Hilla University College Journal For Medical Science

Manuscript 1113

Evaluation of the Oxidative Effect of Magnetic Resonance Imaging (MRI) on Patients With Type 1 Diabetes, With and Without the Use of Gadolinium Contrast Agent

Dunya Ali Mustafa

ORIGINAL STUDY

Hilla Univ Coll J Med Sci

Evaluation of the Oxidative Effect of Magnetic Resonance Imaging (MRI) on Patients With Type 1 Diabetes, With and Without the Use of Gadolinium Contrast Agent

Dunya Ali Mustafa

Radiological Techniques Department, College of Health and Medical Techniques - Baghdad, Middle Technical University, Baghdad, Iraq

Abstract

Background: Type-1 diabetes (T1D) is one of the most prevalent chronic autoimmune diseases, which is characterized by the progressive destruction of insulin-secreting β cells. Evidence indicates that repeated or high-dose exposure to Gadolinium-Based Contrast Agents (GBCAs) during MRI can result in long-term tissue deposition and increased oxidative stress.

Objectives: This study aimed to estimate the oxidative effects of MRI exposure in patients with type-1 diabetes, before and after gadolinium contrast, for different time intervals, using cyclic voltammetry (CV) as an electrochemical analysis tool.

Materials and Methods: The study was performed at Ghazi Al-hariri Hospital in Baghdad, Iraq, from January to July 2025. It included (30) type-1 diabetic patients (15 males and 15 females), with ages ranging from (30–50) years. The patients were divided into three groups: 10 patients were not injected with GBCAs and were exposed to MRI for (5–50) minutes, 10 patients were injected with GBCAs and exposed to MRI for the same duration, and 10 patients were not exposed to MRI.

Results: The results showed a difference in the oxidation current peak (ΔIpa) suggesting that oxidative stress increased as exposure to MRI increased. Furthermore, patients injected with gadolinium had double this effect. This increase in ΔIpa occurred after 35 minutes of exposure. However, patients who were not exposed to MRI had no oxidative stress.

Conclusion: MRI exposure for a long time, particularly in patients who had type 1 diabetes and were injected with gadolinium, will significantly increase oxidative stress.

Keywords: Magnetic resonance imaging, Type 1 diabetes, Gadolinium contrast, Oxidative stress, Cyclic voltammetry, Radio frequency

1. Introduction

Type 1 diabetes mellitus (DMT1) is a chronic disease characterized by insulin deficiency and increased oxidative stress due to the destruction of pancreatic beta cells by autoimmunity, leading to chronic hyperglycemia [1, 2]. This condition arose as a result of an imbalance between reactive oxygen species (ROS) and antioxidants [3]. In the diagnostic context, although high accuracy is provided by magnetic resonance imaging, as it is a non-invasive technique that produces high-resolution images [4], but strong magnetic fields and radiofrequency waves with the use of gadolinium may lead to oxidative and reduction imbalances [5, 6] due to changes in the cellular state resulting from exposure to electromagnetic fields (EMFs), although this result is still controversial and depends largely on the strength and duration of the field [7].

Received 27 February 2026; revised 11 May 2026; accepted 12 May 2026.
Available online 20 June 2026

E-mail address: dunya.ali@mtu.edu.iq (D. Ali Mustafa).

https://doi.org/10.62445/2958-4515.1113

Several studies have indicated that electromagnetic fields may alter the redox balance, especially in diabetic patients [8], and in those with impaired kidney function who already suffer from reduced oxidative capacity [9–11]. Despite the ongoing debate about the severity of these effects and their dependence on the period of time, the need for precise monitoring techniques is highlighted. Cyclic voltammetry is emerging as a method for analyzing oxidation-reduction changes and monitoring peak current in blood samples [12]. This technology has a high ability to detect the electrical activity of biochemical reactions instantly during the imaging process [13, 14]. The study purpose was to estimate the oxidative effects of MRI exposure in patients with type-1 diabetes, before and after gadolinium contrast, for different time intervals, using cyclic voltammetry (CV) as an electrochemical analysis tool.

2. Patients and methods

2.1. Study design and patients

In this study, 30 type-1 diabetes patients, 15 males and 15 females, aged (30–50) years, were examined by MRI at Ghazi Hariri Hospital/Medical City Complex in Baghdad, Iraq, from January to July 2025. The 30 patients were divided into three groups as follows:

Group A: 10 patients with type 1 diabetes (receiving insulin injections) were exposed to magnetic fields and radiofrequencies for different periods of time (5, 10, 15, 20, 25, 30, 35, 40, 45, and 50) minutes without using the contrast medium.

Group B: 10 patients with type 1 diabetes (receiving insulin injections) were injected with 20 ml of gadolinium and exposed to magnetic fields and radiofrequencies for different periods of time (the same as before).

Group C: 10 patients included the control group without exposure to magnetic fields.

The study was a paired design with repeated measures, and the experimental protocol used in the study involved collecting blood samples from the same patient at multiple times (at ten time intervals (5, 10, . . . 50 minutes) during the MRI examination). To establish a clear correlation between MRI exposure and chemical changes, a blood sample was taken from the patient during MRI exposure; the patient was injected with a gadolinium contrast agent (Group B). The patient was then exposed to MRI at a magnetic field strength of 1.5 Tesla. During this time, a timer was used to track the exposure time, and blood samples were drawn at minutes 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50. The patient remained inside the MRI machine at this time. Each sample was immediately sent for electrochemical analysis to prevent any external oxidation, and each sample was labeled to prevent sample similarity. Therefore, any chemical changes, specifically oxidation and reduction, that can occur in the blood and within the same biological environment were assessed.

The three groups of patients (except group C) were examined in an MRI type Philips with 1.5 tesla using standardized clinical protocols. These protocols consisted of T1 and T2-weighted (TSE) sequences. The operating strength of the gradient system was 33 mT/m, with a variable rate of 120 T/m/s. To monitor the biological effects of radiofrequency energy, the whole-body specific absorption rate (SAR) was maintained below 2.0 W/kg. The SAR was restricted to its normal operating state, in accordance with the International Electrotechnical Commission (IEC) guidelines. These parameters were maintained to minimize thermal fluctuations and to standardize energy deposition within the study. 10 ml of venous blood was taken from each patient to be examined by cyclic voltammetry. To ensure a comparison, samples were obtained from the control group (Group C) and analyzed for the same time periods as the other groups, from (5 – 50) minutes, but without injecting the contrast agent or undergoing MRI. Several factors, such as glycated hemoglobin (HbA1c) levels, kidney function, and the duration of diabetes, that may influence oxidative stress were controlled by holding these parameters constant during MRI scans using a repeated-measures design across individuals. This design neutralized clinical differences and long-term medication history, allowing each individual to act as a self-control. Patients with metabolic disorders and significant renal impairment, as well as those taking antioxidant supplements, were excluded to maintain the homogeneity of the study group and to avoid interventions that could affect oxidative stress levels.

2.2. Statistical analysis

The statistical analyses for the study were conducted using SPSS software (Version 20). Quantitative data were expressed as the mean and standard deviation. Among the analyses used was a repeated-measures ANOVA to compare the differences resulting from the peak current of the three groups over time, in addition to calculating the effect size (partial eta squared) with the observed power to show the adequacy of the sample size. Non-linear regression analysis was used to find the difference between the time of exposure and the current change (ΔIpa). The value of $P < 0.05$ was considered to be statistically significant.

Table 1. Demographic distribution of patients (N = 30).

Demographical data	Ranking and Intervals	Frequency	Percentage %
Age (years)	30–35	7	23.4 %
	36–45	15	50.0 %
	46–50	8	26.6 %
	Total	30	100%
Gender	Male	15	50 %
	Female	15	50 %
	Total	30	100%

Table 2. The relationships between levels of current peak among the experimental groups and time points.

Factors	Mean square	df	F	Sig	Partial Eta Squared	Observed Power
Time	2497.161	10	658601.738	<0.001	1.000	1.000
Between Groups	31146.655	2	6,394,865.5	<0.001	1.000	1.000
Time* Group	2498.225	20	658,882.348	<0.001	1.000	1.000

3. Results and discussion

The (30) study sample participants were evenly distributed between males and females 15 (50%) each. The highest rate (50%) of patients was in the age group (36–45) years, followed by (26.6%) in the age group (46–50) years, then (23.4%) in the age group (30–35) years. This distribution suggests that the sample primarily represented middle-aged adults, which may influence the generalizability of the results to other age groups, as shown in Table 1.

Table 2 demonstrates that the results were not a coincidence because the results proved that the time factor plays a role in increasing the peak current level for the experimental groups. This indicates that increasing exposure time leads to electrochemical changes, meaning that time has a highly statistically significant effect ($F = 658{,}601.7$, $p < 0.001$), which displays substantial fluctuations in current measurements across the time points. It was also found that there are significant differences between subjects' effects ($F = 6{,}394{,}865.5$, $P < 0.001$); this demonstrates that the three groups have different and unequal current levels.

This proves that the blood of the control group has an electrical signal that differs from the signal in the presence of T1DM, and adding the contrast agent immediately changed the chemical state of the blood, causing each group to start from a different baseline level. Furthermore, the results showed a clear statistical significance ($P < 0.001$) between time and groups, with an ($F = 658{,}882.3$). This suggests that the oxidation current pattern was not uniform between groups but rather resulted from the presence of the contrast agent, which led to a deviation in the results compared with the control group. The adequacy of the sample size was also assessed using post-hoc power analysis, which revealed a maximum observed power of 1.000 for all tests, in addition to a partial eta-squared effect size of 1.000. These results demonstrate a large effect size and full test power, indicating that the sample size used ($n = 10$) was sufficient for the test and ideal for identifying statistically significant differences. Consequently, the results are reliable and protected from the risk of statistical error.

The results showed that there are distinct contrast patterns between the behavior of the blood sample containing insulin without contrast (black line) and the behavior of the blood sample with contrast (green line) when exposed to magnetic resonance imaging for specific time periods. This indicates that the electromagnetic properties of the blood samples change in the presence of the contrast agent gadolinium, as shown in (Figs. 1 to 3). The metabolic processes of the human body are affected by electromagnetic waves, as these fields cause a disruption in the chemical composition of tissues, thus causing changes in oxidation and reduction levels within the body as a result of exposure to electromagnetic waves for a period of time [15].

The results showed a difference in peak oxidative current (ΔIpa) between samples containing the contrast agent gadolinium and those without. This difference gradually increased with increasing exposure time to electromagnetic waves, reaching a high of ΔIpa of 18 at minute 50, as shown in (Table 3). Fig. 4 illustrates a non-linear relationship between ΔIpa and time, suggesting that the electromagnetic waves used in MRI may affect the electrochemical behavior of blood, thereby increasing oxidative stress. This, in turn, may impact blood characteristics in some patients, including those with type 1 diabetes [16].

The observed changes in the peak oxidative current (ΔIpa) over time indicate that prolonged exposure to MRI conditions alters electrochemical behavior. This is consistent with the studies conducted by Simkó & Mattsson, 2019 and Okano, 2008 [17, 18], who demonstrated that an increase in oxidative current is due to

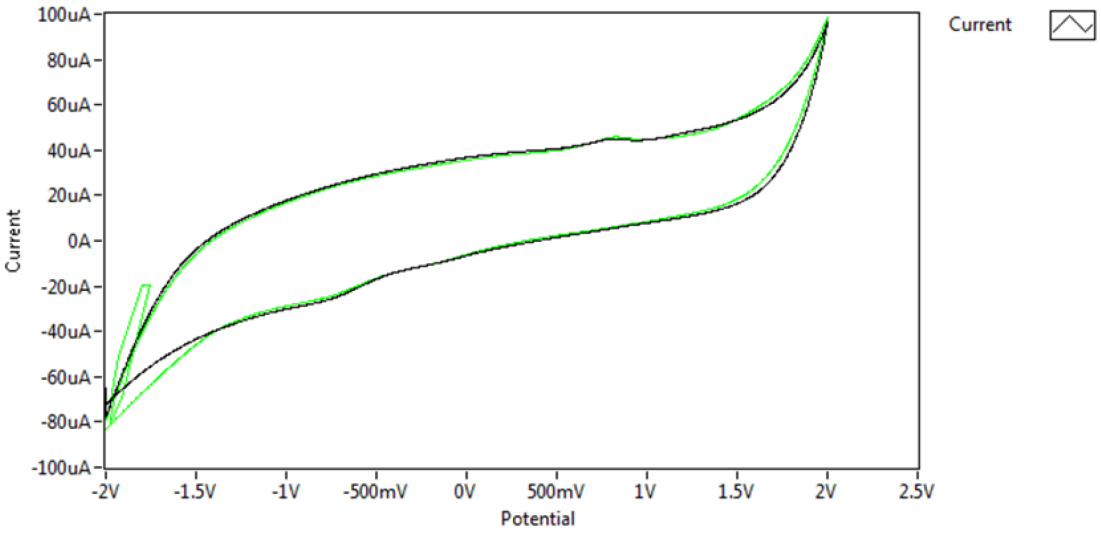

Fig. 1. Cyclic voltammogram of blood with insulin from a diabetic type 1 sample (black line) and with gadolinium contrast agent (green line) after 5 min. Exposure to the magnetic field and radiofrequency of MRI.

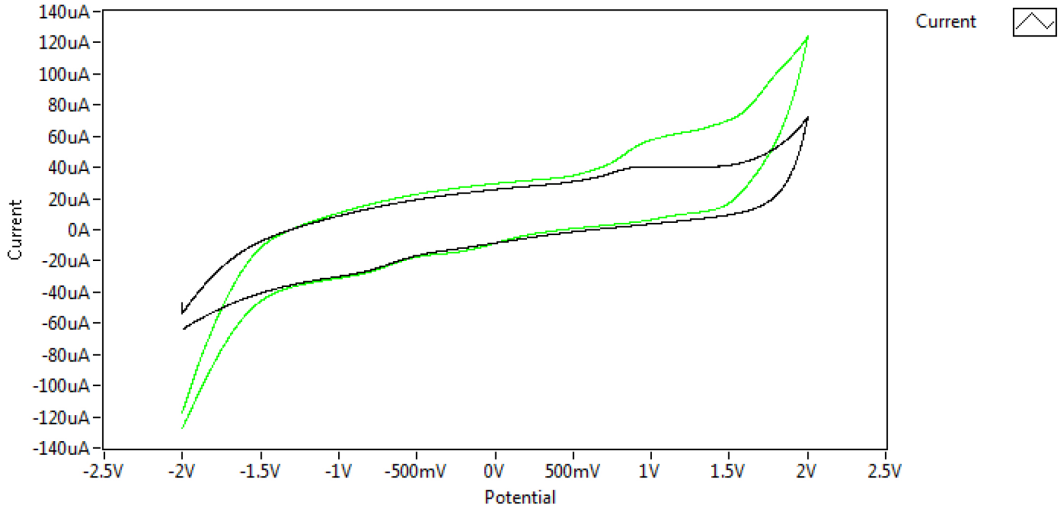

Fig. 2. Cyclic voltammogram of blood with insulin from a diabetic type 1 sample (black line) and with gadolinium contrast agent (green line) after 50 min. exposure to the magnetic field and radiofrequency of MRI.

Table 3. Relationship between different exposure time in the magnetic field and radiofrequency of MRI and effect of oxidation current peak of diabetic blood samples of type 1 with and without contrast agent (gadolinium agent).

Time (Min)	ΔIpa (with contrast-without contrast)	mean ± SD	Time Range	Number of replicates
5	1	5.8 ± 5.023	May-50	10
10	2			
15	2.5			
20	3			
25	4			
30	5			
35	6			
40	6.5			
45	10			
50	18			

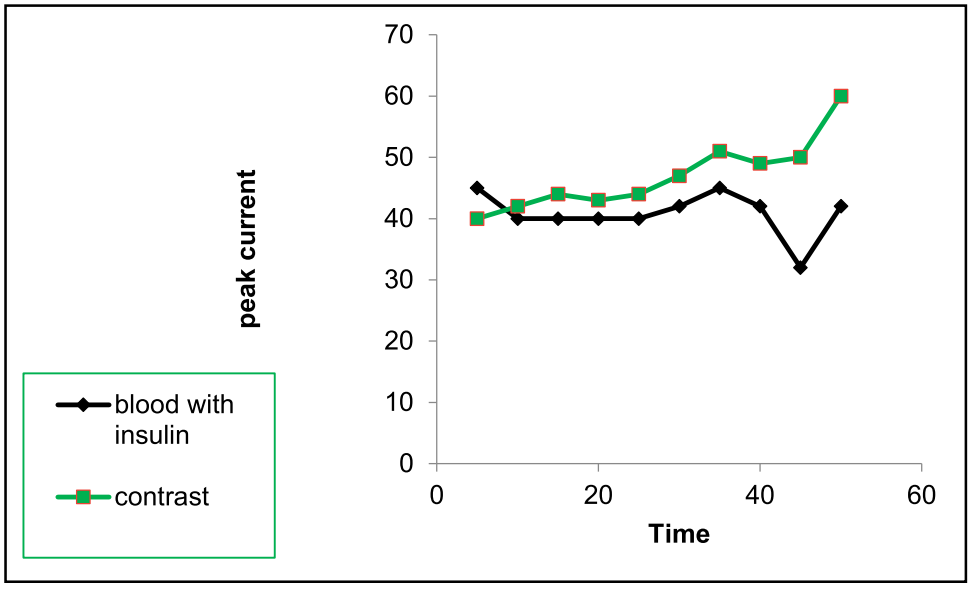

Fig. 3. Electrochemical analysis of the enhancement of current peak of blood with insulin in a diabetic type 1 sample and with gadolinium contrast agent.

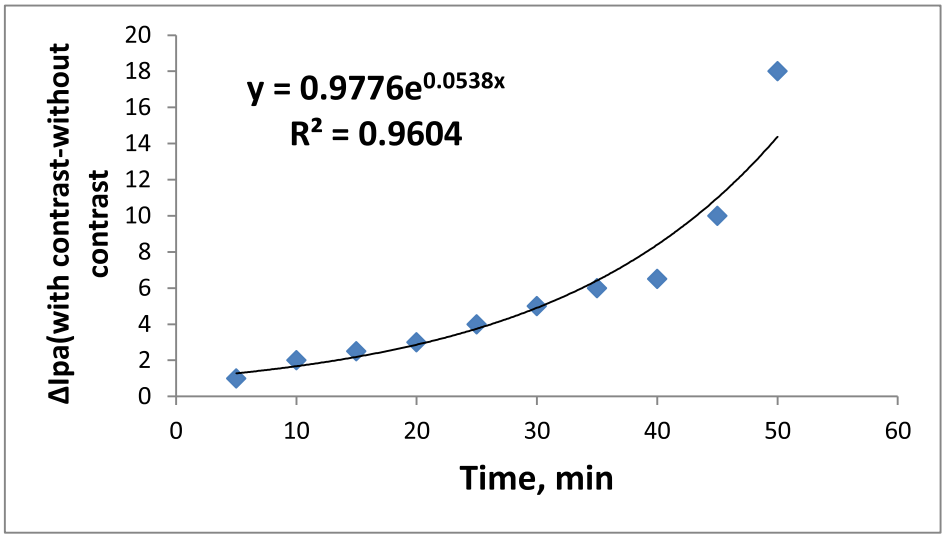

Fig. 4. Plot the ΔIpa (with contrast-without contrast) against the exposed time of the magnetic field and the radiofrequency of MRI

increased exposure to electromagnetic waves, which alters ion transport during redox and thus affects redox reactions in biological systems. Oxidative stress in blood cells, induced by radiofrequency fields from MRI, was represented by increased ΔIpa values in the study.

The results showed that an electrochemical reaction occurred between blood samples with gadolinium. These results were consistent with Rogosnitzky & Branch [19], who found that gadolinium contrast agents have the strength to make interaction molecules that cause changes in the redox state of cells. In addition, Kanda et al. found that biochemical changes can occur due to the remaining gadolinium within tissues; this establishes that gadolinium may alter the characterization of blood in the examination of MRI [20]. This is consistent with present results, which found that the value of the oxidation current ΔIpa increased when exposed to electromagnetic waves for a certain period, especially after 35 minutes. Therefore, it is necessary to understand the accumulation of gadolinium [21–23] and to conduct more research on the effects resulting from the accumulation of the contrast agent gadolinium in the body and its effect on human life.

Finally, the study found that the electrochemical properties, such as oxidation and reduction processes, in type 1 diabetic patients' blood were affected

by electromagnetic waves resulting from magnetic resonance imaging for a period of (5 to 50 minutes) especially when gadolinium is present in the blood.

4. Conclusion

The study demonstrated a strong correlation between increased MRI exposure time and oxidative stress levels, as reflected in peak current measurements. The study showed a high, statistically significant difference in oxidative stress over time; mean, despite the small sample size, the mean was able to detect this relationship. The study also indicated that oxidative stress is significantly affected in the MRI environment, particularly with the use of gadolinium as a contrast agent. However, MRI cannot be considered a definitive cause of increased oxidative stress due to the absence of certain biomarkers, such as glutathione, superoxide dismutase (SOD), and malondialdehyde (MDA), which play a crucial role in identifying biochemical pathways. Therefore, future research incorporating these biomarkers is recommended to monitor the pathophysiology of MRI-induced oxidative stress and track peak current levels in the clinical setting to confirm the diagnosis.

Ethical issue

This study has been approved by the college's scientific committee, and all patients have given their informed consent to the study after receiving a thorough explanation of the study, with all patient data and confidential information kept strictly confidential.

Acknowledgement

I would like to thank Dr. Muhammad Mizhar Radhi for help in this work. I also thank the Radiology Techniques Department/Medical City-Baghdad/Iraq for their assistance in conducting this research.

Information about the source of funding

No source of funding.

Conflicts of interest

The author affirms no conflicts of interest.

References

1. Jain S, McVie R, Bocchini Jr. Hyperketonemia (ketosis), oxidative stress and type 1 diabetes. Pathophysiology. 2006;13(3):163–170. https://doi.org/10.1016/j.pathophys.2006.05.005.
2. Baynes JW. Role of oxidative stress in development of complications in diabetes. Diabetes. 1991;40(4):405–412. https://doi.org/10.2337/diab.40.4.405.
3. Giacco F, Brownlee M. Oxidative stress and diabetic complications. Circulation Research. 2010;107(9):1058–1070. https://doi.org/10.1161/CIRCRESAHA.110.223545.
4. Scarciglia A, Papi C, Romiti C, *et al.* Gadolinium-based contrast agents (GBCAs) for MRI: A Benefit–Risk balance analysis from a chemical, biomedical, and environmental point of view. Global Challenges. 2025;9(3):2400269. https://doi.org/10.1002/gch2.202400269.
5. Formica D, Silvestri S. Biological effects of exposure to magnetic resonance imaging: An overview. Biomedical engineering online. 2004;3(1):11. https://doi.org/10.1186/1475-925X-3-11.
6. Kangarlu A, Robitaille L. Biological effects and health implications in MRI. Magnetic Resonance Imaging Clinics of North America. 2000;8(4):731–748. https://doi.org/10.1002/1099-0534(2000).
7. Simko M, Mattsson O. Extremely low frequency electromagnetic fields as effectors of cellular responses in vitro: Possible immune cell activation. Journal of Cellular Biochemistry. 2004;93(1):83–92. https://doi.org/10.1002/jcb.20198.
8. Bhattacharya E., Mandal M, Bhattacharya D. Effects of microwave radiation on human brain: The positives and negatives. European Journal of Engineering and Technology Research. 2022;7(1):25–30. https://doi.org/10.24018/ejeng.2022.7.1.2650.
9. Darrah T, Prutsman-Pfeiffer J, Poreda R, *et al.* Incorporation of excess gadolinium into human bone from medical contrast agents. Metallomics. 2009;1(6):479–488. https://doi.org/10.1039/b905145g.
10. Perazella M. Current status of gadolinium toxicity in patients with kidney disease. Clinical Journal of the American Society of Nephrology. 2008;4(2):461–469. https://doi.org/10.2215/CJN.06011108.
11. Grobner T. Gadolinium—A specific trigger for the development of nephrogenic fibrosing dermopathy and nephrogenic systemic fibrosis? Nephrology Dialysis Transplantation. 2006;21(4):1104–1108. https://doi.org/10.1093/ndt/gfl294.
12. de Oliveira G, da Silveira Alvares T, de Siqueira Melo R. Electroanalytical methods as a tool for determining the antioxidant capacity in blood samples. The Journal of Engineering and Exact Sciences. 2024;10(8):20793–20793. https://doi.org/10.18540/jcecvl10iss8pp20793.
13. Wang H, Bringans C, Hickey A, *et al.* Cyclic voltammetry in biological samples: A systematic review of methods and techniques applicable to clinical settings. Signals. 2021;2(1):138–158. https://doi.org/10.3390/signals2010012.
14. Terán-Alcocer Á, Bravo-Plascencia F, Cevallos-Morillo C, *et al.* Electrochemical sensors based on conducting polymers for the aqueous detection of biologically relevant molecules. Nanomaterials. 2021;11(1):252. https://doi.org/10.3390/nano11010252.
15. Radhi M, Moosa A, Kareem N, *et al.* Effect of different temperatures as electrochemical behaviour of paracetamol using nano sensor of modified electrode. Journal of The Electrochemical Society. 2025;172(5):057518. https://doi.org/10.1149/1945-7111/addb83.
16. Radhi M, Hassoon J, Obaid A, *et al.* Effect of aspirin nanoparticles as a safer anti-gastric ulcer agent in a blood medium: An electrochemical approach, Journal of The Electrochemical Society. 2025;172(6):067519. https://doi.org/10.1149/1945-7111/ade346.
17. Simkó M, Mattsson O. Extremely low frequency electromagnetic fields as effectors of cellular responses in vitro: Possible immune cell activation. Journal of Cellular Biochemistry. 2019;93(1):83–92. https://doi.org/10.1002/jcb.20198.
18. Okano H. Effects of static magnetic fields in biology: Role of free radicals. Front Biosci, 2008;13(1):610–25. https://doi.org/10.2741/3141.
19. Rogosnitzky M, Branch S. Gadolinium-based contrast agent toxicity: A review of known and proposed mechanisms.

Biometals, 2016;29(3):365–376. https://doi.org/10.1007/s10534-016-9931-7.
20. Kanda T, Oba H, Toyoda K, *et al.* Gadolinium retention in the brain after administration of contrast agents. Radiology. 2016;37(1):E1–E2. https://doi.org/10.3174/ajnr.A4586.
21. Ramalho M, Ramalho J, Burke M, *et al.* Gadolinium retention and toxicity—An update. Advances in Chronic Kidney Disease. 2017;24(3):138–146. https://doi.org/10.1053/j.ackd.2017.03.004.
22. Kanda T. The new restrictions on the use of linear gadolinium-based contrast agents in Japan. Magnetic Resonance in Medical Sciences. 2019;18(1):1–3. https://doi.org/10.2463/mrms.e.2017-0176.
23. Dekkers A, Roos R., van der Molen J. Gadolinium retention after administration of contrast agents based on linear chelators and the recommendations of the European medicines agency. European radiology. 2018;28(4):1579–1584. https://doi.org/10.1007/s00330-017-5065-8.