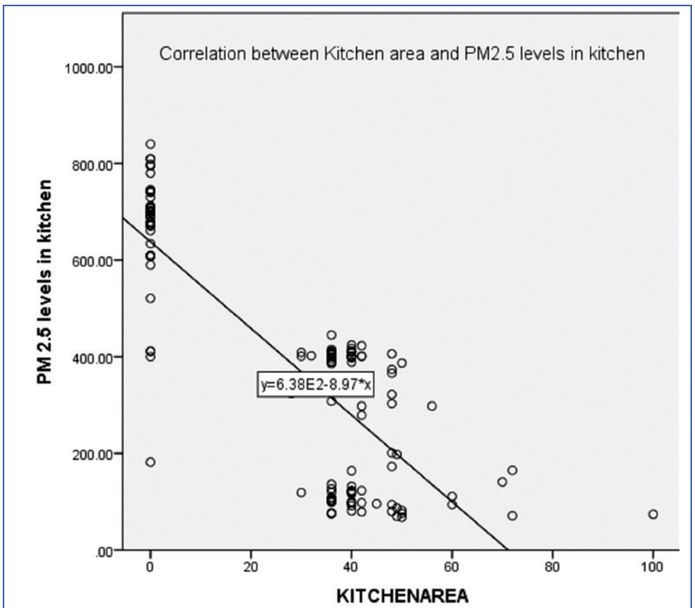
which may be due to the influence of other factors like type of fuel and ventilation (pucca: r=0.274, p=0.51, semi pucca: r=0.002, p=0.727, kutcha: r=0.142, p=0.260).

Variables	Correlation coefficient	p-value	Squared correlation R^2
Living room area	-80.8	<0.0001	55.5
Kitchen area	-74.5	<0.0001	65.3

[Table/Fig-6]: Correlation between floor surface area in square feet and PM 2.5 levels.



[Table/Fig-7]: Correlation between floor surface area and PM 2.5 concentrations in the living area.
X-axis: Living area, Y-axis: PM 2.5 levels in living room.
A negative correlation was seen between floor surface area of living room (r=-80.8, p=<0.0001) and PM 2.5 concentration levels



[Table/Fig-8]: Correlation between floor surface area and PM 2.5 concentrations in kitchen.
X-axis: Kitchen area, Y-axis: PM 2.5 levels in kitchen
A negative correlation was seen between floor surface area of kitchen (r=-74.5, p=<0.0001) and PM 2.5 concentration levels

All kutcha houses had high PM 2.5 levels posing health risks among the residents. Semi pucca houses had a 5.33 times risk of having high PM 2.5 levels compared to pucca houses and this was statistically significant. The association between cross ventilation in the kitchen (OR 3.24, p=0.042), artificial ventilation (OR 3.23, p=0.026), type of fuel (firewood OR 2.85, p=0.042), and PM 2.5 levels is significant at 95% CI limits [Table/Fig-9].

Variables	Odds ratio	CI (95%)	p-value
Type of house			
Semi pucca	5.33	1.45-19.54	0.007
Pucca			
Cross ventilation-Semi pucca			
Absent	1.06	0.977-1.156	0.170
Cross ventilation kitchen-Semi pucca			
Absent	3.24	1.015-10.38	0.042
Artificial ventilation-Semi pucca			
Absent	3.23	1.13-9.23	0.026
Type of secondary fuel-Semi pucca			
Firewood	2.85	1.02-7.97	0.042
Kerosene	0.480	0.047-4.88	0.527
Electricity	1.59	0.36-7.02	0.538

[Table/Fig-9]: Association between house characteristics and PM 2.5 levels in the kitchen.
*Odds was calculated as per the WHO indoor air quality standards of very high PM 2.5 levels of 400 μg/m³ and above. Both kerosene and electricity have association, it is not statistically significant and would have arisen due to chance rather than the real association

DISCUSSION

This study demonstrated the poor air quality standards prevailing within kutcha houses with levels often reaching 800 μm³ exposing the residents to the impact of indoor air pollution. The majority of the kutcha houses were built on unapproved lands by the migrant population with non availability of electricity and LPG. Floor space area is an important determinant of PM 2.5 levels, studies by Balakrishnan K et al., on kitchen floor space areas strengthen the negative correlation between floor space area and PM 2.5 levels similar to the present study [5]. As the floor size area increases PM 2.5 levels decrease implying the need for adequate spacing within the house.

Internal Sources of PM 2.5

One of the most important sources of indoor PM 2.5 levels was cooking oil fume emission [14]. The increase of PM 2.5 concentration caused by the cooking is however not restricted to the kitchen and affects other indoor rooms as well due to the close connectivity between rooms [15]. This study showed a significant association between the type of fuel and PM 2.5 levels, especially with firewood when compared with LPG and kerosene. Studies by Rahman MM et al., (2004) in Bangladesh found that PM 2.5 constituted up to 50% of biomass combustion [16]. In the same study, it was found that PM 2.5/PM10 ratio for LPG is significantly lower than the other fuels thereby resulting in relatively low PM 2.5 mass emissions. Ash-forming inorganic compounds, as well as organic byproducts, are produced by incomplete combustion of biomass such as wood, dried plant vegetation and dried cow dung [17,18]. In a study by Siddiqui AR et al., the mean concentrations of carbon monoxide and PM 2.5 levels were significantly high among those houses which used wood as their primary fuel source [19]. Similar to the findings of this study, a study in Nepal by Ranabhat CL et al., has shown that the use of traditional mud stoves and biomass fuel are major risk factors for indoor air pollution (OR of 8.6 and 2.8 respectively) [20]. PM 2.5 resulting from the combustion of solid fuels for household cooking is an important contributor, accounting for more than 10% of PMC2.5 pollution in seven regions of Southeast Asian countries housing >50% of the global population in 2010 [21]. The importance of this source of pollution extends to India in South Asia and China in East Asia, both with high ambient pollution levels; 90% of the estimated global deaths from ambient air pollution in these regions were attributed to the use of solid fuels for household [21].

The kutcha houses being single dwelling units did not have partitions/separate kitchens and all cooking and burning activities happened in the living room. Overcrowding as evident by per capita square feet less than 100 sq feet (mean floor space area of less than 280 and minimum occupancy of three per house) was also commonly encountered in kutcha houses which could further worsen the situation. Both cross ventilation and artificial ventilation were absent in kutcha houses.

With the increased availability of good quality materials for the construction of houses and support from the government in the form of Pradhan Mantri Gramiya Awas Yojana, 51% of houses in the present study were of the semi pucca variety [22]. The houses were either owned as a part of an ancestral property/constructed/rented. Cross ventilation was not seen in any of the kutcha houses and most of the semi pucca houses but was fairly present among pucca houses. Direct comparisons of various factors influencing PM 2.5 levels with other studies conducted elsewhere are difficult due to variations in monitoring techniques, prevailing socio-economic conditions, and climatic factors. In a study by Balakrishnan K et al., configuration of the kitchen played a major role in determining PM 2.5 levels, especially in solid fuel using houses. In this study, a negative correlation was observed between floor space area and PM 2.5 levels which is concurrent with present study [5].

Measures to Control Indoor PM 2.5 Levels and its Recommendations

Health education: Awareness through mass and social media should be carried out at frequent intervals to the public on the hazards of indoor air pollution. The common problems encountered especially among children and women who are more exposed to hazardous pollution levels should be highlighted.

Fuel type: Limited availability and high expenditure of LPG makes people go in search of other fuel sources. Subsidised kerosene through public distribution outlets regularly was helping people ease out the situation. With the recent Pradhan Mantri Ujjawala Scheme LPG cylinders are been provided at subsidised rates for the general public.

Proper housing: Houses should be constructed with proper ventilation under guidance. The importance of cross ventilation should be stressed and, in the absence, the need for artificial ventilation should be instigated. The population of the rural areas in India can make use of the "Pradhan Mantri Gramiya Awas Yojana" for the construction of houses as well as the implementation of smokeless chullah which provides chimneys for preventing the indoor escape of pollutants.

Limitation(s)

The impact of other parameters like smoking, type of cooking and duration of cooking was not done. Similarly, the effect of PM 2.5 levels on the health of the house dwellers could not be assessed. The PM 2.5 level measurements were done on working days when the residents were away from indoor sites and this could affect the ventilation characteristics.

CONCLUSION(S)

Rural areas which are dominated by kutcha and semi pucca houses should consider restructuring with proper ventilatory mechanisms. This is invested in the hands of the local governing bodies for ensuring the availability of good quality construction materials and supervised construction of houses. Simple cost-effective measures like the use of LPG for cooking could reduce indoor PM 2.5 levels in the long run. This study may be used as a starting point for intervention studies employing quantification of PMC2.5 levels and the impact of other parameters in reducing the PM 2.5 levels.

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PARTICULARS OF CONTRIBUTORS:
1. Senior Resident, Department of Community Medicine, Panimalar Medical College Hospital and Research Institute, Chennai, Tamil Nadu, India.
2. Associate Professor, Department of Biochemistry, Panimalar Medical College Hospital and Research Institute, Chennai, Tamil Nadu, India.
3. Associate Professor, Department of Biochemistry, Panimalar Medical College Hospital and Research Institute, Chennai, Tamil Nadu, India.
4. Professor, Department of Community Medicine, Sri Ramachandra Institute of Higher Education and Research, Chennai, Tamil Nadu, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:
Anusha Raja Jagadeesan,
B14, Sterling Bhandari, Kattupakkam, Chennai, Tamil Nadu, India.
E-mail: maya.anusha@gmail.com

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