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Original Article

Medical Biomonitoring of Maternal and Fetal Exposure to Carbon Monoxide and its Modification by Demographic and Obstetric Characteristics.

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Abstract

Background: There is a paucity of organized human biomonitoring, including that of carbon monoxide (CO) in the Niger Delta, Nigeria. The study aims to quantify the impact of maternal exposure to CO in the first trimester of pregnancy and its modification by maternal demographic and obstetric factors.

Methodology: It was of cross-sectional design conducted at the Rivers State University Teaching Hospital (RSUTH) in Nigeria. Four hundred and ninety consecutive pregnant women in the first trimester were recruited from the antenatal clinic from January 2021 to January 2022. Demographic, social, and obstetric characteristics were recorded. Maternal exhaled CO concentration (ECOC) and maternal and fetal carboxyhaemoglobin concentrations (MCOHC and FCOHC) were measured with the aid of a smokelyzer. Data were analyzed, using SPSS version 25.0 software. Ethical approval was obtained from the RSUTH Ethics Committee.

Results: The mean values of ECOC, MCOHC, and FCOHC were 3.25±2.51 ppm, 1.15±0.40%, and 0.93±0.72% respectively and the severity (mild, moderate, and severe) of the impact was inversely proportional to the number of women affected. There were statistically significant differences in the mean values of ECOC, MCOHC, and FCOHC in the following maternal characteristics: age, educational levels, BMI, gravidity, and parity. In the case of FCOHC, the measures of the differences were as follows: p:<0.019, <0.020, <0.0001, <0.0001, and <0.038 for age categories, educational levels, BMI, gravidity, and parity respectively. There were statistically significant positive correlations between the BMI and the mean values of ECOC, MCOHC, and FCOHC.

Conclusion: The higher the severity of exposure to CO (mild, moderate, and severe), the lower the number of impacted pregnant women. There were statistically significant differences in the mean values of ECOC, MCOHC, and FCOHC in women of different ages, educational levels, BMI, gravidity, and parity categories.

Keywords: Medical Biomonitoring; Maternal and Fetal Exposure; Carbon Monoxide; Modification; Characteristics**.**

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Quick Response Code:

Introduction

The study was prompted by the popular belief that the core Niger Delta area of Nigeria was plagued with environmental pollution. The Niger Delta consists of nine coastal Southern Nigerian States [Abia. Akwa-Ibom, Bayelsa, Cross-River, Delta, Edo, Imo, Ondo, and Rivers] with Rivers and Bayelsa regarded as the core Niger Delta States. The Delta is a petroleum-rich region and has been the center of international concern over environmental pollution. It hosts upstream and downstream oil-related and non-oil-related industries that release tons of pollutants including carbon monoxide (CO) into the ecosystem. Other sources of CO pollution in the Delta were tobacco fumes, generators, firewood, kerosene, and gas stoves, bush and refuse burning, fire outbreaks, barbecues, burning of fossil fuels in old vehicles, crude oil, and gas industry (three refineries, oil wells, flow stations, gas flaring, crude oil, condensate spills, etc.). [1]

CO is an inorganic colorless, odorless, and non-irritating gas, a product of incomplete combustion of carbonaceous compounds. It is emitted from a source directly into the atmosphere and therefore it is a primary pollutant. Its route of entrance into the body is via inhalation; there is also nominal endogenous production of the gas. In pregnancy, chronic exposure to CO can lead to maternal carboxyhaemoglobin concentration (MCOHC) of up to 5-20%, presenting with minor symptoms and signs such as headaches, impaired physical performance, a sensation of weakness, etc. Acute poisoning affects all body systems with the CNS, respiratory, cardiovascular, and gastrointestinal systems most affected.

Accumulation of CO in fetal circulation in the form of fetal carboxyhaemoglobin (FCOH) is associated with maternal exposure to CO. Maternal exposure to the gas in the first and second trimesters can cause intrauterine growth restriction due to induced chronic hypoxia, [2,3] preterm labor, [4] birth defects, [3, 5-9] intrauterine fetal death, [10, 11] and sudden infant death. [10]FCOHC remains unchanged for several days after death and can be measured and used in retrospect as a diagnostic tool for CO poisoning.

Environmental and human biomonitoring was not practiced in Nigeria. [1] There were no data on the clinical presentations of CO pollution in the Delta. [12] However recently, there have been few publications on the impact of maternal exposure to CO in the first trimester. [13-15] Available guidelines on environmental protection against pollutants in the region were not adhered to. However, there were sporadic data on environmental biomonitoring in areas of interest, conducted by multinational companies and university research Fellows.

Clinical research has demonstrated that a useful relationship between carbon monoxide and carboxyhaemoglobin is obtained after a short period of breath-holding. The instrument called Smokerlyzer only directly measures the exhaled CO concentration [16] while MCOHC and FCOHC are calculations based on clinical evidence. CO ppm - percentage of carboxyhaemoglobin concentration (%COHb) calculation was taken from Jarvis M et al (1986). [17] COHb = 0.63 + 0.16(EC50**),** where (EC50) is the concentration of CO in ppm that is expired after inhalation as measured with a smokerlyzer (breath test). [16] COppm - %FCOHb calculation was taken from Gomez C. et al (2005). [18] Although women in the core Niger Delta almost do not smoke, they are perpetually exposed to CO because of the presence of several sources of the gas in the Delta. We, therefore, hypothesized that they were likely to be affected by the gas just like women who smoke were. The smokerlyzer was therefore used to measure the concentration of exhaled CO in the women and indirectly, the MCOHC and the FCOHC were given by the machine.

The aim of the study therefore was to establish the severity of maternal exposure to CO in the first trimester of pregnancy by assessing maternal ECOC, MCOHC, and FCOHC and to ascertain how maternal demographic and obstetric factors affect the impact of her CO exposure.

Methodology

Study area/population/design.

The study was of cross-sectional design conducted at the Rivers State University Teaching Hospital (RSUTH) in Rivers State, which is one of the States in the core Niger Delta area of Nigeria (Figure 1). The study population included all pregnant women attending the antenatal clinics in the first trimester of pregnancy up to 14 weeks from January 2021 to January 2022. Consecutive attendants were counseled about the research project and informed consent was obtained.

Inclusion/exclusion criteria

All antenatal attendees in the first trimester of pregnancy in the study area were included in the study. The exclusion criteria were pregnant women with physical disabilities such as deafness and dumbness, critically ill patients, as well as those with a history of ongoing mental illness/retardation (because of the difficulties associated with taking history from the patients), and uncertain date of last menstrual period with no ultrasonographic estimation of gestational age between 11-14 weeks of gestational age. Gestational age was estimated with the aid of dating scans in the first trimester of pregnancy. Demographic, social, and obstetric characteristics including age, education, drinking alcohol, smoking status, BMI, and parity were taken.

Measurement of maternal exhaled carbon monoxide.

A hand-held instrument called Smokerlyzer® by Bedfont Scientific (normally used in measuring CO exhalation in smokers) was used to measure the concentration of CO in expired air (ECOC. [16] It displays CO in part per million (ppm) and indirectly measures concentrations of maternal carboxyhaemoglobin (MCOHC), which is synonymous with the percentage of oxygen that is displaced by CO in the molecules of oxyhaemoglobin and fetal carboxyhaemoblobin concentration (FCOHC), which, is synonymous with the percentage of oxygen that is displaced by CO in the molecules of oxyhaemoglobin in fetal circulation. The reference values are illustrated in **Table 1.**

Table 1: Derivation of the %COHb and %fCOHb from CO ppm based on clinical evidence.

a			b	
CO ppm	**%COHb**		**CO ppm**	**%FCOHb**
30	**5.43**		**20+**	**5.66**
29	**5.27**			
28	**5.11**		**19**	**5.58**
27	**4.95**			
26	**4.79**		**18**	**5.09**
25	**4.63**			
24	**4.47**		**17**	**4.81**
23	**4.31**			
22	**4.15**		**16**	**4.53**
21	**3.99**			
20	**3.83**	**Red zone**	**15**	**4.25**
19	**3.67**			
18	**3.51**		**14**	**3.96**
17	**3.35**		**13**	**3.69**
16	**3.19**		**12**	**3.40**

15	**3.03**		**11**	**3.11**
14	**2.87**		**10**	**2.83**
13	**2.71**		**9**	**2.55**
12	**2.55**		**8**	**2.26**
11	**2.39**		**7**	**1.98**
10	**2.23**	**Gray zone**	**6**	**1.70**
9	**2.07**		**5**	**1.42**
8	**1.91**		**4**	**1.13**
7	**1.75**			
6	**1.59**	**Green zone**	**3**	**0.85**
5	**1.43**			
4	**1.27**		**2**	**0.57**
3	**1.11**			
2	**0.95**		**1**	**0.28**
1	**0.79**			

The severity of maternal exposure to CO was assessed, using the data in Table 1(a and b) which came with the smokerlyzer - %COHb in Table 1a for MCOHC while COppm and %FCOHb in Table 1b for maternal ECOC and FCOHC were used as reference ranges for comparison. The smokerlyzer, during the exhalation test, measured exhaled CO in ppm. MCOHC and FCOHC in percentages of the displaced oxygen from maternal and fetal oxyhaemoglobin respectively were deduced from the exhaled CO, using Gomes C et al. calculation. [18]

Green zone: This is where a mother really needs to be! It means she does not exhale more than 3 ppm of CO in her breath and that corresponds to less than 2% carbon monoxide (CO) in her blood.

Gray zone: Having a reading in this zone would indicate a light smokeror a non-smoker breathing in air that is of poor quality or a passive smoker.

Red zone: Having a reading in this zone indicates that the person may well be a regular smoker with higher levels of CO in the blood.

Determination of the sample size

The outcome measures in the study were the prevalence of different measures of severity of exposure to CO and the effect of maternal age, parity, BMI, and smoking status on the severity of the impact. Therefore, the sample size was calculated using the sample size formula for a cross-sectional study with a categorical outcome.

$n = Z\alpha/22\ P\ (1-P)\ /\ d2$ where

$Z\alpha/22$ = Standard normal deviation at 95% confidence interval =1.96.
P - Expected proportion in population based on previous studies. Since there were no figures in the past for a complete assessment of the parameters in the study, 50% was used in the calculation of the sample size.
d = Absolute error or precision=0.05.

Therefore,
N = 1.962 x 0.5(1-0.5)/0.052 = 3.8416 x 0.5x0.5/0.0025 = 384.16

The required number of patients for the study was therefore 384.16. Giving allowance for an attrition rate of 10%, the final sample size for the study was 10/100×384+384 = 422.56. Therefore, the number of patients to be recruited for the study was 423. We were however able to recruit 490 patients, thus increasing the external validity of the study.

Statistical analysis

Data was collected on a special pretested proforma and then transferred into an Excel file where they were cleaned and fed into SPSS version 25.0 (Armonk, NY) software for analysis. Simple proportions were used in the descriptive analysis. Quantitative data were summarized and presented as mean and standard deviation while qualitative data were presented as numbers and percentages. A comparison of related variables was conducted, using the t-test and the P-values. When the P-value was less than 0.05, the differences between the variables were said to be statistically significant. When an expected count was less than 5 in a cell, the Fisher Exact test was used. Pearson's correlation analysis was conducted between the mean values of ECOC, MCOHC, and FCOHC and maternal BMI.

Ethical consideration

The study was carried out in compliance with the international ethical guidelines for biomedical research involving human subjects. Ethical approval was obtained from the RSUTH ethics committee. Verbal consents were obtained from all the women who were enrolled in the study. All the information that was collected from individual patients was available for clinical use and for research purposes. Privacy rules were maintained, and confidentiality was observed at all levels of dealing with patients' data.

Results

Demographic, obstetric, and general characteristics

Four hundred and ninety pregnant women were recruited for the study from $11\text{-}13^{+6}$ weeks of pregnancy. Details of the results are shown in Table 2.

Table 2: Demographic, obstetric, and general characteristics of the patients.
n=490

Demographic obstetric and general characteristics		Frequency (n)	Percentage. (%)
Maternal age, Years (mean= ± 31.57±4.49 yrs. median age = 32 years. range = 21 – 50 years)	20 – 24 years	24	4.9
	25 – 29 years	133	27.1
	30 – 34 years	215	43.9
	35 – 39 years	103	21.0
	40 – 44 years	11	2.2
	≥45 years	4	0.8
Education	secondary	73	14.90
	tertiary	417	85.10
Smoking	no	487	99.39
	yes	3	0.61
Alcohol	No	372	75.9
	Yes	118	24.1

Gravida (Median=1, Range= 1-8)	G1	246	50.2
	G2	108	22.0
	G3	88	18.0
	>G3	48	9.8
Parity (Median=P1; Range = 0 – 5)	Para 0	230	46.9
	Para 1	128	26.1
	Para 2 – 4	128	26.1
	≥ Para 5	4	0.8
BMI	18.5–24.9 (Normal weight)	101	20.60
	25.0–29.9 (Overweight)	212	43.30
	30.0–34.9 (Class I Obesity)	107	21.84
	35.0–39.9 (Class II Obesity)	51	10.61
	≥40.0) (Class III Obesity)	18	3.67
Marital Status	Married	490	100
	Not married	0	0

Measures of the severity of maternal exposure to Carbon monoxide

The sustained impact of maternal and fetal exposure to CO was measured by the mean and median concentrations of maternal exhaled CO (ECOC), maternal carboxyhaemoglobin (MCOH), and fetal carboxyhaemoglobin (FCOH), and the 3 degrees of severity of exposure to CO which were mild, moderate, and severe for each of the forms of the gas (Table 3).

Table 3: Degrees of severity of exposures to CO.
n = 490

Types of exposure to CO	Severity of impact	Values	Frequency	Percentages %
Exhaled CO concentration, (ECOC) (ppm).	Mild	1-3	335	68.37
	Moderate	4-6	129	26.33
	Severe	More than 6	26	5.31
MCOHC (%)	Mild	0.78 to 1.59	461	94.08
	Moderate	1.75 to 2.23	18	3.67
	Severe	2.3 and above	11	2.20
FCOHC. (%)	Mild	0.28 to 0.85	331	87.60
	Moderate	>0.85 to 1.70	125	25.51
	Severe	>1.70	34	6.90

The classification was adapted from the hitherto attained norms that came with the instrument Smokerlyzer Bedmont and was based on previous studies. [17, 18] The average values and ranges of maternal ECOC, MCOHC, and FCOHC are shown in Table 4.

Table 4: Average values and ranges of Maternal ECOC, MCOHC, and FCOHC

Measures	**ECOC**	**MCOHC**	**FCOHC**
Mean ± SD	3.25±2.51 ppm	1.15±0.40%	= 0.93±0.72%
Median	3.00ppm	1.11%	0.85%;
Range	1 – 19ppm	0.79 – 3.67%	0.28 – 5.38%.

The 3 degrees of exposure to CO were assessed based on the levels of maternal ECOC, MCOHC, and FCOHC and were as shown in Figure 1 – 3 and Table 3.

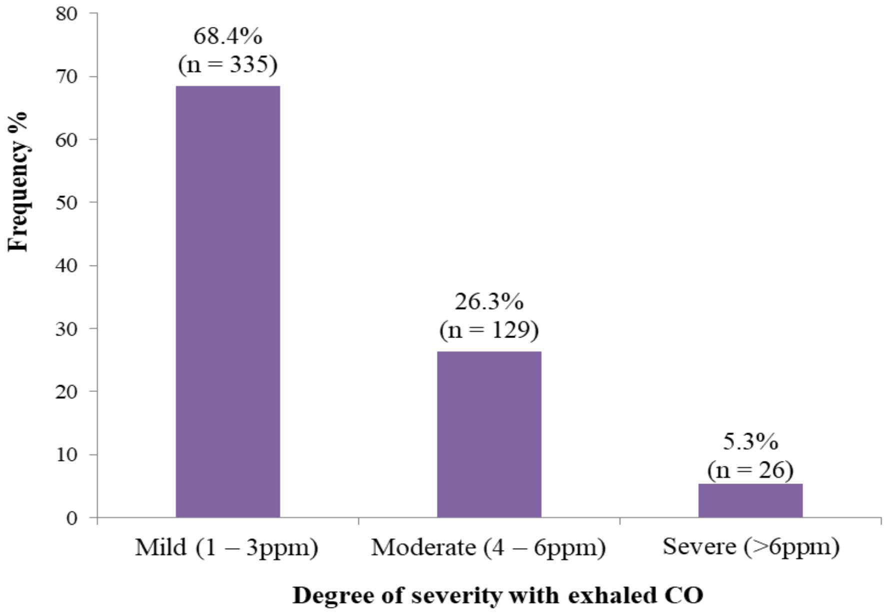

Figure 1: The three degrees of severity of maternal ECOC after their exposure to the gas.

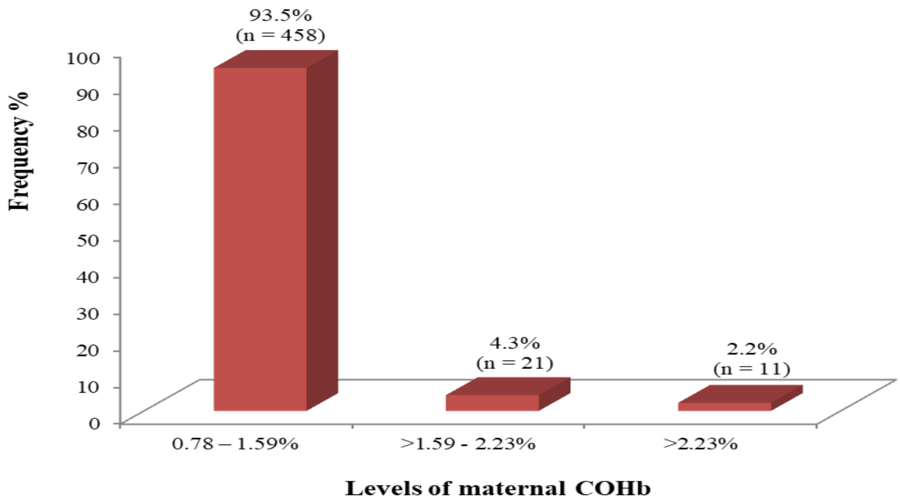

Figure 2: The three degrees of severity of MCOHC after maternal exposure to CO

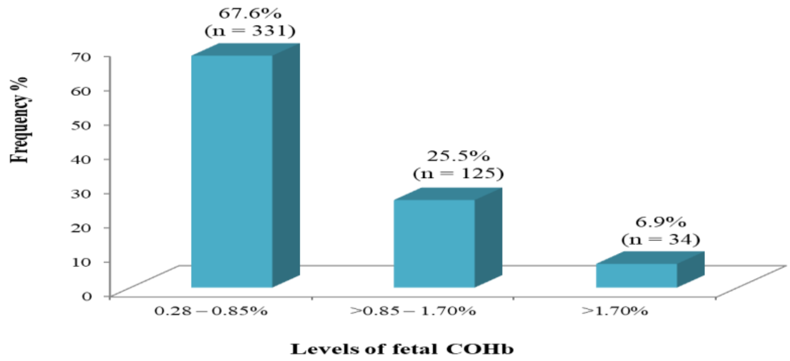

Figure 3: The three degrees of severity of FCOHC after maternal exposure to CO.

Effects of demographic, social, and obstetric characteristics on the mean ECOC.

As already stated, the mean value of maternal exhaled CO after 490 mothers were exposed to CO ± SD was 25±2.51parts per million (ppm). The value was modified by the demographic, social, and obstetric characteristics of the patients as shown in Table 5.

Table 5: The effects of maternal demographic, social, and obstetric characteristics on the mean ECOC.

Variables	**Exhaled CO concentration (ppm) Mean ± SD**	**t**	**p-value**
Age category			
20 – 24 years	2.54±1.14		
25 – 29 years	3.16±2.07		
30 – 34 years	3.13±2.10	*3.594* [A]	*0.0001**
35 – 39 years	3.93±3.78		
40 – 44 years	2.00±0.63		
≥45 years	2.50±0.58		
Educational level			
Secondary	3.79±3.52	*2.025*	*0.043**
Tertiary	3.15±2.28		
Intake of alcohol			
Yes	3.50±2.41	*1.256*	*0.210*
No	3.17±2.54		
Smoking history			
Yes	2.00±0.00	*-0.862*	*0.389*
No	3.25±2.52		
Gravidity			
G1			
G2	3.08±2.19		
G3	2.70±1.25	*6.945* [A]	*0.0001**
G4	3.75±2.18		
Parity	1.00±0.00		
Para0	3.14±2.25		

Para 1	3.04±2.77		
Para 2-4	3.72±2.66	*3.042* ^{A}	*0.029**
Para 5 and above	1.00±0.00		
BMI			
18.50 – 24.9Kg (Normal)	2.96±1.69		
25.0 – 29.9 (Over-wt)	3.17±2.55	*6.332* ^{A}	*0.0001**
30.0 – 34.9Kg (OC I)	2.92±1.74		
35.0 – 39.9Kg (OC II)	3.96±3.35		
≥40Kg (OC III)	5.67±4.71		

***Statistically significant (*p<0.05*)** **SD – Standard deviation** ***A* – ANOVA**

There were statistically significant differences in the mean values of ECOC in different groups of maternal demographics, social, and obstetric characteristics namely age categories (t=*3.594*, p<0.0001), educational levels (t=*2.025*, p<*0.043*), BMI (t=*6.332*, p<0.0001), gravidity (t=*6.945*, p<0.0001) and parity (t=*3.042*, p<*0.029*). Paradoxically, the differences in its levels among other groups namely smoking (t= *-0.862*, p<*0.389*) and drinking habits (t=*1.256*, p<*0.210*) were not statistically significant and there was a reverse relationship between those that smoke and the mean value of maternal ECOC.

Furthermore, a significant positive correlation was established between the mean exhaled CO and maternal BMI – the higher the BMI, the more the likelihood of having a higher mean exhaled CO (r=0.224, p<0.0001) (Table 6).

Table 6: Correlation between exhaled CO concentration and maternal BMI

	Exhaled CO concentration (ppm)	
Variable	**Pearson Correlation co-efficient (r)**	**p-value**
Maternal weight at booking	0.192	0.0001*
Maternal height at booking	-0.058	0.204
BMI	0.224	0.0001*

***Statistically significant (*p<0.05*)**

The correlation was due mainly to maternal weight (r=0.192; p<0.0001).

The effects of demographic, social, and obstetric characteristics on the mean MCOHC after exposure to CO.

As already stated, the mean value of MCOHC for the 490 participants in the study ± SD was 1.15±0.40%. The value was modified when calculated in association with the demographic, social, and obstetric characteristics of the patients as shown in Table 7.

Table 7: The associations of maternal demographic, social, and obstetric characteristics on the mean values of MCOHC.

Variables	Maternal COHb Mean ± SD. (%)	t	p-value
Age category			
20 – 24 years	1.04±0.18		
25 – 29 years	1.14±0.34		
30 – 34 years	1.14±0.33	*2.742* **A**	*0.019**
35 – 39 years	1.26±0.60		
40 – 44 years	0.95±0.10		
≥45 years	1.04±0.09		
Educational level			
Secondary	1.25±0.56	*2.140*	*0.033**
Tertiary	1.14±0.36		
Intake of alcohol			
Yes	1.19±0.38	*1.225*	*0.221*
No	1.14±0.41		
Smoking history			
Yes	0.95±0.00	*-0.884*	*0.377*
No	1.16±0.40		
Gravidity			
G1	1.12±0.35		
G2	1.07±0.21	*6.407* **A**	*0.0001**
G3	1.23±0.34		
>G3	1.33±0.80		
Parity			
Para 0	1.14±0.36		
Para 1	1.12±0.45	*2.836* **A**	*0.038**
Para 2 – 4	1.22±0.41		
≥ Para 5	0.79±0.00		
BMI			
18.50 – 24.9Kg (Normal)	1.12±0.30		
25.0 – 29.9 (Over-weight)	1.14±0.41		
30.0 – 34.9Kg (Obesity class I)	1.10±0.28	*5.789*	*0.0001**
35.0 – 39.9Kg (Obesity class II)	1.27±0.52		
≥40Kg (Obesity class III)	1.52±0.73		

***Statistically significant (*$p<0.05$*)** **SD – Standard deviation**

There were statistically significant differences in the mean values of MCOH concentrations in different groups of maternal demographics, social and obstetric characteristics namely age categories (t=*2.742*, p<0.019), educational levels (t=*2.140*, p<*0.033*), BMI (t=*5.789*, p<0.0001), gravidity (t=*6.407*, p<0.0001) and parity (t=*2.836*, p<*0.038*). Paradoxically, the differences in its levels among other groups namely smoking (t= *-0.884*, p< *0.377*) and drinking habits (t=*1.225*, p<*0.221*) were not statistically significant but there was a reverse relationship between those that smoke and the mean value of maternal MCOH

Furthermore, a significant positive correlation was established between the mean maternal COHb concentration and maternal BMI – the higher the BMI, the more the likelihood of having a higher mean MCOHC (r=0.217, p<0.0001) (Table 8).

Table 8: Correlation between maternal COHb concentration and maternal BMI

	Maternal COHb concentration (%)	
Variable	**Pearson Correlation co-efficient (r)**	**p-value**
Maternal weight at booking	0.16	0.0001*
Maternal height at booking	-0.060	0.194
BMI (Kg)	0.217	0.0001*

***Statistically significant (*$p<0.05$*)**

The correlation was due mainly to maternal weight (r=0.16; p<0.0001).

Modification of the mean value of FCOHC by demographic, social, and obstetric characteristics after maternal exposure to CO.
As already stated, the mean value of FCOHC concentration for the 490 mothers who were exposed to CO ± SD was 0.93±0.72%. The value was modified by the demographic, social, and obstetric characteristics of the patients as shown in Table 9.

Table 9: The effects of maternal demographic, social, and obstetric characteristics on the mean FCOHC

Variables	Fetal COHC (%) Mean ± SD	t	p-value
Age category			
20 – 24 years	0.72±0.32		
25 – 29 years	0.91±0.60		
30 – 34 years	0.89±0.61	*2.742* ^{A}	*0.019**
35 – 39 years	1.12±1.07		
40 – 44 years	0.53±0.13		
≥45 years	0.61±0.05		
Educational level			
Secondary	1.11±1.00	*2.328*	*0.020**
Tertiary	0.89±0.65		
Intake of alcohol			
Yes	1.01±0.70	*1.433*	*0.153*
No	0.90±0.73		
Smoking			
Yes	0.57±0.00	*-0.860*	*0.390*
No	0.93±0.72		

Gravidity	0.88±0.64		
G1	0.78±0.37	*6.447* ^{A}	*0.0001**
G2	1.06±0.59		
G3	1.25±1.43		
>G3			
Parity	0.89±0.66		
Para 0	0.87±0.79		
Para 1	1.05±0.74	*2.833* ^{A}	*0.038**
Para 2 – 4	0.28±0.00		
≥ Para 5			
BMI	0.86±0.53		
18.50 – 24.9 (Normal)	0.90±0.72		
25.0 – 29.9 (Over-weight)	0.84±0.50	*5.545*	*0.0001**
30.0 – 34. (Obesity class I)	1.14±0.94		
35.0 – 39.9(Obesity class II)	1.56±1.38		
≥40Kg (Obesity class III			

***Statistically significant (*p<0.05*) SD – Standard deviation A - Anova**

There were statistically significant differences in the mean values of FCOHC in the following groups: age, educational levels, BMI, gravidity, and parity but the differences in its levels were not statistically significant among smokers and alcohol consumers.

Furthermore, a significant positive correlation was established between the severity of fetal impact on maternal exposure to CO, measured by the mean FCOH and maternal BMI – the higher the BMI, the more the likelihood of having severe fetal impact (r=0.214, p<0.0001) (Table 10).

Table 10: Correlation between mean fetal COHb concentrations and clinical factors among patients

	Fetal COHb concentration (%)	
Variable	Pearson Correlation co-efficient (r)	p-value
Maternal weight at booking	0.181	0.0001*
Maternal height at booking	-0.066	0.149
BMI (Kg)	0.214	0.0001*

***Statistically significant (*p<0.05*)**

The correlation was due mainly to maternal weight (r=0.181, p<0.0001)

Discussion

There were similar tendencies in the proportion of patients that had mild, moderate, and severe exposure to CO as measured by the ECOC, MCOHC, and FCOHC; for each of the forms of CO, the higher the severity of exposure to CO, the lower the number of patients that were affected. There was no explanation for the finding in the literature. However, it could be that more women were exposed to sources that exude less CO when compared with those that were exposed to sources that exude high concentrations of CO. Another explanation could be the disparity in the metabolism from inhalation to its appearance in blood.

The mean value of ECOC in the present study was 3.25±2.51parts per million (ppm) with the study population primarily non-smokers lying in the green zone of severity, corresponding to mild exposure to carbon monoxide (table 1). [18] It was more than that obtained in other studies, also in non-smokers from Tanzania where it was 2.0 ppm. [19] However, in the Tanzanian study, the stage of pregnancy was not specified. It was interesting to further note that the level of ECOC that was observed in the present study was greater than 3ppm obtained in smokers in early pregnancy in Europe; the level was associated with low birth weight. [20] Generally, there was a paucity of studies on the levels of exhaled CO concentrations in the first trimester of pregnancy.

The statistically significant differences in the mean values of ECOC and MCOHC in different groups of maternal demographics, social and obstetric characteristics namely age categories, educational levels, BMI, gravidity, and parity may be due to the differences in the pharmacodynamics and pharmacokinetics of carbon monoxide in the human system, but we do not have evidence for that. However, because of its short half-lives (biphasic elimination, half-lives 3.6 and 4.5 hours), [21] carboxyhemoglobin would rapidly return to a concentration governed by typical ambient levels and endogenous production after exposure if the exposure is not continuous. That would have explained the significant positive correlation that was observed between the mean ECOC MCOHC and FCOHC and maternal BMI – the higher the BMI, the more the likelihood of having a higher mean exhaled CO ($r=0.224$, $p<0.0001$), MCOHC ($r=0.217$, $p<0.0001$) and FCOHC ($r=0.214$, $p<0.0001$). Probably, the more the BMI, the longer it takes to metabolize CO and therefore to increase the half-life of MCOHC. There was no explanation for the paradoxical findings in those who smoke – lower concentrations in smokers than non-smokers.

The mean concentration of MCOH in the present study 1.15±0.40% falls within the range for mild impact on maternal exposure to CO, [18] and below the agreed level in non-pregnant adults of 2% at which angina will develop. Based on the laboratory studies of reduction in exercise capacity in both healthy individuals and volunteers with cardiovascular disease, it was determined that MCOHC levels should not exceed 2%. The Coburn-Forster-Kane (CFK) equation is used to determine the levels of carbon monoxide to which a normal adult under resting conditions for various intervals can be exposed without exceeding an MCOHC level of 2%. [22, 23] However, apart from the endogenous level of MCOHC of 0.4-0.7%, [24] no other level of MCOHC is safe, in terms of clinical implications.

The mean value of fCOHb concentration out of the 490 participants in the study population ± SD was 0.93±0.72%, constituting a moderate fetal impact by carbon monoxide. [18] There were statistically significant differences in its values in different groups of maternal demographics, social and obstetric characteristics namely age categories ($t=2.742$, $p<0.019$), educational levels ($t=2.328$, $p<0.020$), BMI ($t=5.545$, $p<0.0001$), gravidity ($t=6.447$, $p<0.0001$) and parity ($t=2.833$, $p<0.038$). Generally, a pattern was established – similar changes in the levels of ECOC, MCOGC, and FCOHC when analyzed in association with maternal demographic, social, and obstetric characteristics. Paradoxically, the differences in its levels among other groups namely smoking categories ($t=-0.860$, $p<0.390$) and drinking habits ($t=1.433$, $p<0.153$) were not statistically significant. There were reverse relationships between those that smoke and the mean values of ECOH, MCOHC, and fCOHb, although, they were not statistically significant.

Conclusions

The mean values of ECOC, MCOH and FCOH concentrations ± SD were 3.25±2.51 ppm, 1.15±0.40%, and 0.93±0.72% respectively. There were statistically significant differences in the above mean values in the following groups of patients: age group, educational levels, BMI group, gravidity group, and parity.

Paradoxically, there was a reverse relationship between those who smoked and the mean values of ECOC, MCOH, and FCOH. Furthermore, there were similar tendencies in the proportion of patients that had mild, moderate, and severe exposure to CO as measured by the ECOC, MCOHC, and FCOHC with the highest number of patients in the mild exposure category followed by those in the moderate exposure and then the least number in the severe exposure group.

Recommendations

A Nigerian Government–assisted air quality assessment and a universal maternal and fetal biomonitoring of the impact of maternal exposure toCO in the Niger Delta were highly recommended. They would go a long way in identifying those regions that were worse affected and the women and the fetuses that were most at risk of the exposure.

References

1. Green KI, Abbey M. Sources of Carbon Monoxide (CO) Pollution in the Niger Delta area of Nigeria. Saudi J Biomed Res 2022; 7(2):107-113.
2. Gomez C, Berlin I, Marquis P, Delcroix M. Expired air carbon monoxide concentration in mothers and their spouses above 5 ppm is associated with decreased fetal growth. Prev Med 2005;40(1):10-15.
3. Dalhamn T, Edfors M L, Rylander R. Retention of cigarette smoke components in human lungs. Archives of Environmental Health: An International Journal 1968; 17(5):746-748.
4. Silverman RK, Montano J. Hyperbaric oxygen treatment during pregnancy in acute carbon monoxide poisoning. A case reports. The Journal of Reproductive Medicine 1997; 42(5):309-311.
5. Woody RC, Brewster MA. Telencephalic dysgenesis associated with presumptive maternal carbon monoxide intoxication in the first trimester of pregnancy. Journal of Toxicology Clinical Toxicology 1990; 28(4):467-475.
6. Singh J. Early behavioral alterations in mice following prenatal carbon monoxide exposure. Neurotoxicology 1986; 7(2):475-481.
7. Bailey LTJ, Johnston MC, Billet J. Effects of carbon monoxide and hypoxia on cleft lip in A/J mice. The Cleft palate-craniofacial journal 1995; 32(1):14-19.
8. Tachi N, Aoyama M. Effect of cigarette smoke and carbon monoxide inhalation by gravid rats on the conceptus weight. Bulletin of Environmental Contamination and Toxicology 1983; 31(1):85-92.
9. Osborne JS, Adamek S, Hobbs ME. Some components of gas phase of cigarette smoke. Analytical Chemistry 1956; 28(2):211-215.
10. Cramer CR. Fetal death due to accidental maternal carbon monoxide poisoning. Journa of Toxicology: Clinical Toxicology 1982; 19(3):297-301.
11. Farrow JR, Davis GJ, Roy TM, McCloud LC, Nichols GR. Fetal death due to nonlethal maternal carbon monoxide poisoning. Journal of Forensic Science, 1990; 35(6):1448-1452.
12. Mkpe Abbey, Oloyede O. Adebari, Kinikanwo I. Green, Bruno C. Chinko. Carbon Monoxide (CO) Pollution in the Niger Delta area of Nigeria and Its Impact on Feto-Maternal Health. Sch Int J ObstetGynec2022; 5(2): 57-64.
13. Abbey M, Amadi SC, Ocheche US, Wekere FCC, Altraide BO, Oloyede OA, et al. Maternal exposure to carbon monoxide in the first trimester (7-13+6 weeks) of pregnancy in the core Niger Delta. Int J Reprod Contracept ObstetGynecol2022; 11(7):1839-1847.
14. Abbey M, Amadi C. S, Alpheaus MBA, Kwosah NJ, Nonye-Enyidah E, Kua P, Okagua Kenneth. Human Biomonitoring of Maternal exposure to Carbon Monoxide in the First Trimester of Pregnancy in the Core Niger Delta. Sch Int J Obstet Gynec 2022; 5(5): 272-280.

15. Abbey M, Amadi SC, Mba AG, Kwosah NJ, Altraide BO, Sapira-Ordu L, Nonye-Enyidah E, Akani CI.Biomonitoring of Fetal Exposure to Carbon Monoxide in the First Trimester of Pregnancy in the Core Niger Delta. Scholars International Journal of Obstetrics and Gynecology 2022; 5(5): 261-271.
16. Smokerlyzer. Bedfont www.bedfont.com. 1996.
17. Jarvis MJ, Belcher M, Vesey C, Hutchison DCS. Low-cost carbon monoxide monitors in smoking assessment. Thorax 1986; 41:886-887.
18. Gomez C, Berlin I, Marquis P, Delcroix M. Expired air carbon monoxide concentration in mothers and their spouses above 5ppm is associated with decreased fetal growth. Preventive Medicine 2005; 40:10-15
19. Wylie BJ, Kishashu Y, Matechi E, Zhou Z, Coull B, Abioye AI, Dionisio KL, Mugusi F, Premji Z, Fawzi W, Hauser R, Ezzati M. Maternal exposure to carbon monoxide and fine particulate matter during pregnancy in an urban Tanzanian cohort. Indoor Air2017 ;27(1):136-146.
20. Ciara ME Reynolds, Brendan Egan, Rachel A. Kennedy, Eimer O'Malley, Sharon R. Sheehan, Michael J. Turner. The implications of high carbon monoxide levels in early pregnancy for neonatal outcome. European Journal of Obstetrics & Gynecology and Reproductive Biology2019; 233:6-11.
21. Bruce MC, Bruce EN. Analysis of factors that influence rates of carbon monoxide uptake, distribution, and washout from blood and extravascular tissues using a multicompartment model. Journal of Applied Physiology2006; 100:1171–1180.
22. Coburn RF, Forster RE, Kane PB. Considerations of the physiological variables that determine the blood carboxyhemoglobin in concentration in man. Journal of Clinical Investigation 1965; 44:1899–1910.
23. Raub JA, Benignus VA. Carbon monoxide and the nervous system. Neuroscience and Biobehavioral Reviews 2002; 26:925–940.
24. Scherer G. Carboxyhemoglobin and thiocyanate as biomarkers of exposure to carbon monoxide and hydrogen cyanide in tobacco smoke. Experimental and Toxicological Pathology 2006; 58:101– 124.