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Review on patch antenna for 5G Networks at Ka-Band

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ABSTRACT

Microstrip antennas for Ka-band wireless applications will be thoroughly examined in this research. To utilize 5G wireless applications, a new research topic that has been established is the creation of microstrip patch antennas. Patch antennae are made of different shapes, such as rectangles, circular shapes, triangles, donuts, rings, etc. Many substrate materials are used in patch antenna designs. This article examines the geometric configurations of antennas, the many methods of analysis for attributes of antennas, the dimensions of antennas, the issues that antennas face, and the potential solutions to those challenges. Wireless communication technologies, such as television broadcasts, microwave ovens, mobile phones, wireless local area networks (LANs), Bluetooth, global positioning systems (GPS), and two-way radios, all use it. This article examines the geometric structures of antennas, including several characteristics and materials by which they are constructed, as well as the numerous shapes they can produce. This paper will also examine return loss (S_{11}), bandwidth, voltage standing wave ratio (VSWR), gain, directivity, efficiency, and Bandwidth discussed in the prior studies. In the future, a novel patch antenna can be designed for 5G wireless applications.

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1. INTRODUCTION

The network and telecommunications sector is experiencing rapid growth, and a significant need for antennas will likely ensure this growth is seen daily. First, in the 1980s, the 1G communication network was established, and then, over the years, the 2G, 3G, and 4G networks were established. We are now discussing 5G, a network with distinct characteristics, forty years after its introduction. All of these developments are being seen since human requirements are increasing. The engineers operate around the clock to fulfill all of these requirements. The era of fifth-generation (5G) wireless communication is quickly coming, pushed by the ongoing breakthroughs in wireless communication technology. The bar for performance expectations has been raised due to these improvements, which include ultra-low latency, faster data throughput, and broader bandwidth capabilities. As a result of its capacity to improve transmission rates, boost channel capacity, decrease latency, and lessen the impacts of multipath fading, patch antenna systems have emerged as an indispensable component of the infrastructure for 5G networks. Antennas used in 5G communication systems are engineered for high gain and directivity to mitigate signal loss and a broad bandwidth to facilitate the transmission of substantial data at elevated speeds [1], [2]. Patch antennas are extensively utilized in mobile communication systems, such as mobile phones, RFID and global positioning systems (GPS). It is a well-liked option for 5G applications operating at the Ka-band (26.5–40 GHz) because of their low profile, the ease with which they can be fabricated, and the possibility of being integrated into various appliances [3], [4].

Even though they typically have benefits such as low weight and cost, they frequently have drawbacks such as limited bandwidth and low gain. Conversely, researchers are formulating techniques to enhance these features to satisfy the demands of 5G. These methods encompass arrays, metamaterials, and various slotting and feeding systems. Numerous studies have been undertaken to demonstrate successful methods for enhancing antenna gain, directivity, efficiency, bandwidth and surface current, such as employing an array of patches, which is a conventional strategy. Figure 1 illustrates the physical architecture of the patch antenna [5]. Furthermore, Figure 2 illustrates the various configurations of patch antennas [6].

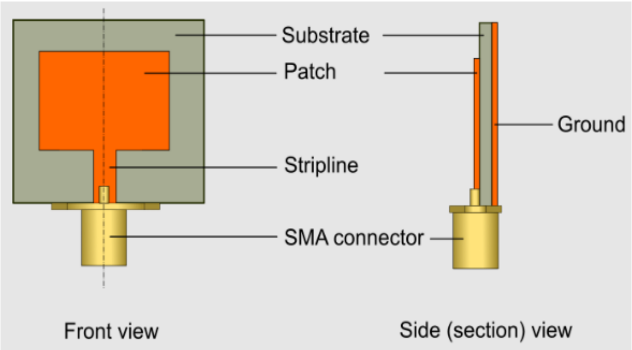

Figure 1. Illustrations of the front and side views of the physical microstrip patch antenna [5]

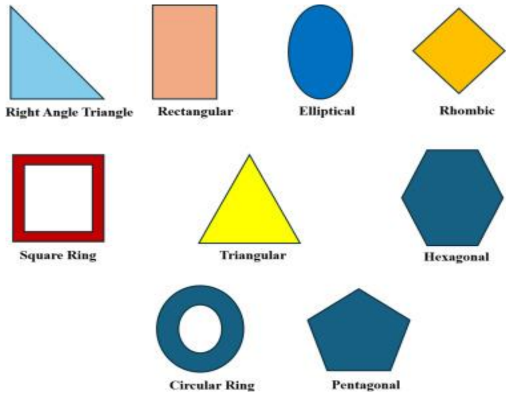

Figure 2. Depictions of several shapes of patch antenna configurations [6]

2. LITERATURE REVIEW

Much research has been conducted on microstrip patch antennas over the years. A primary issue identified is the delivery of elevated power to the receiver, a prevalent challenge associated with high-gain antennas [7]. Patch antennas are essential for 5G technology since they can meet the needs of these kinds of networks, which are high data rates and low latency. Various studies emphasize the importance of these findings to diverse aspects of 5G applications. The usefulness of patch antennas in various elements of 5G applications has been highlighted in several research articles.

This work aims to propose [8] an enhanced rectangular-shaped MPA for 5G and future wireless applications. The antenna exhibits advantageous return loss, gain, and directivity. The suggested antenna exhibits substantial enhancements in return loss and bandwidth, among other factors. This study presents [9] a single patch antenna for Ka-band, aimed at achieving bandwidth, gain, directivity, voltage standing wave ratio (VSWR) and efficiency. Research by Borel and Priyadarshini [10], design and analysis of a hexagonal patch antenna for 5G applications. Various parameters have been examined, including gain, bandwidth, radiation pattern, directivity, and electric field E distribution. The results are adequate for the device's millimeter-wave (mmWave) 5G applications.

This article presents [11] a patch antenna for 5G operating at Ka-band. Specifically, it improves the patch antenna's gain at Ka-Band while simultaneously lowering the side lobe level (SLL) in the radiation pattern. The proposed antenna has a high gain and boosts bandwidth simultaneously. This research presents [12] design a patch antenna design at K-band. During these simulations, the results that were acquired include S_{11}, the bandwidth gain, and efficiency. This article demonstrates [13], a planer patch antenna for 5G networks. To improve the S_{11}, transmission efficiency, directivity, and gain parameters from the simulation results. This paper presents [14] a focused analysis and simulation-based exploration of a patch antennas for K-band applications. These antennas use radiating surface materials to achieve the desired S_{11}, VSWR, and bandwidth improvement. This research presents [15], a novel proximity-coupled feed CPA for 5G applications. The suggested antenna exhibits superior S11 characteristics and impedance matching.

In this article [16], a design a dipole patch antenna for 5G applications. An impedance bandwidth of 57.1% is achieved for a single antenna element by applying the lifted ground (LGND). This paper introduces [17] a planar patch antenna element for 5G mmWave applications. A stepped narrow strip positioned between the two pairs of large rectangular patches enhances the band of operation and simultaneously improves the impedance matching. The antenna achieves gain, and its bandwidth is improved. This study presents [18] design and analysis a patch antenna for 5G applications. The simulation yields return loss, VSWR, gain, directivity, and bandwidth. This study presents [19] E-shape patch antenna design with defective ground structures (DGS) for 5G mmWave applications. The simulation allows for the return of both loss and gain. In this study [20] is to introduce a patch antenna with an H-shape for use in 5G applications at a frequency of 28.5 GHz, designed to provide high return loss, wide bandwidth, and high gain, making it an excellent candidate for 5G applications.

This study [21] presents a slotted patch antenna design with DGS for millimeter waveband. Its improve the antenna's bandwidth and gain. This study [22] presents design a patch antenna for 5G applications. The S_{11}, VSWR, and gain are examined by simulation analysis. After modeling, the provided antenna performs better than an alternative existing model. This literature review aims to understand better the principles of patch antennas and their significant role in implementing 5G technology. At the same time, it will investigate the development of patch antennas over time and how they have advanced to the point where they are currently operating within 5G technology. This study [23] introduces a circular patch antenna with a parasitic reflector element. The antenna is designed for Ka-band applications and operates at 28 GHz. The proposed design optimises parasitic element configuration to provide high gain, 2 GHz bandwidth, and consistent VSWR performance. The developed antenna [24] has a low VSWR (meaning it loses very little signal), sends signals in all directions, and can also send signals more strongly in certain directions and at different frequencies. Simulations show the antenna covers a wider range of frequencies, increases signal strength, and reduces unwanted signal reflection compared to earlier designs.

This work presents [25] a single-band Ka-band antenna explicitly designed for 5G applications. The antenna achieves favorable return loss, peak gain, and VSWR, supporting its suitability for integration into 5G technologies. This research examines [26] how different forms affect the performance of microstrip patch antennas at 28 GHz. Simulations show that the rectangular configuration provides the best results, yielding the highest gain and directivity, along with a considerable bandwidth. This study investigates [27] a single-band rectangular microstrip patch antenna with rectangular slots for Ka-band applications, focusing on its return loss, radiation patterns, VSWR, impedance, and gain. This paper introduces [28] a new T-shaped patch antenna that utilises a superstrate technique, resulting in improved return loss, gain, and directivity. The researchers examined three configurations: a fundamental design, a copper ring-loaded version, and a seawater-loaded version. The shown performance increases emphasise the appropriateness of these designs for a variety of applications, including 5G, WLAN, tracking, and detection. The purpose of this work [29], is to provide a design for a rectangular patch antenna capable of achieving a high gain of 28 GHz for 5G applications. Additionally, the simulations should show that the return loss is of good quality, the VSWR is within the specified range, and the antenna's directivity and radiation efficiency have been improved. The design of a single-element rectangular patch antenna at 28 GHz is the subject of this paper [30]. The implementation of partial DGS in the antenna design improves its bandwidth. The return loss (S_{11}) characteristics of the antenna structure demonstrate that it has a wider bandwidth.

This study presents [31] the design of a microstrip antenna for 5G applications at 29 GHz. The suggested antenna has several features, including high radiation efficiency, good return loss, improved bandwidth, gain, and a standard VSWR of approximately 1. This investigation [32] aims to design a rectangular patch antenna optimized for mmWave and 5G mobile network applications. The proposed slotted patch antenna is expected to deliver both high gain and improved radiation efficiency, as indicated by its performance evaluation. This study investigates [33] the challenges of reducing the size of mmWave antennas and achieving impedance matching to achieve effective radiation within the desired frequency range. The findings reveal that the antenna's directivity, compactness, and gain have been significantly improved compared to those of traditional mmWave antennas. A super-wideband flower-sloped microstrip patch antenna (SWB-FSMPA) with a small footprint and a high bandwidth ratio (BDR) is proposed for use in SWB applications [34]. A rectangular beveled defective ground structure (RB-DGS) and a 50 Ω tapered microstrip line are both incorporated into the SWB-FSMPA. A multiple-input multiple-output (MIMO) microstrip patch antenna, designed for 5G communication systems and operating at 28 GHz, is presented [35]. The antenna employs a coaxial feed mechanism for efficient power transfer. Comprehensive electromagnetic simulations using ADS software evaluate impedance matching, radiation pattern, and gain.

3. DESIGN METHODOLOGY

When building a rectangular patch antenna, three essential components must be present to achieve optimal performance. These components are the height of the substrate, the frequency of operation, and the dielectric constant [36]. Figure 3 illustrates the flowchart of the proposed paper.

i) Dielectric constant of the substrate (ε_r): the substrate material's dielectric constant (εr) substantially impacts the electromagnetic performance of the antenna. If the value of εr is lower, the radiation efficiency will be higher, the radiation patterns will be wider, the conductor losses will be more minor, and the bandwidth will be stronger. Nevertheless, when the value of εr is increased, the dimensions of the antenna patch are subsequently lowered. This is because the antenna patch is more minor.

ii) Operational frequency (f_r): the resonance frequency (fr), a key component in antenna operation, significantly influences the performance and efficiency of antennas.
iii) Dielectric substrate of height (h_S): the height of the dielectric substrate (h_s) considerably influences various antenna performance attributes, including bandwidth, surface wave characteristics, radiation efficiency, unintended feed radiation, and the overall dimensions of the antenna.

For the purpose of designing the rectangular patch antenna, the (1)–(8) that are defined in the technique are utilized [8], [37]. The proposed architecture's flow chart is presented in Figure 3.

Step: 01: a metric measuring the specific patch's breadth

$$\mathrm{Wp} = \frac{c_0}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}$$

Step: 02: the subsequent equation pertains to the effective dielectric constant:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} \times \sqrt{\left(1+\frac{12h}{w}\right)} \tag{2}$$

Step: 03: these are the comprehensive forms of the length equation:

$$L_{ext} = \frac{c_0}{2f_r\sqrt{\varepsilon_{reff}}} \tag{3}$$

Step: 04: an increase in the length of the antenna

$$\Delta L = 0.412\,\frac{\left(\frac{w}{h}+0.264\right)(\varepsilon_{reff}+0.3)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h}+0.813\right)} \tag{4}$$

Step 05: the process of determining the appropriate length for the antenna system

$$Lp = L_{ext} - 2 \times \Delta L \tag{5}$$

Step: 06: the dimensions of the antenna ground plane encompass its length and width:

$$L_g = 6h + L_P \tag{6}$$

$$W_g = 6h + Wp \tag{7}$$

Step: 07: width of feedline

$$W_f = \frac{7.48 \times Hs}{e^{Zo\frac{\sqrt{\varepsilon_r+1.41}}{87}} - 1.25 \times t} \tag{8}$$

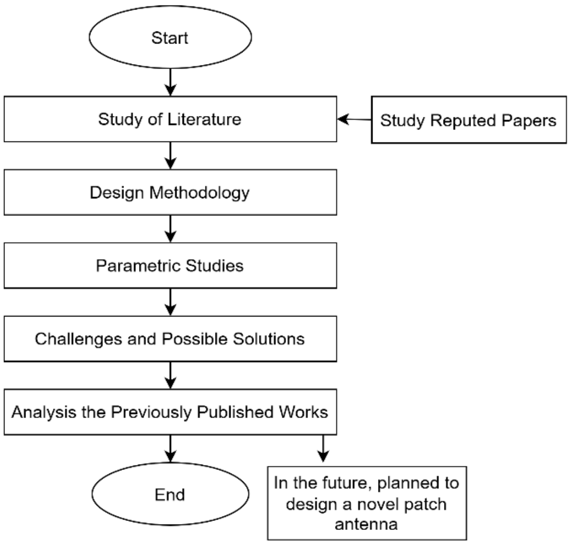

Figure 3. Flow chart of the planned paper

4. PARAMETRIC STUDIES

The radiation emitted by patch antenna installations originates from the fringing fields located between the ground plane and the border of the open-circuited conductor. Feeding can be accomplished in various ways as shown in Figure 4, including coaxial, proximity coupling, aperture coupling, microstrip line, and coplanar waveguide (CPW) feed. Figures 4(a) to (d) illustrates the various feeding mechanisms of the antennas. It is common practice to use microstrip and coaxial line feeds because of their benefits, including the ease of matching and the low spurious radiation they produce [6], [37].

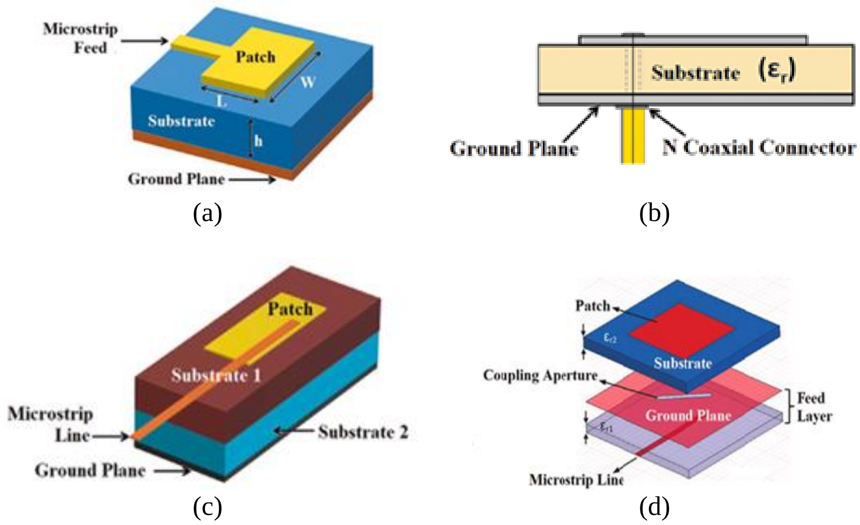

Figure 4. Depiction of various feeding mechanisms in patch antennas [6]: (a) microstrip feed line (b) coaxial cable, (c) proximity coupling and (d) aperature coupling

4.1. Antenna

An antenna is the most fundamental component of communication. An antenna is a type of transducer that can convert electromagnetic waves that are steered into waves that are moving freely in space and vice versa [38]. For transmission, it transforms high-frequency electrical impulses into electromagnetic waves and emits them into the atmosphere. Also, for receiving, it absorbs electromagnetic waves from space and transforms them into electrical signals.

4.2. Patch antenna

Patch or microstrip antennas are low-profile, flat antennas consisting of a flat plate placed over a ground plane. The four main components of a patch antenna are the substrate, transmission line, patch, and ground plan. Generally speaking, an antenna of this kind consists of a few essential components [2].

4.3. Return loss (S_{11})

The return loss (S_{11}) is a property of an antenna that signifies the degree of power reflected. The S_{11} parameter has a base value of −10 dB, signifying that the antenna absorbs 90% of the power, with 10% being reflected [8].

4.4. Antenna bandwidth

The term *"bandwidth"* describes the frequency range in which an antenna operates at its highest efficiency. The range between the highest and lowest frequencies is also referred to as the bandwidth, and it is measured in the S_{11} parameter at around -10 decibels. This parameter sheds light on the amount of data an antenna can transmit in a single second and, as a result, the rate at which data can be transferred [8], [36].

4.5. Voltage standing wave ratio

When determining how well the impedance of an antenna matches that of its transmission line, the VSWR is used as a measurement. A comparison of the higher and lower voltage levels throughout the transmission line calculates the VSWR. When the VSWR is equal to one, it indicates that the impedance matching is perfect. A decent antenna must have a VSWR number that falls between 1 and 2, although the closer the value is to 1, the more it implies that the antenna is performing nearly perfectly; values that are higher than or lower than these indicate that the antenna is not performing well [8], [36], [39].

4.6. Gain and directivity

The term *"gain"* denotes the effectiveness with which an antenna transforms input power into radio waves in a designated direction. This efficiency is assessed relative to an isotropic antenna [36]. Directivity measures an antenna's or optical system's capacity to concentrate emitted energy in a particular direction. This characteristic is essential for applications necessitating focused or directed transmission. This value is crucial in systems where targeted signal transmission enhances efficiency and minimizes interference [12].

4.7. Radiation pattern

The radiation pattern of the antenna and its radiation pattern are both representations of the angular dependency of the strength of radio waves emanating from the antenna [37]. Understanding the antenna radiation pattern, which indicates the directional emission of energy from the antenna, is vital to understanding an antenna's coverage and effectiveness in wireless applications [36]. This radiation pattern depicts the changes in power emitted by the antenna in several different spatial directions. This indicates the spatial directions (θ^0), (φ^{90}) responsible for the maximum amount of radiated power. Only when the wave is spherical can the radiation pattern contain any vital information [12].

4.8. Efficiency and surface current

The efficiency of an antenna is measured by its capacity to convert input energy into radiated energy, accounting for losses due to heat, impedance mismatches, and other factors [36]. It is a term that describes the process by which an electromagnetic field causes an electrical current to be produced when a metallic antenna is subjected to the field.

4.9. Benefits of patch antennas for 5G

Patch antennas are widely used in 5G systems due to their simple structure, compact size, and ease of integration. They support multi-band operation and offer suitable radiation characteristics, making them well suited for high-speed and reliable 5G communication. The main benefits are as follows:

i) Minimal profile and compact dimensions: patch antennas are slender and can be included in mobile devices and other tiny 5G apparatus.
ii) Cost-effective and easily fabricated: their uncomplicated design renders them reasonably economical to produce.
iii) Dual/multi-band operation: patch antennas can be engineered to function at many frequencies, which is crucial for the numerous bands of 5G.
iv) Optimal radiation attributes: well-engineered patch antennas can attain excellent directivity and radiation patterns appropriate for 5G communication.

4.10. Specific 5G applications

Patch antennas are widely applied in various 5G systems due to their compact size, flexibility, and ability to operate at high frequencies. In particular, they support a range of 5G applications from millimeter-wave communication to user equipment and network infrastructure. The specific 5G applications of patch antennas include:

i) mmWave communication: the Ka-band is an essential component of 5G mmWave, and patch antennas are now being constructed for frequencies in this band.
ii) Mobile devices: the emphasis is on developing tiny and efficient patch antennas for smartphones and other portable 5G devices.
iii) Base stations: patch antennas are also being designed for use in 5G base stations, which are currently in the process of design.

5. CHALLENGES AND POSSIBLE SOLUTIONS

Limited bandwidth: patch antennas often have a narrow bandwidth, which can be a limitation of 5G's extensive frequency range. Patch antennas are typically used in wireless communications. Low gain: patch antennas often have a lesser gain when compared to other types of antennas. Mitigation techniques: to address these restrictions, researchers are employing the following mitigation techniques: i) arrays: the creation of arrays of patch antennas can achieve amplification of gain and bandwidth, ii) metamaterials: the incorporation of metamaterials to improve antenna performance, including miniaturization and bandwidth increase, iii) slotted structures: it refer to the addition of slots or other alterations to the patch to broaden the bandwidth and improve impedance matching, iv) feeding techniques: utilizing various feeding techniques to improve bandwidth and gain is called "feeding techniques", v) reflector layers: it is possible to boost gain by utilizing reflector layers.

6. ANALYSIS THE PREVIOUSLY PUBLISHED WORKS

Most researchers focus on patch antennas, and their discoveries have been disseminated through papers in several academic journals. Table 1 compares the proposed study with previous work at a Ka-band. Compared to the findings of previously published works, the proposed research has produced superior results, indicating that it may be suitable for future wireless applications.

Table 1. Consider the works that have been published in the past

Ref	Band	Materials	S_{11} (dB)	VSWR	Gain (dBi)	BW (GHz)	Applications
[8]	Ka-Band	FR-4	-28.39	1.08	7.04	4.9	5G
[9]	Ka-Band	FR-4	-	1.3	6.08	3	5G
[11]	Ka-Band	RO3003	-26.14	-	8.10	1.4	5G
[12]	Ka-Band	RT5880	-20.95	1.19	7.5	1.06	5G
[14]	Ka-Band	RT5870	-53.57	1.00	-	5.26	5G
[15]	Ka-Band	RT5880	-40.28	1.02	5.8	0.200	5G
[17]	Ka-Band	-	-25	-	3	4.1	5G
[18]	Ka-Band	RT5880	-26.97	1.094	6.69	3.25	5G
[19]	Ka-Band	RT5880	-39.51	1.021	5.77	-	5G
[21]	Ka-Band	RT5880	-37.78	1.13	7.12	-	5G
[40]	Ka-Band	FR-4	-45	-	5.58	1.763	5G
[41]	Ka-Band	RT5880	-35.91	1.03	9.42	1.43	5G
[42]	Ka-Band	RT5880	-17.28	1.31	6	0.9	5G
[43]	Ka-Band	Taconic TLY-5	-36.17	1.03	6.72	0.454	5G
[44]	Ka-Band	FR-4	-24.50	1.12	7.19	1.352	5G

7. CONCLUSION

Microstrip patch antennas have been widely employed in advancing contemporary mobile communication technology, including 5G. Integrating diverse slot geometries into a singular rectangular patch, prevalent in 5G antennas, has proposed an appropriate patch antenna for 5G applications. This patch antenna aims to improve the gain, efficiency, reflection coefficient, bandwidth, and other radiation characteristics. Because they are more compact, less expensive, and easier to integrate, patch antennas provide an attractive solution for various 5G applications. Even though there are still obstacles to achieving high gain and wide bandwidth, ongoing research is producing encouraging results in optimizing patch antennas for the demanding needs of 5G technology.

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Md. Sohel Rana	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no competing interests. This work was not supported in part by a grant.

DATA AVAILABILITY

The data that has been used is confidential.

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