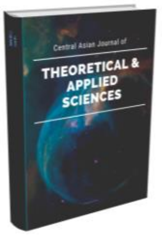

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Article

Applying Inductively Coupled Plasma Optical Emission Spectroscopy to Determine Trace Elements in the Blood of Workers in Radiation Sources

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Abstract: Examining the long-term effects of radiation on workers necessitates taking into account the parameters where even minor adjustments may have a significant impact on the biological system. In this regard, we believe that body trace elements play essential functions. The objective of this study was to examine how occupational exposure affected blood trace element concentrations. in the blood of (30) employees of the Iraqi Radioactive Resources Control Authority who had a deal with radioactive sources, in addition to (20) other administrators working in the central laboratories of the Iraqi Atomic Energy Commission as a control group, had not a history of radiation exposure, the analyses were carried out using optical plasma emission spectroscopy coupled to induction (ICP-OES). All employees and administrators are between (30-64) years old and have worked for at least (15) years. The study was conducted in the Directorate of Central Laboratories at the AL-Tuwaitha site in Baghdad. The study found a significant reduction in iron, and zinc levels among radioactive sources body workers in contrast with the control group, and found a significant increase in Cu in the employees compared with the control while no significant change was observed in manganese and selenium levels. Furthermore, the quality and confidence interval across the future operating characteristics curve was estimated. Specificity and confidence interval of 95% were estimated via the receiver operating characteristic curve (ROC). At the same time, serum manganese level (p-value 0.001) decreased proportionately with longer exposure times, which also showed statistical significance. Age and manganese levels were significantly correlated, but there was no association with the other trace elements. The study provided conclusive evidence of disturbances in the amounts of trace elements in the blood of workers in the Radioactive Sources Authority, which makes them more susceptible to many diseases due to their radiation exposure There was a correlation between trace element disturbances and increasing serving years, which portends the use of more preventive measures and adherence to the principles of radiation protection protocols to reduce the effects of radiation exposure.

Keywords: Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES), Trace elements, Iraqi Radioactive Resources Control Authority

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1. Introduction

Radiation workers were defined as those who were exposed to low levels of radiation due to their occupation. When the occupational radiation dosage is added to the natural background radiation, the accumulated dose may cause health problems [1].

Ionizing radiations affect human health by creating free radicals, breaking down chemical and DNA molecules, inducing apoptosis in growing cells, and so causing malignancies [2]. This radiation exposure has numerous detrimental impacts on cells. Ionizing radiation, which excites atoms and molecules, causes irreversible damage to cells, which vary in size based on radiation dose and time [3]. According to recent studies, high-energy ionizing radiation, like gamma rays, can break up water molecules inside cells, producing extremely reactive radicals like hydroxyl free radicals (OH^-), which can be extremely harmful to cells [4]. These radicals are extremely reactive and readily target biological macromolecules like lipids, proteins, DNA, and enzymes because they have unpaired electrons. This can result in significant cell damage and even death [5].

An element in a sample having an average concentration of less than 100 parts per million, measured in atomic count, or less than 100 micrograms per gram is referred to as a trace element in analytical chemistry. They are necessary for human health, just as vitamins and minerals. Significant changes in physiological activity are caused by small variations in the concentration of a trace element [6]. Trace elements including manganese (Mn), copper (Cu), iron (Fe), zinc (Zn), and selenium (Se) are necessary for vital metabolic reactions in the body and are crucial for human nutrition. The human body uses trace elements for many vital functions. They are primarily structural elements of enzymes; some serve as catalysts in enzyme systems, which are vital for enzyme reactions; others are cofactors, whose functions include immune system support, nutritional deficit prevention, gene expression regulation, antioxidant defense, and the avoidance of chronic diseases [7]. A trace element imbalance can have many dangerous consequences. The majority of human biological functions could be negatively impacted by any modifications to the ideal concentrations of these components. Excessive trace element concentrations can occasionally be harmful to the body's health [8, 9, 10].

Furthermore, a lack of trace elements can cause a variety of health issues, including anemia, anorexia, and slowed wound healing. Deficits in some trace elements have been linked to immunological problems, faster aging, lower antioxidant capability in the organism, and developmental retardation in children [11]. The aim of this study was to compare the concentrations of five important trace elements in the serum of twenty administrators who work in the central laboratories of the Iraqi Atomic Energy Organization employees as the control group and thirty radiation workers in the Iraqi Authority for the Control of Radioactive Sources as the case group.

2. Materials and Methods

Instruments:

A centrifuge (6000 U/min, Germany) was used to separate blood samples. Microwave digestion models were digested using the high-performance Microwave Pigesbon System. The levels of Fe, Cu, Zn, Mn, and Se were measured in Plasma Optical Emission Spectroscopy Inductively Coupled (ICP-OES by using Agilent, 5800, USA).

Chemicals:

Each chemical has been sourced to the highest possible level of purity and from discreet origins, including nitric acid (HNO3 69.72% from THOMAS BAKER). Hydrogen peroxide solution (H2O2 35% from Riedel-de Haen). Standard solutions of copper, lead, cadmium, calcium, zinc, and selenium (Agilent Technologies) (100 mg/L) in HNO_3.

Subjects:

The current study included (30) radiation workers working for the Iraqi Radioactive Resources Control Authority who dealt with radioactive sources, with an age group ranging between (30-64) years, and they were compared with (20) other administrators working in the central laboratories of the Iraqi Atomic Energy Commission as a control group with an age group ranging between (32-60) years and had not a history of radiation exposure. All samples were male and collected for six months from November 2023 to April 2024 in this study, smokers, diabetics, hypertensive patients, and those taking supplements were excluded. The analysis was performed using inductively coupled plasma optical emission spectroscopy (ICP-OES).

Blood Samples Collection:

Every person was given six milliliters of vein blood, which was extracted into gel tubes. The serum that was isolated after centrifuging the blood in gel tubes for ten minutes at 3000 rpm was kept in Eppendorf tubes at -20 °C until analysis.

Methods:

Microwave digestion of models using microwave beams High-performance microwave pigsson system by adding (1 ml) of serum in an acid-washed digestion bowl, then adding (5 ml) of nitric acid, then adding (2 ml) of hydrogen peroxide, then closing the sample container tightly and placing in the digestion device to complete the digestion process according to the following conditions: It started from (20°C to 180°C) in a time of (15) minutes, then lasts for (15) minutes, at (180oC), which is equivalent to a digestion period of (30) minutes, then the models are taken out and left to cool, after which they are filtered into (50 ml) volumetric bottles, then the volume is increased to (50 ml) by adding deionized water, and then the models are measured using a dual plasma induction ICP-OES.

Statistical Examining:

Version 26.0 of the statistical software SPSS was used to analyze the data. The significance of any differences discovered between each group was assessed using a Student's t-test. The data's mean ± standard deviation (SD) was shown. The specificity and 95% confidence interval were computed using the operating characteristics (ROC) curve. For statistical analysis, $p<0.05$ was considered significant, and all p-values were two-tailed.

Table 1. ICP-OES analyses for each element

Element	**Wavelengths (nm)**
Fe	238.204
Mn	257.610
Cu	327.395
Zn	213.857
Se	196.026

Table 2. Common Conditions

Replicate Count	**3**
Nebulizer Pump speed (rpm)	12
Sample uptake time (s)	15
Read time (s)	5
RF Power (KW)	1.2
Nebulizer gas flow (L/min)	0.7
Plasma gas flow (L/min)	12
Aux flow (L/min)	1

3. Results

The descriptive data used in the current study indicates as in Table 3, that there was a significant decrease ($p<0.001$) in the levels of serum iron (Fe) and zinc (Zn) in the blood of workers (0.53±0.29 ppm, 0.0019±0.0.01 ppm) compared to the control group (1.57±1.04 0.0075±0.0064 ppm) respectively, an independent t-test statistical comparison of the two groups revealed a significant difference in the concentrations of iron and zinc ($P<0.01$) as in Fig. 1 and Fig. 4.

Table 3. T-test statistical study for trace elements in control and workers

Parameters	Control (mean ± SD)	workers (mean ± SD)	*p-value*
Fe	1.57±1.04	0.53±0.29	**0.001***
Mn	0.0065±0.0049	0.0087±0.0050	0.138
Cu	0.0256±0.0089	0.0317±0.008	**0.016***
Zn	0.0075±0.0064	0.0019±0.0.01	**0.001***
Se	0.001±0.004	0.0013±0.004	0.795

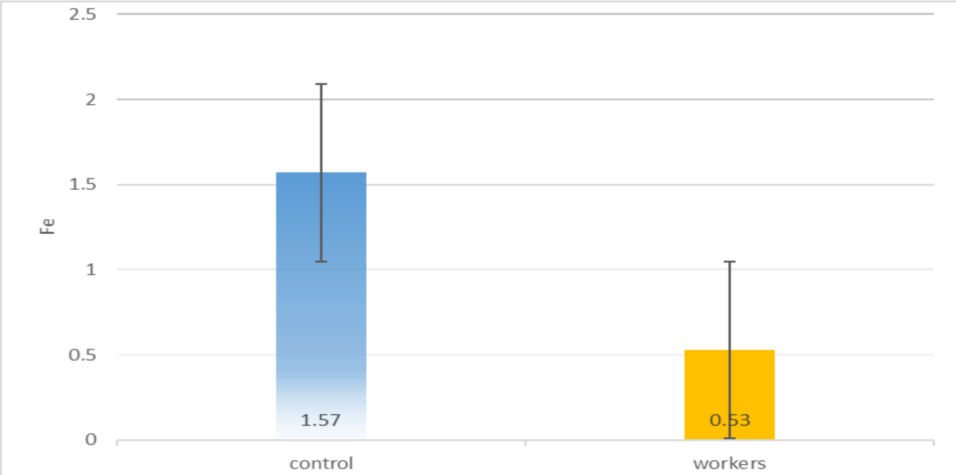

Figure 1. Mean and SD for control and workers for Fe

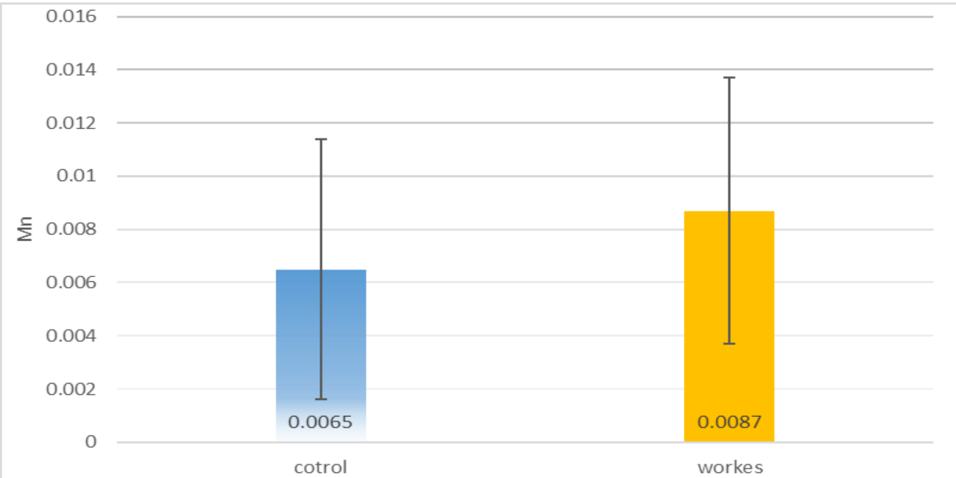

Figure 2. Mean and SD for control and workers for Mn

Also, Table 3 shows the mean concentration of copper, that there was a significant increase in the worker's group compared to the control group (0.0317±0.008) and (0.0256±0.0089) respectively. In this study, we found no significant difference ($p>0.005$) in manganese and selenium in the worker's group compared to the control group (0.0087±0.0050, 0.0013±0.004) and (0.0065±0.0049, 0.001±0.004) respectively as Fig. 2 and Fig. 3.

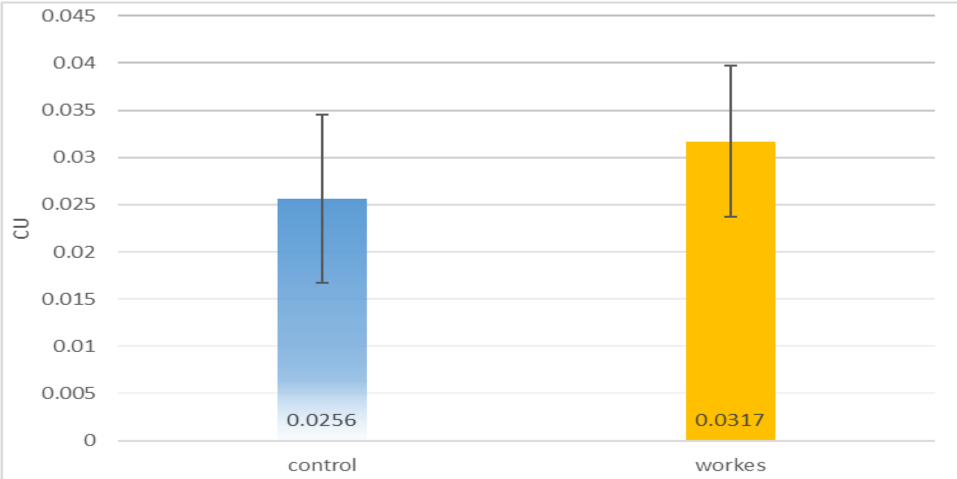

Figure 3. Mean and SD for control and workers for Cu

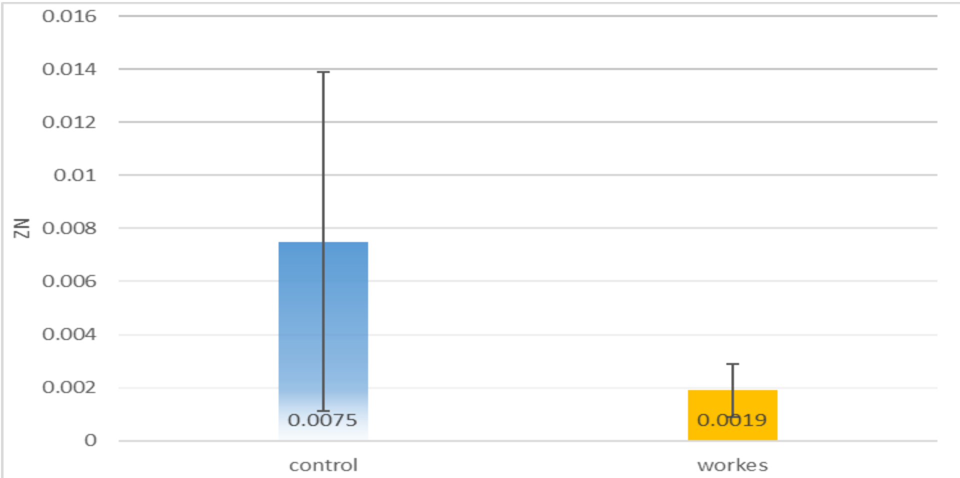

Figure 4. Mean and SD for control and workers for Zn

Table 4. The correlation between the studied trace elements in workers

Variables		Fe	Mn	Cu	Zn	Se
Fe	r	-	-.060	-.153	**-.387***	-.111
	P	-	.754	.420	**.035**	.560
Mn	r	-.060	-	**.744****	.291	**.553****
	P	.754	-	**.000**	.118	**.002**
Cu	r	-.153	**.744****	-	.321	**.736****
	P	.420	**.000**	-	.084	**.000**
Zn	r	**-.387***	.291	.321	-	.117
	P	**.035**	.118	.084	-	.538
Se	r	-.111	**.553****	**.736****	.117	1
	P	.560	**.002**	**.000**	.538	

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

In Table 4 Spearman's test revealed a meaningful significant association at the 0.05 level (2-tailed) for the workers group. We demonstrated a significant correlation at the 0.01 level (2-tailed) between the concentrations of Cu and Mn (r=.744**), between the concentrations of Fe and Zn, level (r=-.387*), and the Pearson test also revealed a significant correlation between the concentrations of Se and Cu (r.736**) = and a significant correlation between the Se and Mn. (r= .553**) as in Fig. 5 Fig. 6, Fig. 7, Fig. 8 and Table 4.

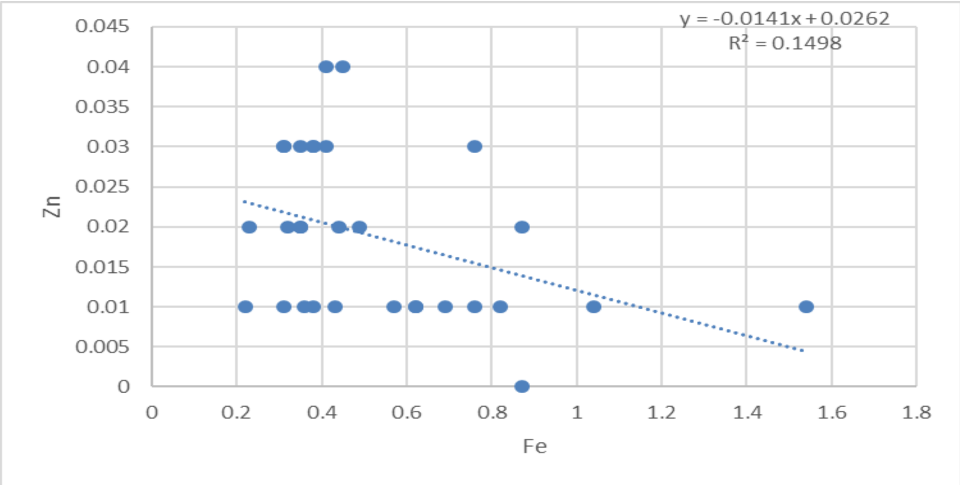

Figure 5. Correlation between Fe and Zn

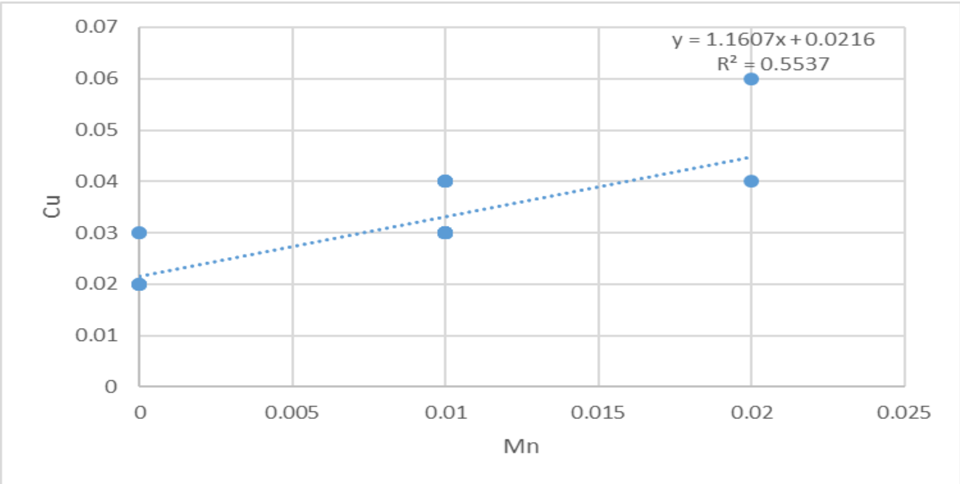

Figure 6. Correlation between Cu and Mn

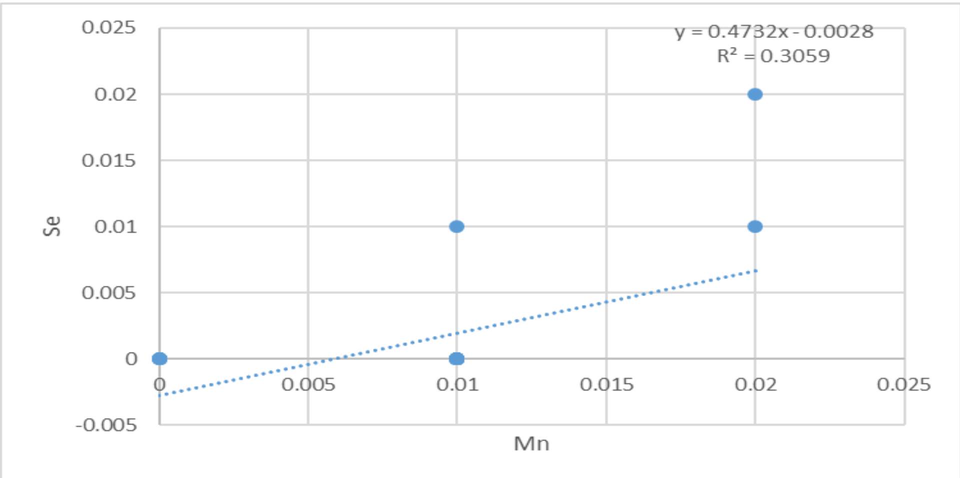

Figure 7. Correlation between Se and Mn

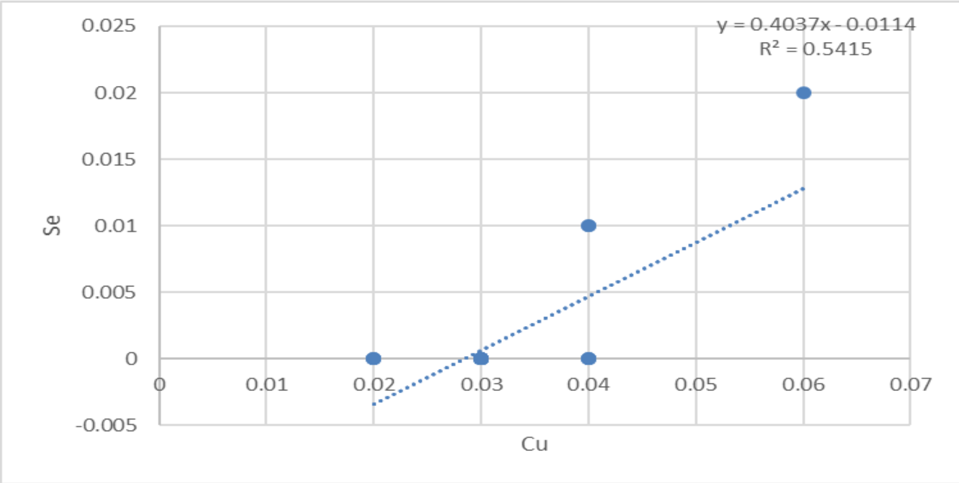

Figure 8. Correlation between Se and Cu

As in Table 5. It also showed the acquired AUC data that serum iron (Fe) might be a more precise predictive biomarker in radiation workers (AUC = 0.901. which means that it has the highest sensitivity (80%) and specificity (77.5%) followed by Zn (AUC= 0.798), Cu (AUC=0.672) has the sensitivity (70%, 70%) and specificity (60%,70%) respectively. as demonstrated in Fig. 9, Fig. 10 and Fig. 11.

Table 5. The significant workers trace elements Parameters ROC outcomes

Parameter	AUC	SE	*p*-value	Cut-off value	Sensitivity	Specificity
Fe	0.901	0.041	<0.001	0.72	80%	77.5%
Mn	0.597	0.082	0.251	-	-	-
Cu	0.672	0.079	0.041	0.3	70%	60%
Zn	0.798	0.062	<0.001	0.1	70%	70%
Se	0.523	0.084	0.782	-	-	-

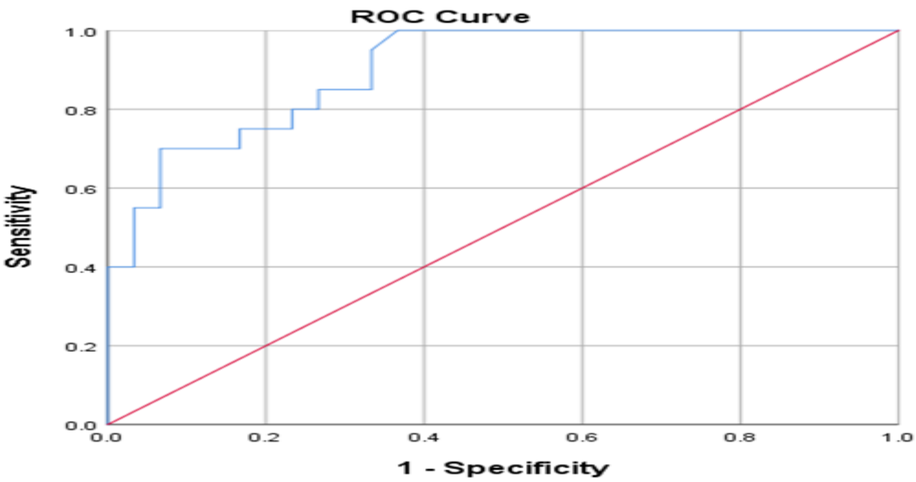

Figure 9. ROC analysis study for Fe

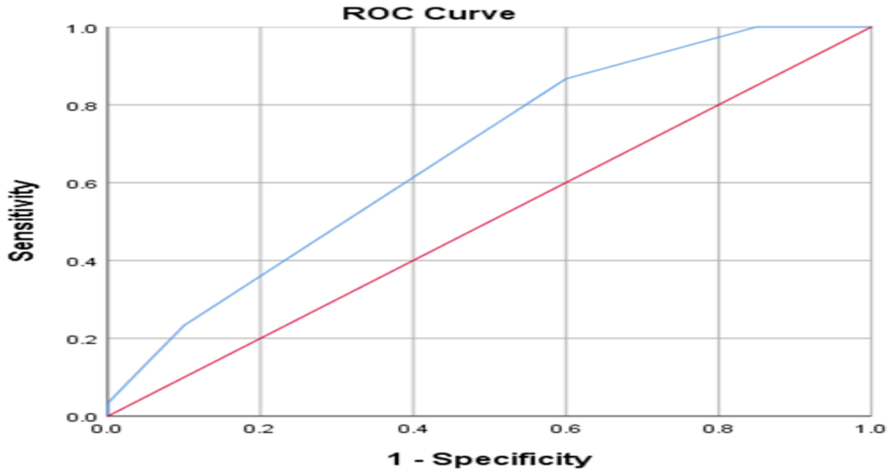

Figure 10. ROC analysis study for Cu

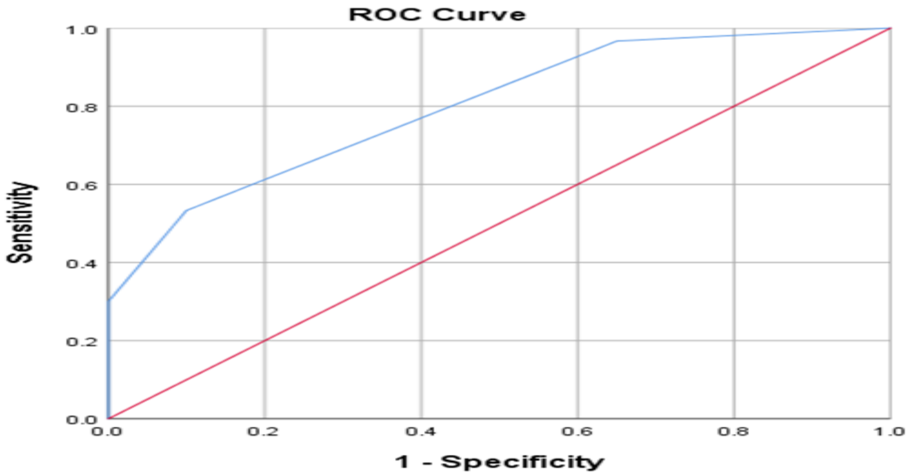

Figure 11. ROC analysis study for Zn

The Pearson test also showed that as the serving years increased, the trace elements decreased and there was a significant correlation between the concentrations of studied trace elements, especially Mn (p-value < 0.05). But there was no significance in rest trace elements, such as iron (p-value > 0.05), Se (p-value > 0.05), Zn (p-value > 0.05), and Cu (p-value >0.05), Table 6 Fig. 12.

Table 6. T-test statistical study for trace elements in workers >15 years and workers <15 years of work

Parameters	**workers <15 years (mean ± SD)**	**workers >15 years (mean ± SD)**	***p-value***
Fe	0.49±0.33	0.57±0.25	0.482
Mn	0.0115±0.0037	0.00657±0.0049	**0.003***
Cu	0.035±0.000088	0.0294±0.0066	0.088
Zn	0.022±0.01	0.016.±0.0.01	0.096
Se	0.0031±0.0063	0.000±0.000	0.104

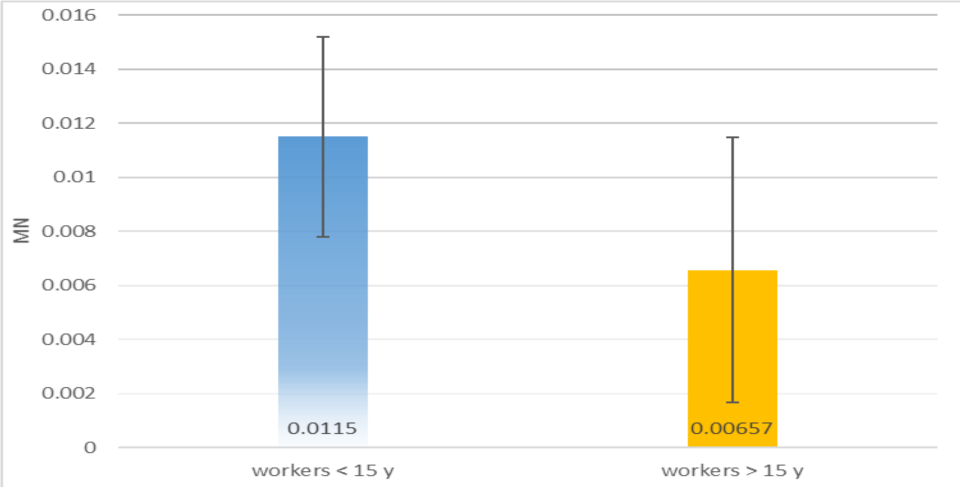

Figure 12. Mean and SD for patients < 15 years and workers >15 years for Mn

Age-related changes in the trace element values The worker's group's concentrations of the trace elements did not significantly correlate with age, according to the results of the Pearson test, except Mn (p-value < 0.05) it was observed that there was a significant change as age increased, as Table 7 and Fig. 13.

Table 7. HSD turkey by ANOVA one-way statistical study for trace elements in workers less than 40 years, workers 40-50 years, and older than 50 years old

Parameters	**workers <40 years (mean ± SD)**	**workers 40-50 years (mean ± SD)**	**workers >50 years (mean ± SD)**	***p-value***
Fe	0.55±0.38	0.52±0.24	0.53±0.28	[a] 0.987 [b] 0.983 [c] 0.999
Mn	0.0122±0.0044	0.0063±0.0052	0.0077±0.0044	**[a] 0.033*** [b] 0.078 [c] 0.768
Cu	0.036±0.0101	0.0275±0.0046	0.0315±0.0069	[a] 0.09 [b] 0.448 [c] 0.469
Zn	0.019±0.009	0.0175.±0.0.0116	0.0192±0.011	[a] 0.962 [b] 0.997 [c] 0.932
Se	0.0044±0.0072	0.000±0.000	0.000±0.000	[a] 0.071 **[b] 0.039*** [c] 1.000

*/a less than 40 vs 40-50 b- less than 40 vs older than 50 c- 40-50 vs older than 50 years' workers.

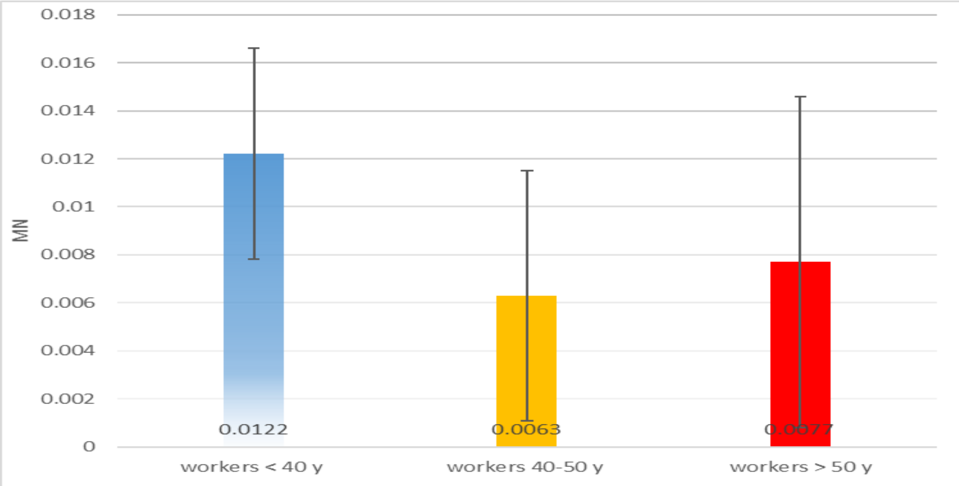

Figure 13. Effect of age on an element Mn

4. Discussion

Trace elements play an important function in maintaining genomic stability within the cell. Trace elements are found in several endogenous defense enzymes, including metalloproteins and superoxide dismutase. Ionizing radiation causes reactive oxidative species (ROS), which these enzymes help the cells detoxify. The main trace elements that guard against DNA damage caused by radiation are zinc, copper, manganese, and selenium. Since the body needs trace elements at very low concentrations to maintain normal physiology, even a small change in these concentrations can have a significant impact on physiological processes. Trace elements in free salt forms provide defense against oxidative stress-induced cell damage. Low quantities can cause substantial harm to the human body [12].

This study was carried out to emphasize the effects of low-dose ionizing radiations on the concentration of various trace elements such as copper, zinc, iron manganese, and selenium in radiation workers. In our investigation, serum copper levels were evaluated and compared to the control group to highlight the potential impacts of low-dose ionizing radiation. The exposed group had high serum copper levels but low serum iron and zinc levels when compared to the controls. Our study also revealed that the duration of the radiation had no inverse relation with serum copper, zinc, or iron and a direct relationship with manganese. It was discovered that there was a significant decrease with an increase in serve years. This disturbance could be associated with chronic exposure to ionizing radiations on trace elements. One more study revealed that the case group's concentration of copper was much higher than that of the control group, which is consistent with the researchers' findings [13, 14].

The results of this study agree with [23] who found a decrease in zinc and an increase in Cu in radiation workers, In addition, this study, like a previous one, demonstrated variations in trace elements in radiology professionals. In comparison to the exposed group, the zinc levels in the control group were greater [15]. Because zinc has antioxidant qualities, low blood zinc levels can therefore result in higher free radical levels, oxidative stress, DNA damage, and eventually cell death. Numerous investigations have demonstrated a connection between rising levels of oxidative stress, oxidative damage, cell death, and falling zinc levels [16, 17].

According to [18], the blood of radiographers had higher iron and lower zinc and copper concentrations when compared to the control group. The blood sample may have contributed to the discrepancy between the current study's results and those of Chatterjee et al. (1994) study, as the latter used whole blood while the current study used blood serum. The study's findings were consistent with those of Ngozyka, O. A. (2019), which found no significant relationship between zinc, iron level, and the age of the worker [19].

This study, however, only looked at manganese that changed with age. Exposure causes free radicals to be produced, which then interact with important components like lipids and modify the cell membrane, which in turn alters the permeability and ion gradient of the membrane. Vitamin C, an antioxidant, can guard against radiation-induced free radicals at low radiation doses, according to prior research on the impact of diet. Vitamin E and albumin can regulate significant reactions in the body brought on by exposure by lowering the activity of free radicals [14].

The study's findings offer compelling evidence that for a long time, radiation exposure puts radiologists at elevated risk for specific disorders, each of which has a unique effect on trace element quantities. To fully understand the relationship between long-time radiation exposure and the amounts of trace elements in human beings, more research is necessary [20].

Radiation workers should implement safety precautions and preventive measures, such as wearing protective clothing and shielding, using beam-limiting devices, and using appropriate beam filtering, based on this study's results. In addition, basic guidelines regarding distance, duration, and shields must be followed to reduce radiation exposure in a work environment [21, 22].

5. Conclusion

Ionizing radiation exposure causes pathophysiological reactions in tissues and cells. DNA damage in cells is mostly caused by radiation-induced ROS and inflammations, which are connected to cell death and genotoxicity. Through a number of mechanisms, including the upregulation of natural defense enzymes and proteins that scavenge free radicals, the modification of cell signaling pathways for DNA repair, and their anti-inflammatory qualities, certain trace elements contribute to the protection against genomic instability brought on by IR.

The findings revealed that workers' average Zn and Fe concentrations decreased while their Cu concentrations increased. The findings also showed that there was a higher chance of long-term exposure impacts on body trace element concentrations and that any dose value might be dangerous. The research yielded definitive proof of anomalies in the trace element concentrations in the blood of radiation workers, which makes them more susceptible to many diseases because of their radiation exposure, it heralds the adoption of more preventative strategies and a dedication to radiation protective procedures' tenets in order to lessen the impacts of radiation exposure.

REFERENCES

[1] P. Okunieff, S. Swarts, P. Keng, W. Sun, W. Wang, J. Kim, ... and L. Zhang, "Antioxidants Reduce the Consequences of Radiation Exposure," in *Oxygen Transport to Tissue XXIX*, pp. 165-178, 2008.

[2] A. Chaparian, I. Tavakoli, and V. Karimi, "Organ Doses, Effective Dose, and Radiation Risk Assessment in Radiography of Pediatric Paranasal Sinuses (Waters View)," *Asian Biomed.*, vol. 7, no. 5, pp. 695-698, 2013.

[3] D. Shahbazi-Gahrouei and M. Abdolahi, "Investigation of Association Between High Background Radiation Exposure with Trace Element Concentrations (Copper, Zinc, Iron, and Magnesium) of Hot Springs Workers' Blood in Mahalat," *Iranian South Med. J.*, vol. 17, no. 4, 2014.

[4] A. Andrey, A. Alexey, Y. S. Medvedeva, I. B. Alchinova, M. Y. Karganov, A. V. Anatoly, and A. A. Nikonorov, "Effect of Short-Term Zinc Supplementation on Zinc and Selenium Tissue Distribution and Serum Antioxidant Enzymes," *Acta Sci. Pol. Technol. Aliment.*, vol. 14, no. 3, pp. 269-276, 2015.

[5] B. Basu and S. K. Apte, "The Gamma Radiation-Induced Proteome of Deinococcus Radiodurans Primarily Targets DNA Repair and Oxidative Stress Alleviation," *Mol. Cell. Proteomics*, vol. 11, no. 1, 2012.

[6] A. K. Ibraheem, M. Z. Thani, and M. T. Mohammed, "Determination of Vitamins, Trace Elements, and Phytochemical Compounds in Ginkgo Biloba Leaves Extracts," *Egypt. J. Chem.*, vol. 66, no. 4, pp. 159-166, 2023

[7] Z. Ullah, M. I. Ullah, S. Hussain, H. Kaul, and K. P. Lone, "Determination of Serum Trace Elements (Zn, Cu, and Fe) in Pakistani Patients with Rheumatoid Arthritis," *Biol. Trace Elem. Res.*, vol. 175, pp. 10-16, 2017.

[8] F. S. Al-Fartusie and S. N. Mohssan, "Essential Trace Elements and Their Vital Roles in the Human Body," *Indian J. Adv. Chem. Sci.*, vol. 5, no. 3, pp. 127-136, 2017.

[9] R. M. El-Gharabawy, M. A. Al-Dubayan, M. S. Alsharidah, A. A. Al-Hadyab, S. A. Alsuhaibani, "Potential Toxic Effects Triggered by Radiation Exposure Among Medical Radiographers Through an Imbalance in Trace Elements and Redox Status," *Poll Res.*, vol. 39, pp. 531-541, 2020. Available: http://www.envirobiotechjournals.com/PR/vol39i32020/Poll%20Res-4.pdf

[10] A. G. Godswill, I. V. Somtochukwu, A. O. Ikechukwu, and E. C. Kate, "Health Benefits of Micronutrients (Vitamins and Minerals) and Their Associated Deficiency Diseases: A Systematic Review," *Int. J. Food Sci.*, vol. 3, pp. 1-32, 2020. [Online]. Available: https://doi.org/10.47604/ijf.1024

[11] V. O. Oyetayo, "Mineral Element Enrichment of Mushrooms for the Production of More Effective Functional Foods," *Asian J. Biol. Sci.*, vol. 16, no. 1, pp. 18-29, 2023.

[12] S. J. Hosseinimehr, "The Protective Effects of Trace Elements Against Side Effects Induced by Ionizing Radiation," *Radiat. Oncol. J.*, vol. 33, no. 2, pp. 66-72, 2015.

[13] A. Ebrahiminia, D. Shahbazi-Gahroui, A. Kargar, and A. Farzan, "Investigation of the Relationship Between Occupational Exposures with Trace Element Concentrations in Radiation Workers in Isfahan," *Sci. J. Ghazvin Univ. Med. Sci.*, vol. 3, pp. 52-8, 2008.

[14] N. Rostampour, T. Almasi, M. Rostampour, H. R. Sadeghi, E. Khodamoradi, R. Razi, and Z. Derakhsh, "Impact of Low-Level Radiation on Concentrations of Some Trace Elements in Radiation Workers," *J. Exp. Ther. Oncol.*, vol. 12, no. 3, pp. 187-192, 2018.

[15] M. M. Niha and M. S. Barough, "The Effect of Gamma Radiation on Plasma Levels of Zinc and Selenium in Nuclear Medicine Staff," *J. Shahrekord Univ. Med. Sci.*, vol. 21, no. 1, pp. 51-56, 2018.

[16] R. Seth, R. S. Corniola, S. D. Gower-Winter, T. J. Morgan Jr, B. Bishop, and C. W. Levenson, "Zinc Deficiency Induces Apoptosis via Mitochondrial p53- and Caspase-Dependent Pathways in Human Neuronal Precursor Cells," *J. Trace Elem. Med. Biol.*, vol. 30, pp. 59-65, 2015.

[17] B. Zhu, J. Wang, F. Zhou, Y. Liu, Y. Lai, J. Wang, ... and Z. C. Hua, "Zinc Depletion by TPEN Induces Apoptosis in Human Acute Promyelocytic NB4 Cells," *Cell. Physiol. Biochem.*, vol. 42, no. 5, pp. 1822-1836, 2017.

[18] J. Chatterjee, B. B. Mukherjee, K. De, A. K. Das, and S. K. Basu, "Trace Metal Levels of X-Ray Technicians' Blood and Hair," *Biol. Trace Elem. Res.*, vol. 46, pp. 211-227, 1994.

[19] O. A. Ngozyka, O. E. Chukwuemeka, M. E. Philippe, and I. Maurice, "Assessment of Heavy Metal Levels in the Blood of Metal Fabricating Factory Workers in Nnewi, Nigeria," *Santosh Univ. J. Health Sci.*, vol. 5, no. 1, pp. 18-23, 2023.

[20] J. Boice Jr, L. T. Dauer, K. R. Kase, F. A. Mettler Jr, and R. J. Vetter, "Evolution of Radiation Protection for Medical Workers," *Br. J. Radiol.*, vol. 93, no. 1112, p. 20200282, 2020.

[21] O. Lakhwani, V. Dalal, M. Jindal, and A. Nagala, "Radiation Protection and Standardization," *J. Clin. Orthop. Trauma*, vol. 10, pp. 738-743, 2019. [Online]. Available: https://doi.org/10.1016/j.jcot.2018.08.010

[22] S. M. Ridzwan, L. Fritschis, and N. Bhoo-Pathyi, "Radiation Safety and Radiation Monitoring Practices Among Medical Radiation Workers in Malaysia," *Int. J. Radiat. Res.*, vol. 21, no. 3, pp. 459-468, 2023.

[23] A. J. Ibrahim, "The Determination and Evaluation of Trace Elements in the Blood of Radiography Workers Using Graphite Furnace Atomic Absorption Spectrometry," *Anal. Methods Environ. Chem. J.*, vol. 7, no. 1, pp. 76-85, 2023.