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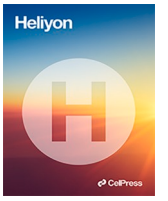

Fabrication of biosensor for the assessment of radon and lead levels in the blood

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ABSTRACT

This study aimed to develop and test a biosensor for detecting radioactive radon gas and lead ions in blood samples collected from donors in Iraq. The biosensor was made up of aptamer, acetic acid, malachite green, and TRIS-HAC, and results were measured using a fluorescence spectrophotometer. This study found that ^{222}Rn in the blood varied between individuals, with higher levels in males and smokers, and the highest concentration found in a male patient with cancer. The biosensor used to detect ^{222}Rn in the blood was effective, sensitive, and low-cost, and the levels detected were within the limits set by the WHO. The study also looked at pb^{+2}, a toxic metal, and found that levels were within permissible limits. The biosensor was also effective in detecting pb^{+2}. The correlations between the variables are generally weak to moderate, and there are some negative relationships between humidity and other variables. There are also some strong positive relationships between temperature (Tin) and temperature (Tout). The results suggest that these variables are not strongly correlated with each other, which is an important finding for understanding their potential effects on health outcomes. However, further validation and testing may be necessary before its widespread use in clinical settings. This study highlights the importance of monitoring these substances in the blood, especially for individuals with occupational exposure to radiation. The biosensor was found to be sensitive, cost-effective, fast to manufacture, and efficient compared to other detection devices. Therefore, the study recommends the use of this biosensor for measuring radon and lead ions in blood samples. The biosensor used in this study could be a useful tool for such monitoring.

1. Introduction

Radon gas and lead ions are both substances that can have a negative impact on human health if present at elevated levels. Radon is a naturally occurring radioactive gas that is produced from the decay of uranium in soil and rock, and it can seep into buildings where it can accumulate and pose a risk of lung cancer. Lead is a toxic heavy metal that can also pose a health risk, especially to young children, as it can damage the developing brain and nervous system [1]. The determination of radon gas and lead ion concentrations is important for identifying potential exposure risks and for taking steps to reduce exposure levels, if necessary. This can be done through various testing methods, such as radon gas detectors, lead paint testing kits, or laboratory analysis of water or air samples [2]. The results of

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these tests can be used to determine the concentration of radon gas or lead ions in a specific environment, and to determine whether the levels are within safe limits as established by government agencies and health organizations [3]. Biosensors for detecting pollutants are devices that use biological components, such as enzymes, cells, or antibodies, to detect and measure the presence and concentration of environmental pollutants. Some examples include [4,5].

1 .Enzyme-based biosensors - These use enzymes to detect specific pollutants and measure their concentration. For example, an enzyme-based biosensor can detect the presence of heavy metals in water.
2 .Microbial biosensors - These use living cells, such as bacteria or yeast, to detect specific pollutants. The cells can produce a signal, such as a change in color or fluorescence, when they meet the pollutant.
3 .Antibody-based biosensors - These use antibodies to detect specific pollutants. The antibodies are attached to a surface, and when the pollutant is present, it binds to the antibody and triggers a change in the sensor's output.
4 .Nucleic acid biosensors - These use DNA or RNA to detect specific pollutants. The nucleic acids are attached to a surface and will bind to the pollutant, leading to a change in the sensor's output.

These biosensors are useful in detecting pollutants in water, air, and soil, and can provide real-time data on the presence and concentration of pollutants, allowing for quick and efficient response [6,7]. Biosensors based on lead for the detection of radon gas are a promising technology for monitoring radon levels in indoor environments [8]. Radon is a naturally occurring radioactive gas that can accumulate in buildings and pose a significant health risk if not properly addressed [9]. Lead has been used in biosensors for radon detection due to its ability to capture radon and its decay products. In these biosensors, a thin layer of lead is coated onto a surface and exposed to air. As radon and its decay products interact with the lead, they produce charged particles that can be measured by a detector [10]. The main advantage of biosensors based on lead for radon detection is their ability to provide real-time measurements of radon levels. This is especially important for homes and other indoor environments, where radon levels can fluctuate throughout the day and from season to season. However, there are some challenges associated with the use of lead-based biosensors for radon detection. One of the biggest challenges is the potential for lead exposure, as lead is a toxic heavy metal that can be harmful to human health. Additionally, lead-based biosensors can be expensive and may require specialized training and equipment to operate effectively. Overall, while lead-based biosensors have shown promise for the detection of radon, more research and development are needed to address these challenges and make these biosensors more widely accessible and affordable for use in indoor environments [11]. Biosensors for detecting radon and lead in human blood are devices that use biological recognition elements, such as antibodies or enzymes, in combination with physical transducers to measure specific chemical substances [12]. The biological recognition elements are designed to specifically target radon or lead ions in the blood, while the physical transducer converts the change in the biological recognition element into a measurable signal, such as an electrical signal or a change in optical properties [13]. Radon and lead are both toxic substances that can pose serious health risks if present in high concentrations in the human body [14]. The development of biosensors for detecting these substances in human blood can provide a fast, sensitive, and non-invasive means for monitoring exposure levels and detecting potential health risks. However, the development of reliable and accurate biosensors for detecting radon and lead in human blood is a complex and challenging task that requires interdisciplinary expertise in areas such as

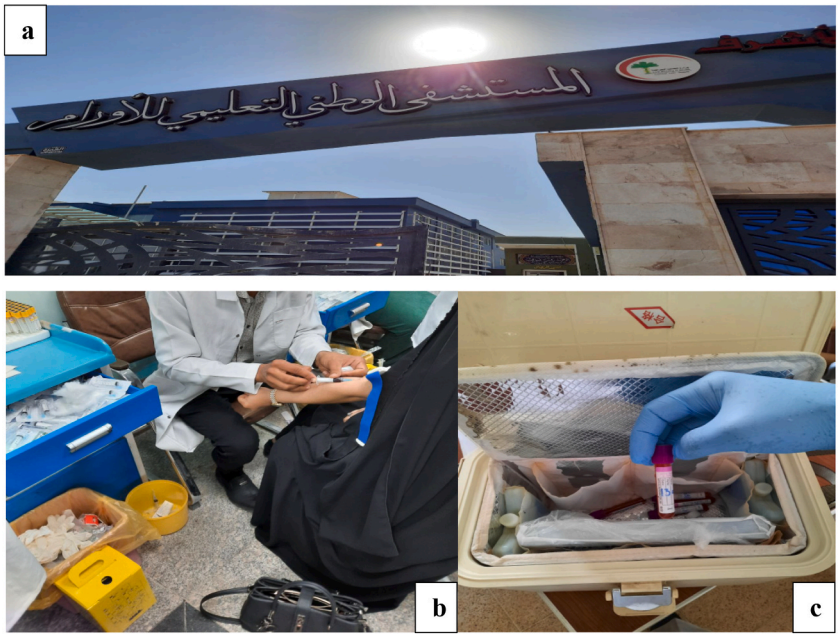

Fig. 1. a. National Educational Cancer Hospital: Najaf Health Department, b. Extraction of blood, c. Preservation of blood in the box.

chemistry, biology, and engineering [15]. In addition, the high sensitivity required for detecting these substances in blood makes it necessary to carefully control factors such as temperature, humidity, and interference from other substances in the blood [16]. Despite these challenges, research in this area is ongoing, and there are several promising biosensors currently under development for detecting radon and lead in human blood. These biosensors hold great potential for improving human health by providing a fast and effective means for detecting exposure to toxic substances [17]. The aim of this study is to create and evaluate a biosensor capable of detecting radioactive radon gas and lead ions in blood samples gathered from donors in Iraq. The biosensor's development and testing will enable early identification and monitoring of radiation exposure and heavy metal toxicity in the population, aiding in the implementation of effective preventive measures and treatment strategies. The main point of this study is to fabricate a biosensor and test its ability to detect radon and lead in blood samples. The goal is to determine if the biosensor is capable of accurately detecting these substances. Statistical analysis is not the main focus of this study, as the main objective is to assess the biosensor's detection capabilities.

2. Materials and methods

The goal of this study is to measure radon and ionizing radiation levels in human blood samples and assess their practical implications. The study was conducted in Najaf Governorate, Iraq, and involved collecting blood samples from both healthy individuals and cancer patients, including both males and females. A total of 25 blood samples were analyzed using a vital sensor. The samples were obtained from the National Cancer Hospital, General Manathra Hospital, and the National Educational Hospital for Oncology in Al-Najaf Governorate, as shown in Fig. 1a–c. The study focused on measuring the concentrations of ^{222}Rn and ^{210}pb in each blood sample, and the results of the analysis were examined.

Furthermore, the study included recruitment of healthy individuals from the General Manathira Hospital, and their blood samples were collected using tubes containing EDTA and labeled with pertinent information. To ensure that the samples did not clot, they were stored in a cool box at 4 °C with their respective sample codes until analysis. Table 1 provides further details on the volunteers, such as their age, gender, smoking habits, injury duration, and location.

EDTA tubes were used to collect samples from both cancer patients and healthy controls. The samples were then stored in a specialized refrigerator to maintain their freshness and prevent any alterations before transportation to the physics laboratory located at the Faculty of Science in the University of Kufa. It is crucial to establish optimal experimental conditions to ensure the most accurate and reliable results. To determine the optimal concentration for obtaining the best possible results, various Aptamer concentrations ranging from 0.1 to 1.2 μM were evaluated in this study. A fluorescence spectrophotometer approved for the experimental work was used for the analysis. The outcomes indicated that the most suitable Aptamer concentration was 0.6 μM. It is essential to determine the ideal pH value in most scientific experiments as it can significantly affect the reaction's nature. Based on the fluorescence results obtained in this study, the optimal pH value was determined to be 7. This finding is essential for conducting experiments under the most favorable conditions and achieving accurate and dependable outcomes. Malachite green is a green, crystalline pigment with a metallic lustre that contains three methyl groups, as reported in Ref. [18]. A strong fluorescence signal can be achieved by promoting

Table 1
The details and information of samples.

SC	Smoking	Age	Gender	Cancer Time	Location	Cancer Type	Health Status
C_1	Non	58	Female	1 year	Najaf	Colon	Cancer
C_2	Non	6	Female	2 years	Najaf	Leukemia	Cancer
C_3	Non	57	Male	3 years	Najaf	Lung	Cancer
C_4	Smoking	77	Male	1 year	Najaf	Lung	Cancer
C_5	Non	51	Male	1 year	Najaf	Brian	Cancer
C_6	Smoking	45	Male	3 years	Manathira	Colon	Cancer
C_7	Non	52	Male	1 year	Najaf	Lung	Cancer
C_8	Non	47	Male	ND	Manathira	ND	Healthy
C_9	Smoking	50	Male	ND	Manathira	ND	Healthy
C_{10}	Non	40	Female	9 months	Kufa	Colon	Cancer
C_{11}	Non	58	Male	ND	Manathira	ND	Healthy
C_{12}	Non	51	Female	2 years	Najaf	Lung	Cancer
C_{13}	Non	43	Female	1 year	Najaf	breast	Cancer
C_{14}	Non	41	Female	1 year	Najaf	Leukemia	Cancer
C_{15}	Non	16	Female	3 years	Najaf	Leukemia	Cancer
C_{16}	Non	49	Male	2 years	Najaf	Lung	Cancer
C_{17}	Smoking	31	Male	ND	Manathira	ND	Healthy
C_{18}	Smoking	65	Male	1 year	Najaf	Lung	Cancer
C_{19}	Non	37	Female	ND	Manathira	ND	Healthy
C_{20}	Smoking	70	Male	4 years	Najaf	Lung	Cancer
C_{21}	Non	32	Female	ND	Manathira	ND	Healthy
C_{22}	Non	37	Female	ND	Manathira	ND	Healthy
C_{23}	Smoking	45	Male	ND	Manathira	ND	Healthy
C_{24}	Smoking	47	Female	ND	Manathira	ND	Healthy
C_{25}	Non	39	Female	ND	Manathira	ND	Healthy

SC: Sample Code; **ND:** No data available.

the interaction between malachite green and G-quadruplex, as per previous research [19]. Furthermore, energy transfer fluorescence spectroscopy of malachite green has been employed in several studies to identify single- and double-stranded DNA, along with intramolecular G-quadruplex structures [20]. When malachite green and G-quadruplex are present together in the same group, it generates a robust fluorescence signal, as per the findings of this study. The optimal condition test performed in this research determined that the most suitable dye volume was 22 μL. This information is crucial for conducting experiments under optimal conditions and achieving the strongest possible fluorescence signal. In this section of the study, the procedure for detecting radon gas and lead ions in human blood samples using a biosensor is described. The aptamers utilized in the biosensor were procured from Bioneer, with a minimum purity level of 99.9%. To prepare the aptamers, 1 mL of deionized water was added to the aptamer powder, and the mixture was centrifuged for 15 min at 1000 rpm. The primer sequences employed in the biosensor were as follows: (5′-AGGGTTAGGGTTAGGGTTAGGG-′3). To capture ^{222}Rn and ^{210}Pb, a dilute acetic acid solution was utilized, consisting of 0.2 mL of acetic acid (99.9% purity) and 1000 mL of deionized water. It is essential to note that a strong acid was not used to prevent any impact on the dye and hydrolysis of the aptamer. To prepare the biosensor cell, the sample was placed in a 5 mL tube, and a tube partially filled with 10 mL of 0.2% acetic acid was added. To detect radon gas and lead ions in human blood samples, precise procedures were used in this study. A dilute acetic acid solution was used to capture ^{222}Rn and ^{210}Pb, but a strong acid was avoided to prevent affecting the dye and causing hydrolysis of the aptamer. The biosensor cell was prepared by placing the sample in a 5 mL tube, and partially placing a tube filled with 10 mL of 0.2% acetic acid. To prevent other contaminants from entering the acid, the tube was covered with a cellulose acetate film. The biosensor cell was then placed in a vacuum chamber and connected to a vacuum pump equipped with a pressure gauge to measure the pressure. For 4 days, the cell remained under a pressure of 30 bar to obtain a large amount of radon gas from the sample. This information is important for understanding the methods used in this study for detecting radon gas and lead ions in human blood samples. Additionally, the equipment used in the process is shown in Fig. 2a and b.

To prepare the Tris-HAC complex, Tris Amino methane at a concentration of 3 mM and a pH of 9.5 was used. The molecular mass of Tris Amino methane is 121.14 g/mol and it was obtained from Shanghai Biochemical Co. In China. The pH value was measured using a pH meter (Jenway 3505, England). This information is important for understanding the precise methods used in the study, and the sources and tools used to prepare the Tris-HAC complex. To equalize the pH of the sample and estimate the amount of lead, we added acid to the Tris-HAC complex solution until the pH reached 6.5. Following the 4-day exposure time, we added 2 mL of acid to the biosensor cell and transferred the solution to a container. Next, we added 20 μl of Aptamer at a concentration of 0.6 μM to the container and placed it in an incubator at 37 °C for 90 min. After that, we added 22 μl of malachite green dye (AVONCHEM, UK) to the container and returned it to the incubator at the same temperature for 15 min, as shown in Fig. 3a–d. This precise procedure ensures that the sample is prepared and analyzed under optimal conditions, enabling accurate detection of radon gas and lead ions in human blood samples.

The aptamer-based biosensor used in this study induced a conformational change in the aptamer upon binding with the acid and primer mixture, resulting in the formation of G-quadruplex, a characteristic structure of guanine-rich primers. This technique facilitated accurate detection of lead and radon isotopes with high fluorescence signals. After the incubation period, the sample was transferred to a fluorescence spectrophotometer for the detection of lead and radon isotopes. To create a lead calibration curve, standard lead solutions of varying concentrations (100, 200, 300, 400, 500, and 600 nM) were prepared and measured using a fluorescence spectrophotometer. The correlation coefficient of the resulting calibration curve was 0.978, indicating a strong positive

Fig. 2. a. Radon and lead detection system, b. Chamber with biosensor cell, canary device, and thermometer.

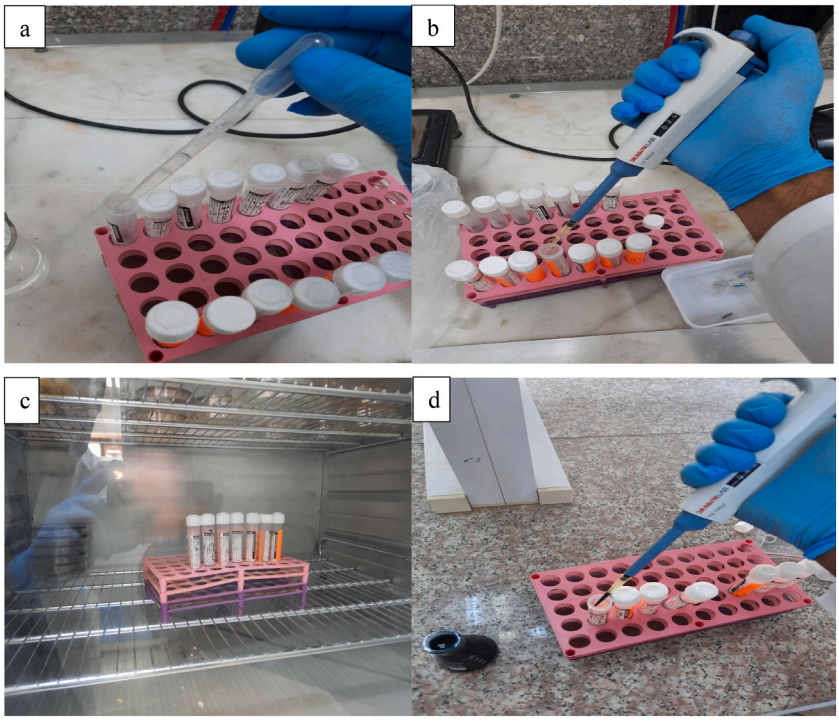

Fig. 3. a–d. Stages and steps of making a biosensor.

Table 2
Radon gas concentration by biosensor.

SC	^{222}Rn (Bqm^{-3})	Pb (ppm)	T_{in} (C°)	T_{out} (C°)	RH%
C_1	7.293	0.0280	21.82	20.75	80.50
C_2	6.809	0.0309	32.00	29.75	79.50
C_3	3.809	0.0364	30.25	26.00	78.50
C_4	6.288	0.0341	21.67	25.00	81.25
C_5	6.181	0.0379	22.30	20.00	82.00
C_6	11.496	0.0515	21.22	20.75	87.75
C_7	6.711	0.0267	21.97	20.25	88.00
C_8	5.770	0.0284	21.10	21.00	88.25
C_9	7.150	0.0297	21.42	20.00	86.00
C_{10}	3.752	0.0276	21.25	20.25	88.25
C_{11}	5.956	0.0271	22.22	20.25	89.25
C_{12}	10.83	0.0302	22.75	20,75	89.50
C_{13}	5.227	0.0341	23.05	21.50	89.00
C_{14}	6.080	0.0299	23.50	22.25	88.50
C_{15}	4.366	0.0442	23.05	22.50	89.25
C_{16}	5.137	0.0335	22.72	21.75	89.50
C_{17}	6.235	0.0393	19.97	21.25	89.75
C_{18}	6.960	0.0304	20.05	19.25	89.50
C_{19}	3.641	0.0402	17.22	19.25	90.25
C_{20}	8.488	0.0436	16.20	17.00	94.25
C_{21}	3.399	0.0254	16.37	16.00	94.00
C_{22}	3.412	0.0266	15.80	16.00	94.00
C_{23}	3.362	0.0291	16.20	14.75	94.50
C_{24}	3.661	0.0287	14.55	15.00	94.00
C_{25}	3.268	0.0282	13.82	13.25	94.25
Avg±SE.	**5.82 ± 0.23**	**0.0329 ± 0.001**	**20.89 ± 0.83**	**20.15 ± 0.80**	**88.38 ± 3.53**
Max	**11.496**	**0.0515**	**32.00**	**29.75**	**94.50**
Min	**3.268**	**0.0254**	**13.82**	**13.25**	**78.50**

SC: Sample Code; **RH**: Relative Humidity; **T**: Temperature.

correlation. The calibration curve is critical for accurately determining the concentration of lead in subsequent experiments and ensuring the reliability of the results.

3. Results and discussion

Table 2 shows the concentration of radon gas by the biosensor (BIOS, consisting of a raw material containing 12 nitrogenous bases of the guanine type), relative humidity (RH%), and temperature (T). A radon value was found by BIOS ranged from 3.268 to 11.496 Bqm-3 in all blood. The lowest radon concentration is 3.268 Bqm^{-3} in sample C25 (healthy person (39 y)) and the highest radon concentration is 11.496 Bqm^{-3} in patient C6 (45 years old). There was a variation in humidity levels during the application of the experiment, which ranged from 78.5% to 94.5%, with an average of 88.38% ± 3.53. Temperature values range from 13.25 °C to 29.75 °C (average 20.15 °C ± 0.80). The lead value is found to be from 0.0254 ppm to 0.0515 ppm. The lowest concentration of lead ion is 0.0254 ppm in the young female, healthy, a non-smoker (32 years old). The highest lead ion is 0.0515 ppm for male has cancer and smoker (45 years old). There was a variation in humidity levels during the application of the experiment, which ranged from 78.5% to 94.5%, with an average of 88.38% ± 3.53. Temperature values range from 13.25 °C to 29.75 °C, average 20.15 °C ± 0.80.

It is important to note that the concentration of radon gas in blood samples can vary depending on several factors, including geographic location, environmental conditions, and individual lifestyle factors. Therefore, the results obtained in this study may not be directly applicable to other populations or regions. However, the use of a biosensor based on guanine-rich primers to detect radon gas in blood samples is a promising technique that can provide accurate and sensitive measurements of radon concentrations. The statistical analysis of the data using ANOVA and Pearson correlation analysis can help to validate the results and provide insights into the relationship between radon concentrations and environmental factors such as temperature and relative humidity. Overall, this study demonstrates the potential of biosensors for detecting radon and other environmental contaminants in biological samples, which can help to improve our understanding of the health effects of exposure to these substances.

The highest level of ^{222}Rn found to be in sample C_6 (male) is probably due to the job in hospital and residential area when he lives. Also, this area is exposure to American bombing in 2003. The lowest concentration of radon may be in C_{25} (39-year-old Female). The level of radon gas concentration in males is higher than in females, the reason is due to the nature of their work. The percentage of environmental pollution, as they are exposed to radiation through their working in hospitals, factories, and on building construction sites. Because of the components of the materials and the percentage of radioactive materials in it. The level of radon gas in building materials is high and it is expected that people working in this field will be to found that the range of radon concentration in smoking ranged between 3.362 and 11.496 Bqm^{-3} with an average of 6.705 Bqm^{-3}. The highest concentration of radon was in the sample C_6 (11.496 Bqm_{-3}) for male patients. The lowest concentration of radon is 3.362 Bqm^{-3} in the sample C_{23} for male healthy smoker. The range of radon concentration in non-smokers was found between 10.83 and 3.268 Bqm^{-3}, with an average of 5.390 Bqm^{-3}. The highest concentration of radon was in sample C_{12} 10.83 Bqm^{-3} for female patients. The lowest concentration of radon was in sample C_{25} (3.268 Bqm^{-3}) for healthy females.

Radon and lead concentration are considered or assessed according to the age of subject (Table 3).

Table 3
Radon gas and lead ion by biosensor with age (patients and healthy).

SC	Age (years)	^{222}Rn (Bqm^{-3})	Pb (ppm)
C_1	58	7.293	0.0280
C_2	6	6.809	0.0309
C_3	57	3.809	0.0364
C_4	77	6.288	0.0341
C_5	51	6.181	0.0379
C_6	45	11.496	0.0515
C_7	52	6.711	0.0267
C_8	47	5.770	0.0284
C_9	50	7.150	0.0297
C_{10}	40	3.752	0.0276
C_{11}	58	5.956	0.0271
C_{12}	51	10.83	0.0302
C_{13}	43	5.227	0.0341
C_{14}	41	6.080	0.0299
C_{15}	16	4.366	0.0442
C_{16}	49	5.137	0.0335
C_{17}	31	6.235	0.0393
C_{18}	65	6.960	0.0304
C_{19}	37	3.641	0.0402
C_{20}	70	8.488	0.0436
C_{21}	32	3.399	0.0254
C_{22}	37	3.412	0.0266
C_{23}	45	3.362	0.0291
C_{24}	47	3.661	0.0287
C_{25}	39	3.268	0.0282
Avg±SE.		**5.82 ± 0.23**	**0.0329 ± 0.0010**

The level of radon concentration in blood samples of cancer patients and healthy people was compared with other studies from different regions in Iraq and other countries as shown in Table 4. Where it was found that the average concentration of radon in the study of cancer patients was (6.628Bqm^{-3}). Higher concentrations than in Iraq, Babylon. And less than Iraq, Karbala, Najaf and Malaysia, Palau Penang. While it was found that the average concentration of radon gas for the healthy sample was (4.541Bqm^{-3}). Higher concentrations than in Babylon and Karbala and less than the concentration of Iraq (Najaf) (Table 4). Comparing the results with previous studies is important to assess the findings of the current study and to provide a better understanding of the levels of radon concentration in different regions. It is important to note that the concentration of radon can vary significantly between different regions and even within the same region due to various factors such as geology, building materials, and ventilation. These findings suggest that the levels of radon concentration in the blood samples of both cancer patients and healthy people in the current study are within the range of what has been reported in previous studies. It is worth noting that the current study used a biosensor to detect radon gas in blood samples, which is a relatively new technique that has shown promising results. However, further studies using larger sample sizes and different detection techniques are needed to confirm the findings of this study and to better understand the levels of radon concentration in different populations (Table 4).

It is important to note that lead exposure can also occur through other sources besides smoking, such as contaminated air, water, soil, and food. The sources of lead in the environment include lead-based paints, leaded gasoline, industrial emissions, and mining activities. Lead is a toxic heavy metal that can accumulate in the body over time, especially in the bones, and can cause various health problems such as anemia, kidney damage, and neurological effects. Therefore, it is important to minimize exposure to lead and implement measures to reduce environmental contamination of this toxic metal. The highest level of lead ion found to be in C_6 (male) is probably due to his job in hospital and residential area when he lives. The lowest concentration of lead ion found to be in C_{21} (32-year-old Female). The highest concentration found in the sample (C_6) for smoker. The lowest concentration of lead found in (C_{21}) for non-smoking female. Fig. 4a and b showed comparing radon gas and lead ion between smokers and non-smokers.

Table 5 shows a comparison of lead levels in blood samples of patients and healthy persons with other studies from different regions in Iraq and other countries. The average lead concentration in the current study for cancer patients was 0.0346 ppm, which is higher than the concentration in Turkey and lower than Nigeria, China, and Egypt. While it was found that the average lead concentration for healthy persons was 0.03027 ppm, which is higher than Turkey and lower than Nigeria, China, and Egypt.

Table 6 shows the Pearson correlation between ^{222}Rn, Pb^{+2}, humidity, and temperature for cancer patients and healthy persons. There is a weak correlation between gender and lead ion concentration, as well as a weak negative relationship between gender and radon concentration and a weak positive correlation between radon and T_{out} and a negative correlation with humidity. There is a strong negative relationship between T_{in} and humidity and a weak positive relationship between lead ion concentration and T_{in}.

Pearson's correlation between ^{222}Rn concentration, humidity, and temperature for cancer patients. There is a weak correlation between radon concentration and humidity, as well as a weak negative relationship between radon concentration and temperature. There is a strong positive correlation between T_{in} and T_{out} and a medium negative relationship with humidity as well as a strong negative relationship between T_{out} and humidity. Pearson's correlation between ^{222}Rn concentration, humidity, and temperature for healthy persons. There is a strong positive correlation between radon concentration and T_{in} and T_{out} and humidity, as well as a strong positive relationship between T_{in} and T_{out}. Also, there is a strong negative relationship between humidity and T_{in} and T_{out}. Pearson's correlation between ^{222}Rn, humidity, and temperature. There is a weak positive correlation between radon, T_{in} and T_{out} as well as negative relationship humidity. Also, a strong positive relationship between T_{in} and T_{out} and there is a strong negative relationship between humidity and T_{in} and T_{out}. Pearson's correlation between ^{222}Rn, humidity, and temperature. There is a weak positive correlation between radon concentration and T_{in} and T_{out} as well as negative relationship humidity and a strong positive relationship between T_{in} and T_{out}. Whereas, a strong negative relationship between humidity and T_{in} and T_{out}. Pearson's correlation between Pb^{+2}, humidity, and temperature. There is a weak correlation between Pb^{+2} and T_{in}, and T_{out}, as well as a weak negative correlation with humidity. There is a strong positive correlation between T_{in} and T_{out}. Whereas, there is a strong negative relationship between humidity and T_{in} and T_{out}. Pearson's correlation between Pb^{+2}, humidity, and temperature. There is a weak correlation negative between Pb^{+2}, T_{in} and T_{out}, as well as a weak positive correlation with humidity and a strong negative relationship between T_{in} and humidity. Whereas, there is a weak positive relationship between T_{out} and humidity. Pearson's correlation between Pb^{+2}, humidity, and temperature. There is a weak correlation positive between Pb^{+2}, Tin and T_{out}. Whereas, a strong positive correlation between T_{in} and T_{out}, as well as a strong negative relationship between Tin, T_{out} and humidity. Pearson's correlations between Pb^{+2}, humidity, and temperature are done. There is a weak correlation positive between Pb^{+2} and T_{in}, as well as a weak negative correlation with humidity. Whereas, there is a strong negative relationship between T_{in} and humidity.

Table 4
Comparison between radon (Bqm^{-3}) of the blood samples of the current study with other studies inside and outside Iraq.

Country	Healthy	Patients	References
Karbala, Iraq	ND	64.30	Hassan et al., 2019 [21]
Najaf, Iraq	7.6	14.5	Zainab, 2021 [22]
Najaf, Iraq	10.96	11.87	Murray and Lopez, 1997 [23]
Babylon, Iraq	1.789	5.890	Tabarek, 2021 [24]
Najaf, Iraq	**4.541**	**6.628**	**This study**

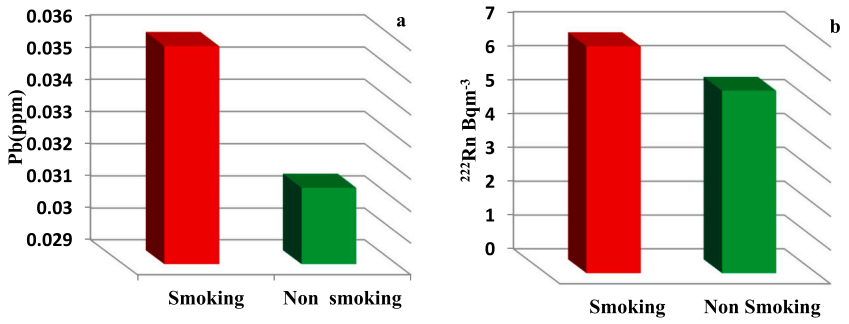

Fig. 4. Comparing between smokers and non-smokers a. Lead ion, b. Radon gas.

Table 5
Comparison between the lead (ppm) from the current study with other countries.

Country	Healthy	Patients	References
Iraq, Najaf	0.0122	0.0129	Alshebly et al., 2019 [25]
Nigeria	0.0500	0.0610	Alatise and Schrauzer, 2010 [26]
China	0.0482	0.0425	Ding et al., 2015 [27]
Egypt	0.2988	0.2336	Hussain et al., 2013 [28]
Turkey	0.0003	0.0007	Demir et al., 2011 [29]
Turkey	0.0003	0.0011	Cobanoglu et al., 2010 [30]
Babylon, Iraq	0.1400	0.0504	Tabarek, 2021 [24]
	0.1266	0.0477	
Dhi Qar, Iraq	0.0017	ND	Mubarak, 2016 [31]
	0.0006	ND	
Najaf, Iraq	0.0334	0.0358	Murray and Lopez, 1997 [23]
Diwaniyah, Iraq	0.10	ND	Abboud and Almayahi [32]
Permissible limit	0.05–0.1		EPA, 2012; CDC, 2012; ATSDR, 2012 [33–35]
Najaf, Iraq	**0.0302**	**0.0346**	**This study**

Table 6
Pearson correlation between^{222}Rn, Humidity, and Temperature.

Pearson Correlation N = 25	Gander	^{222}Rn	T_{in}	T_{out}	RH	Pb^{+2}
Gander	1	−0.296	−0.10	0.21	0.178	0.058
^{222}Rn	−0.29	1	0.27	0.47[a]	−0.25	0.234
T_{in}	−0.10	0.27	1	0.09	−0.82[b]	0.406[a]
T_{out}	0.21	0.47[a]	0.09	1	0.04	0.206
RH	0.17	−0.25	−0.82[b]	0.04	1	−0.214
Pb^{+2}	0.05	0.23	0.40[a]	0.20	−0.21	1

[a] Correlation is significant at the 0.05 level (2-tailed).
[b] Correlation is significant at the 0.01 level (2-tailed).

4. Conclusions

The biosensor used to detect ^{222}Rn in the blood was found to be effective, sensitive, and low-cost, and the levels of ^{222}Rn detected in the blood were within the limits allowed by the WHO. The study also found that pb^{+2} in blood was within permissible limits, and the biosensor was effective in detecting both ^{222}Rn and pb^{+2} in blood. Overall, this study highlights the importance of monitoring ^{222}Rn and pb^{+2} in the blood, especially for individuals working in occupations where they may be exposed to radiation. The biosensor used in this study could provide a useful tool for such monitoring. The main focus of this study is the fabrication of a biosensor capable of detecting radon and lead in human blood samples. The statistical analysis is not the primary focus of this study. The significance of this study lies in the development of a biosensor that can accurately detect these harmful substances, which can have serious health implications. The study provides important insights into the use of aptamers and G-quadruplex structures for detecting radon and lead, and the methods used can be applied in future studies to develop biosensors for other substances as well.

Compliance with ethical standards

This study was approved by the Ethics Committee, University of Kufa. The study protocol was thoroughly explained for using blood samples of peoples and written informed consents were obtained from them prior to participation in the study. This investigation was

done according to the principals of the Declaration of Helsinki. All patients were informed about the aims and protocol of the study.

Author contribution statement

Basim A. Almayahi: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper. Amjad H. Ali: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

No data was used for the research described in the article.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:BASIM ALMAYAHI reports a relationship with University of Kufa Faculty of Sciences that includes: non-financial support. BASIM ALMAYAHI has patent issued to 7864. No.

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