

A new compact CPW-UWB antenna for advanced healthcare monitoring applications

Yaqeen S. Mezaal¹, Nora H. Sultan², Jaafar A. Aldhaibani³, Maryam S. Jameel⁴

^{1,3,4} College of Engineering, University for Information Technology and Communications, Baghdad, Iraq

² University of Kufa, Kufa, Iraq

Corresponding author E-mail: Yaqeen.mezaal@uoitc.edu.iq

Received Sep. 3, 2024

Revised Jan. 30, 2024

Accepted May. 16, 2025

Online Jul. 7, 2025

Abstract

This paper presents the design and simulation for a microstrip antenna, specifically designed to operate within the ultra-wideband (UWB) frequency range of 3.4226 GHz to 13.4 GHz. The antenna employs a coplanar waveguide (CPW) feeding technique and features a slotted patch mounted on an FR4 substrate. The findings of this study indicate that the antenna effectively spans the entire UWB frequency spectrum, achieving an operational bandwidth of 9.9774 GHz while upholding an input reflection coefficient of less than -10 dB. Notably, this design exhibits bidirectional radiation patterns, distinguishing it from traditional planar or microstrip patch antennas. Its lightweight construction, advantageous emission characteristics, and broad frequency range render this compact antenna highly suitable for various medical applications, including Wireless Body Area Networks (WBANs) and healthcare stations. Accordingly, it presents a promising technological solution for enhancing wireless communication and sensing capabilities in future healthcare initiatives.

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Keywords: UWB, CPW, Slotted patch, Compactness, Healthcare monitoring

1. Introduction

Up-to-date advancements in technology have absolutely revolutionized methods of arriving at diagnoses as well as forming treatment regimens. For the potential it has of transmitting and receiving data with a massive frequency band, ultra-wideband (UWB) has quickly risen to a potential for enhancing medical imaging modalities [1, 2]. The use of ultra-wideband in medical imaging systems increases efficiency, signal strength, as well as image resolution of the systems. One of the focuses of this technological integration is the design of small microstrip ultra-wideband antennas [3, 4]. As for the small portable medical devices, these antennas are good because they are small, cheap to build, and can be easily integrated into the various devices. This is particularly useful where there are plans to attain a broader performance degree. Such miniaturization is fitting because of the unique role of size and space in present-day mobile healthcare. This kind of antenna is appropriate when the application requires first detection of a disease with precision imaging, procedure monitoring, or anything in between. It has been stated that their wide range frequency signal transmission as well as reception ability might greatly transform the medical imaging and finally improve the health care as well as diagnostic results [5, 6]. A vulnerability to interference, possibility for creating terminal impedance, radiation pattern

stability, and the potential for generating/receiving brief pulse signals are some of the design principles that dictate success in medical usage [7]. For the identification of cancerous cells in human tissue, like as breast cancer, heart failure, and stroke, the authors of [8] designed a small metamaterial UWB antenna with a high correlation factor. The operation of this antenna is to act as an image sensor in microwave imaging systems. It could be a suitable image sensor if this antenna design can scan tumor simulants, and a correlation factor is high.

The authors of [3] proposed a small, planar CPW-UWB antenna that operates within an impedance bandwidth of 7.4 GHz, utilizing a fan-shaped slotted net patch radiator for biomedical wireless applications. This antenna is mainly employed for WBANs and healthcare stations. The impedance match is improved and the operating frequency range is widened using slots. Furthermore, a concept for an ultra-wideband microstrip antenna was suggested for microwave imaging to detect breast cancer using GPR [9]. The proposed antenna was able to reconstruct images within the allowed bandwidth due to its appropriate return loss. The use of a microstrip patch antenna for the early detection of breast cancer was demonstrated in [10]. A three-dimensional breast structure with distributive permittivity and conductivity was used to evaluate the antenna's picture quality. The use of microwave imaging, and more specifically UWB printed circular monopole antennas, for the diagnosis of breast cancer was also investigated at [11]. The suggested antenna broadside radiation pattern and relatively large impedance bandwidth improved image reconstruction and clutter suppression at breast cancer detection systems.

An advantageous microstrip antenna design with an ultra-wideband facility within the frequency range from 3.4226 to 13.4 GHz is proposed in this research. Its application in medicine and other areas that could benefit from higher frequencies is enormously promising. Several medical applications, including medical imaging technologies, wearable health monitoring devices, and remote patient monitoring systems, can benefit from the proposed UWB microstrip antenna. Therefore, enhancing connectivity and data transmission within healthcare facilities is feasible due to its small, wide bandwidth and sound radiation characteristics.

The proposed CPW-UWB antenna's design process is laid out in Section 2. Antenna bandwidth and radiation patterns are primarily shaped via the slotted patch, which is discussed at length in the same section. The third part for consideration provides an evaluation of the antenna's performance at greater depth. After that, we'll review the S11 response, which is connected to the reflection coefficient and impedance matching inside the UWB spectrum. A further way to look at patterns and metrics that measure the antenna's efficiency at transmitting signals and how it radiates energy in all directions. Section 4 depicts the conclusion points and future trends.

2. Methodology

The CPW design for the ultra-wideband (UWB) antenna has many advantages for systems that handle signals at high frequencies, such as radar, satellite communications, and wireless communication systems [12, 13]. Despite its inherent broad bandwidth, small size, and easy integration with other circuits [14, 15], relatively few antenna designs at the UWB range have been presented employing coplanar waveguides [16, 17].

Figure 1 shows the specific antenna design we will focus on here: the slotted patch radiator. Antennas designed using slotted patch geometry provide better performance by using the many resonant frequencies produced in a relatively small space. The layout must consider the substrate size (25 mm x 38 mm x 1.6 mm) because it significantly impacts the antenna's performance and operating frequency. A loss tangent of 0.02 and a dielectric constant of 4.4 are provided. Numerous design choices and dimension characteristics were also intended to be thoroughly studied in bold to improve the UWB features. Lastly, the CST simulator optimized these dimensions to attain the best possible signal transmission and reception performance across the ultra-wideband frequency range for 3.4226 to 13.4 GHz. The slotted patch design helps the antenna's compactness and the ability to widen the bandwidth through the introduction of extra resonances that can be utilized for more excellent performance.

By using a coaxial feed line to power the radiator and a 50-ohm microstrip line, an impedance match for signal transmission is achieved. This combination is commonly used in antenna designs because it maximizes power transfer while minimizing reflection losses. The arrangement also permits a smaller footprint, as the ground plane, CPW feeder, and dielectric substrate are all on the same plane. This coplanar design reduces both the total size of the antenna and the manufacturing expenses.

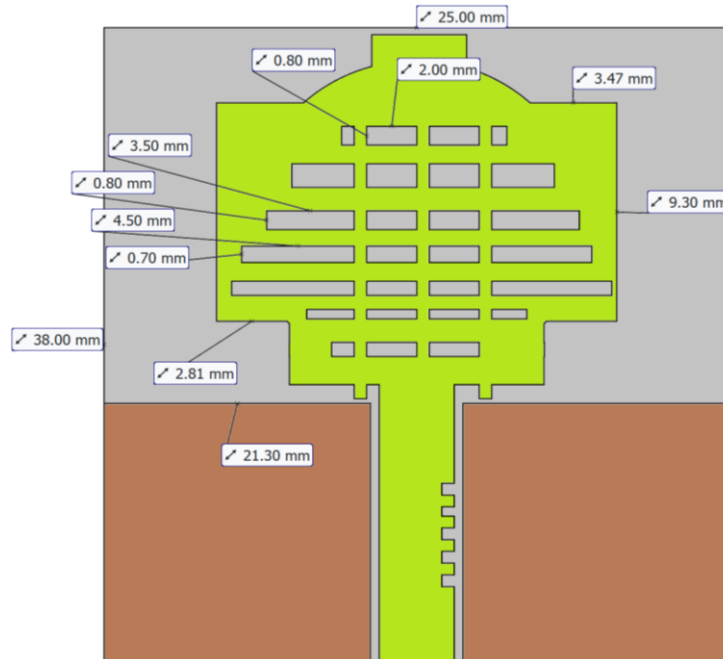


Figure 1. Antenna structure

3. Simulation results

The CST simulation tool is used to model the microstrip ultra-wideband coplanar waveguide (UWB-CPW) antenna with a wide operating bandwidth to better understand complex features associated with proposed antennas. In Figure 2, the results for the simulations show a wideband frequency response from 3.4226 to 13.4 GHz, with a bandwidth of approximately 9.9774 GHz at UWB applications. The antenna's ability to communicate effectively over various frequencies is crucial.

CST Microwave Studio excels at 3D and multilayered structural modeling. The program can often display and solve for a wide variety of circuit performance metrics, including return loss, signal-to-noise ratio (SWR) as seen at a Smith chart, real power as a function of frequency, and electromagnetic field distributions at specific frequencies, such as E-field or H-field. On top of that, it lets us test radiation patterns and gains, which are crucial for knowing how the antenna will work after it's mounted.

Furthermore, the modeling results demonstrate an excellent impedance bandwidth for 9.9774 GHz, with a center frequency of about 8.4 GHz. Loss for return (S_{11} parameter): because it reveals the levels for power reflected into our radio system due to any mismatch between the feed line's impedance and the antenna, this measurement is among the most crucial for evaluating an antenna's performance. A lower-value return loss will be more appropriately balanced, and its power transfer efficiency will be higher. The result was a return loss of 34 dB, which is low for UWB antennas and suggests they reflect very little incoming power; this is theoretically acceptable for efficient design purposes.

Figure 2 displays the projected antenna's S_{11} response to illustrate the general nature of return loss at higher operational frequencies. This proves the antenna's viability for UWB systems and that it can maintain appropriate properties throughout its design band. The simulation results show that the UWB-CPW antenna was

a feasible component for future wireless and communication systems, and they also support the engineering decisions that went into its design.

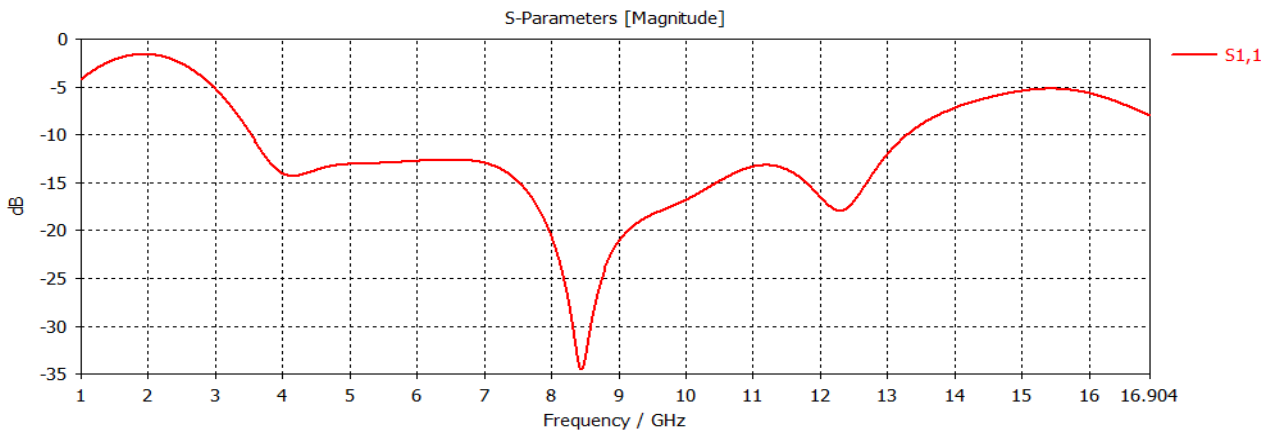


Figure 2. Return loss response for proposed UWB antenna

The surface current distribution for the 5.8 GHz UWB-CPW antenna is shown in Figure 3. It shows the current flow paths via the antenna structure and provides information about the efficiency and performance for this frequency for a specific matched or mismatched impedance. The patch radiator's right side and the feeding lines have the most extensive surface current distribution, so that those places will absorb the most energy. The feed line links to the patch, and the signal is efficiently transmitted because of this concentration. Energy is being radiated from the antenna efficiently, and there are low losses due to inappropriate loading for currents, according to the patterns shown in the current distribution. The maximum magnetic field strength for 5 A/m indicated a high degree of power transmission, measured within the antenna structure. The feeder region and the base for the patch radiator were the most common locations where we detected the strong magnetic field. The significant improvements to radiation efficiency and directivity that these regions bring to the antenna are crucial to its operation. Extremely high magnetic fields in these areas suggest the design uses electromagnetic principles to alter radiation properties. There is no need for extra reflectors or directors because the feeder, which solely radiates and receives RF energy, is a direct feed type device and feeds it into the patch. This seemingly insignificant component for the antenna significantly impacts the antenna's impedance matching and overall performance efficiency, despite how little it may sound. Using only two terminals, the patch maintains its flair.

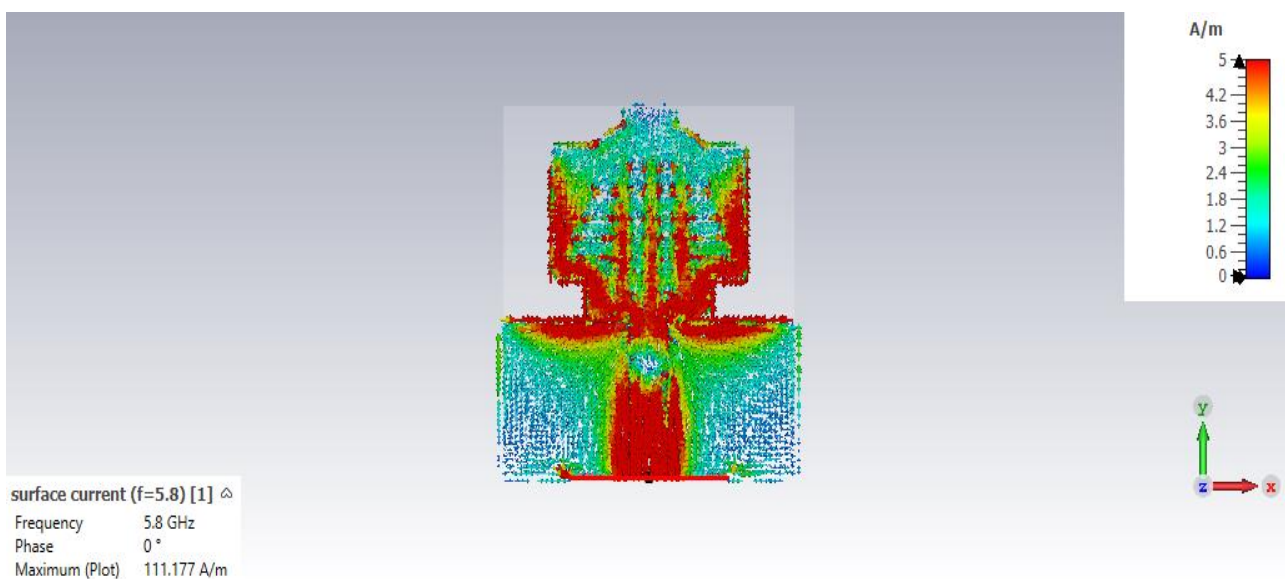


Figure 3. Current intensity distribution for the designed antenna

Figure 4 shows the predicted three-dimensional radiation patterns at 7.2 GHz for the projected ultra-wideband (UWB) antenna. Antenna directivity and global performance can be inferred from these patterns, which reveal the antenna's power radiating patterns to space. The proposed antenna's maximum gain at this operating frequency is 2.66 dBi, partially attributable to its moderate power. For deployments requiring faultless communication across many orientations, the 3D radiation patterns show how stable our antenna's performance is at diverse directions. Particularly for ultra-wideband uses, this improves signal integrity and coverage. Furthermore, the spatial distribution and shape of the radiation patterns provide beneficial information for estimating their polarization characteristics and possible interferences with other nearby devices. By learning these limits, this UWB antenna can be efficiently integrated into complicated communication systems without interference.

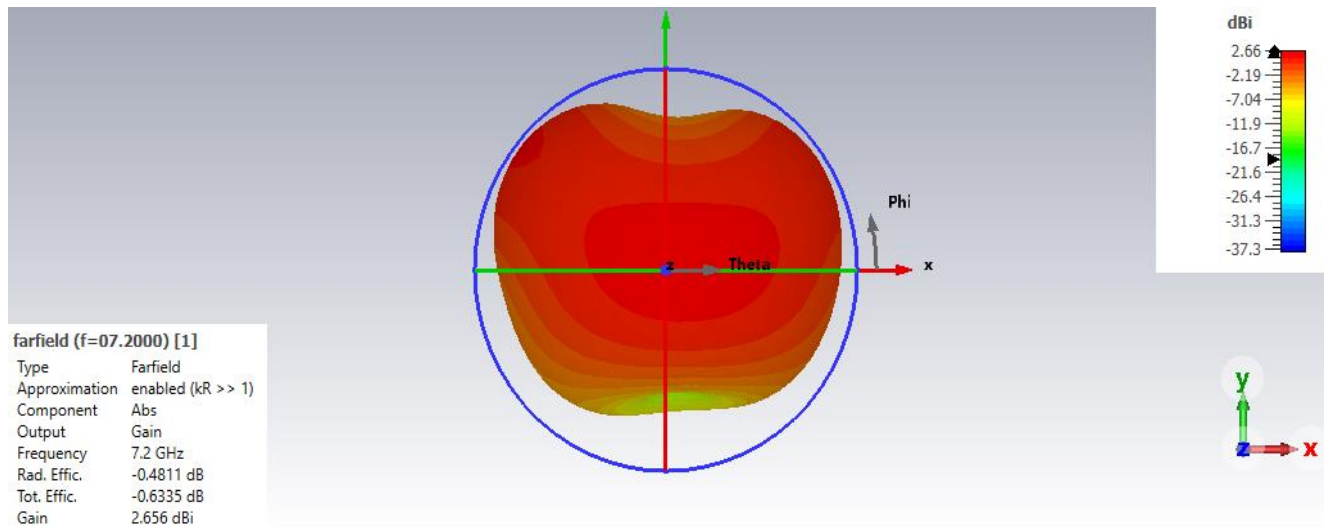


Figure 4. 3D radiation patterns for the projected antenna

As illustrated in Figure 5, the antenna displays a radiation pattern with two distinct directions. This arrangement shows that the antenna is radiating or receiving electromagnetic energy in two different directions, creating two large radiation lobes on either side of the antenna. Energy is uniformly distributed at two opposing angles thanks to the bi-polar radiation pattern, which enables symmetrical radiation around the antenna axis. Typical for antennas intended for bidirectional symmetrical radiation, this pattern shows two prominent peaks in the radiation pattern, each oriented at a different direction according to the antenna's design. Signals can be transmitted in several directions, similar to transpiration systems, thanks to the bipolar radiation pattern's offset beam pattern. The radiation pattern exhibits symmetrical behaviors across frequencies, guaranteeing constant performance. A comparison of the total power received from the generator and the total power emitted via the antenna is used to evaluate the antenna's performance. Inefficient radiation and energy are lost owing to factors including magnetic, dielectric, and metal conduction losses; ineffective radiation, on the other hand, radiates into space.

Figure 6 shows the overall efficiency for the antenna design. The minimum efficiency is at 1.5 GHz (-15.591 dB), and it increases dramatically as the frequency increases, reaching -0.51482 dB at 7 GHz. The proposed UWB-CPW antenna stands out with its small dimensions and extended impedance bandwidth, as shown in Table 1, which compares it to existing state-of-the-art antennas.

It has the potential to serve as a health monitoring solution for sending crucial biomedical data to the closest medical facilities during emergencies and crises. Additionally, it can be combined with other RF and microwave devices or other systems to achieve this goal as a future trend like bandpass filters [18, 19], artificial intelligence [20], diplexers [21, 22], lowpass filters and wideband filters [23, 24], and microcontrollers [25, 26].

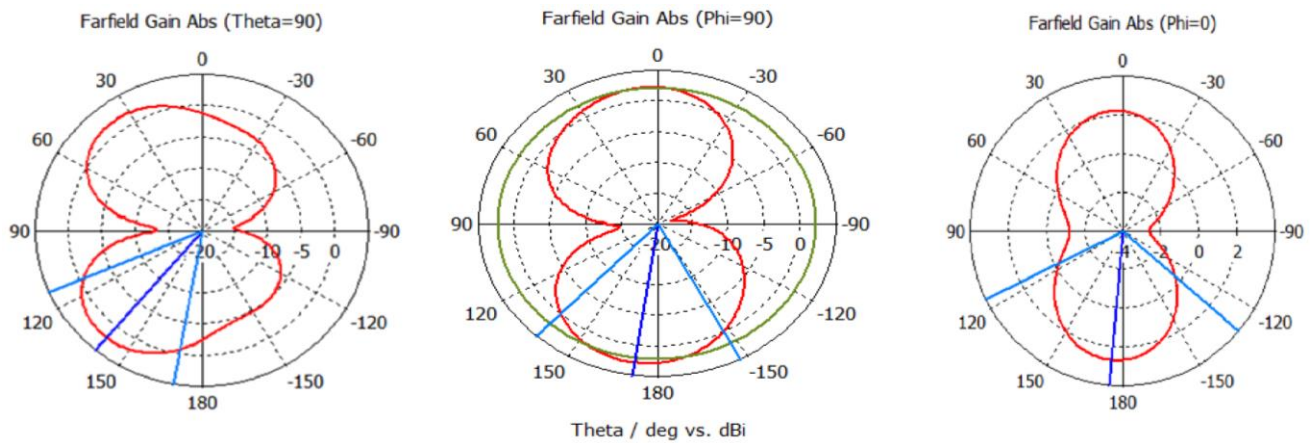


Figure 5. Radiation patterns for projected UWB-CPW antenna

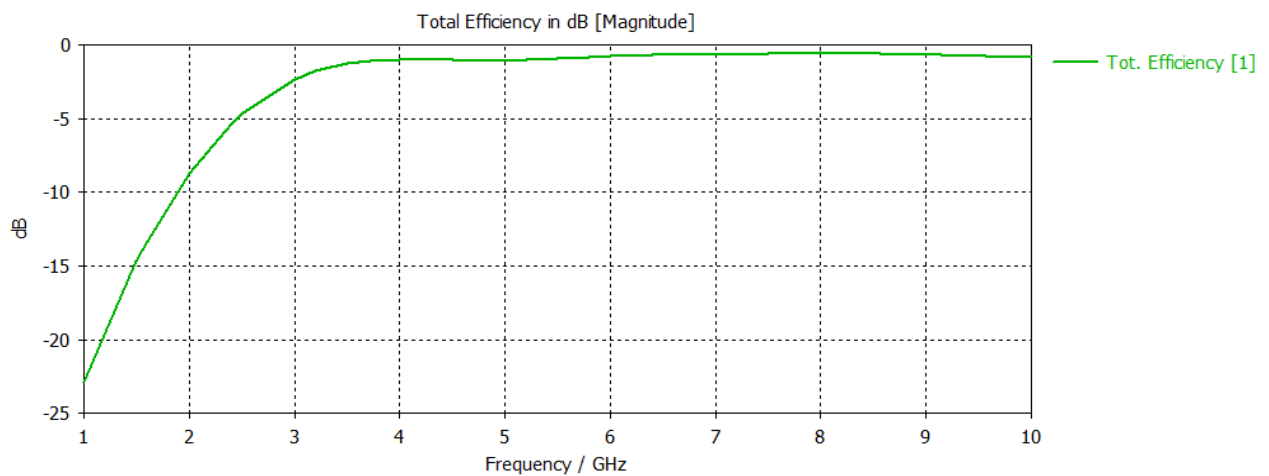


Figure 6. Total radiation efficiency for the UWB-CPW antenna

4. Conclusion and suggestions for future work

Finally, it should be mentioned that the UWB microstrip antenna, which was made utilizing a CPW feed line and a slotted patch on a FR-4 substrate, has shown remarkable performance across a wide frequency range from 3.4237 GHz to 13.4 GHz. Its compact size, low weight, radiation patterns, and frequency responsiveness make it an attractive choice for WBANs and medical imaging, among other advantages. Its bipolar radiation patterns further add to its promise. This antenna's capability to cover the whole UWB frequency band and deliver reliable communication in hospital environments further demonstrates its ability to enable innovative healthcare innovations. By integrating globally acknowledged communication standards, this antenna can improve wireless connectivity among medical equipment and aid people who are deaf or hard-of-hearing.

To verify the accuracy of the simulations, further research can include taking measurements for S11 responses, radiation patterns, and gain. Future innovations and better patient outcomes may be possible thanks to the broad adoption of state-of-the-art antenna technologies in healthcare delivery.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

Funding information

The authors declare that they have received no funding from any financial organization to conduct this research.

Author contribution

Yaqeen S. Mezaal: Conceptualization, methodology, data analysis, and writing the original draft.

Nora H. Sultan: Literature review, data collection, and critical revision of the manuscript.

Jaafar A. Aldhaibani: Supervision, project administration, and validation of results.

Maryam S. Jameel: Data visualization, interpretation of findings, and contribution to the final manuscript editing.

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