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# A Systematic Review on IoT Security (Threats, Mitigations) Strategies and Future Directions

Zarghona Zubair*, Zarrar Muhammad Khan

## Chronicle

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**Zarghona Zubair** is currently affiliated with the Dha Suffa University, Pakistan.
**Email:** zarghonazubair@yahoo.com

**Zarrar Muhammad Khan** is currently affiliated with the Macquarie University, Australia
**Email:** xarrarmuhammad@gmail.com

**Corresponding Author***

## Abstract

This systematic review explores the progression of Internet of Things (IoT) security research between 2015 and 2025, with a focus on emerging threats, mitigation strategies, and future security directions. As IoT technologies have become integral across sectors such as healthcare, manufacturing, transportation, agriculture, and smart cities, security challenges have intensified due to device heterogeneity, constrained resources, and decentralized architectures. The review categorizes security threats based on IoT architecture layers—perception, network, and application—and outlines specific attacks, including physical tampering, DDoS, and data breaches. It evaluates a wide range of mitigation strategies proposed over the last decade, including lightweight encryption, anomaly-based intrusion detection systems (IDS), machine learning, and blockchain-based trust frameworks. Additionally, it addresses domain-specific security concerns, highlighting the need for adaptive, scalable, and standardized solutions in critical applications such as Industrial IoT and remote healthcare systems. The review identifies existing gaps in regulation, real-world validation, and cross-layer security integration, proposing future research directions toward building resilient, context-aware, and interoperable IoT security frameworks.

**Keywords:** EEG Signal Analysis, Feature Extraction, Frequency-Dependent Synaptic Plasticity (FDSP), McCulloch Thresholding Approach, Neural Network Classification, Pre-Seizure Detection.

# INTRODUCTION

The Internet of Things (IoT) has emerged as a transformative technology, revolutionizing various industries by enabling interconnected smart devices and systems that collect, exchange, and analyze data (Abomhara & Koien, 2014). This connectivity facilitates advanced applications across multiple sectors such as healthcare, manufacturing, transportation, agriculture, and smart cities, enhancing operational efficiency, automating tasks, and improving the quality of life for users.The Internet of Things (IoT) has become a cornerstone of digital transformation, enabling smarter infrastructure, efficient monitoring, and data-driven decision-making (Alrawais et al., 2017). Its applications span diverse sectors, including healthcare, manufacturing, transportation, agriculture, and urban development. Esmaeili et al. (2024) proposed by connecting billions of devices, IoT fosters real-time automation and enhances operational efficiency, positively impacting daily life and business processes. However, this extensive connectivity comes with significant security and privacy concerns. The rapid expansion in the size of IoT networks has exposed IoTs to ever-present threats, such as data breaches, malware, DDoS, and unauthorized access, especially due to heterogeneity from the kind of devices that constitute the IoT—a result of low computing capacity combined with a variety of protocols being in use. This, however, makes traditional methods quite insufficient in effectively handling such threats. Moreover, the IoT system properties, such as being mobile, resource-constrained, and intermittently connected, further add to the challenges. Ensuring data integrity, confidentiality, and availability in these dynamic environments requires innovative and specialized solutions (Ahmed & Zhao, 2023). Lightweight security mechanisms that balance effectiveness with the resource constraints of IoT devices are particularly essential. This review synthesizes existing research on IoT security, focusing on threats, defense mechanisms, and future research directions. It aims to offer a holistic understanding of the current state of IoT security and identify areas for further improvement.

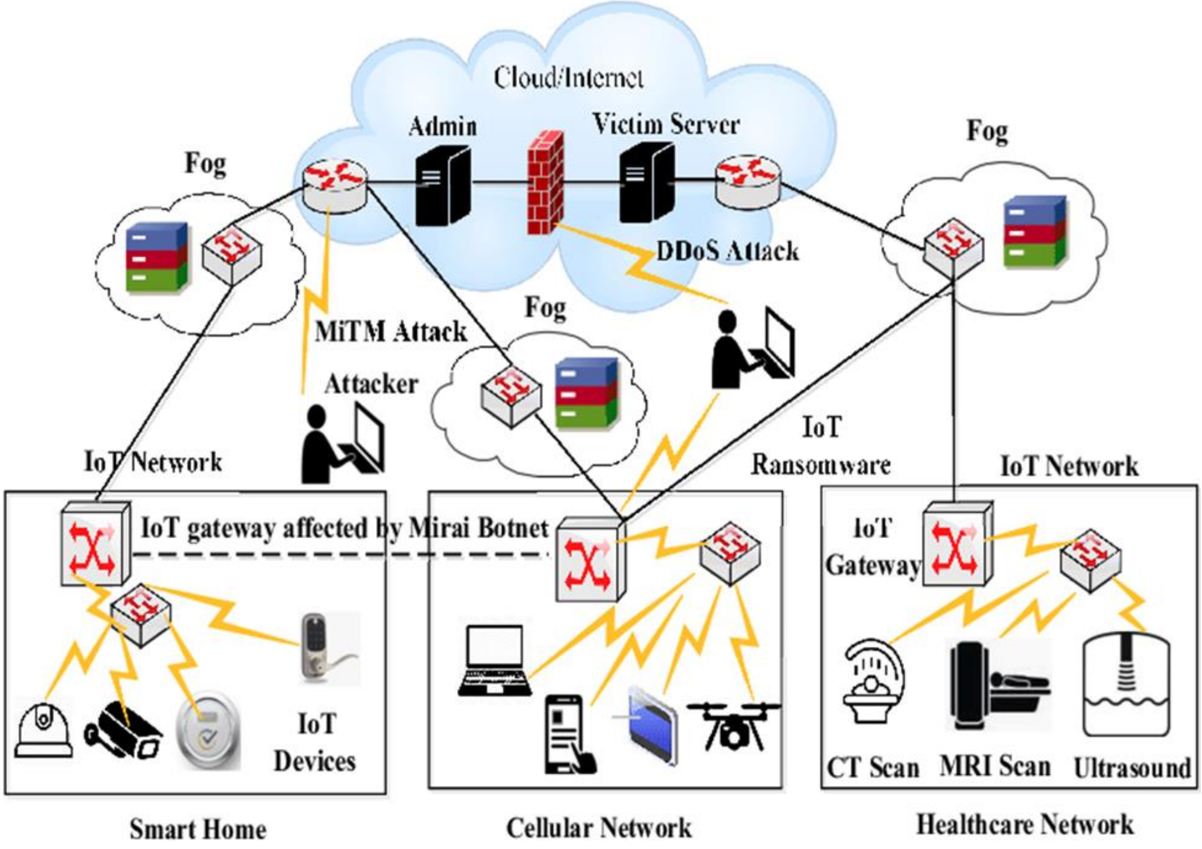

**Figure 1.**
**IoT Attacks**

Unlike traditional computing environments, IoT systems are composed of highly heterogeneous, resource-constrained devices that often operate in distributed and dynamic contexts. These characteristics make IoT systems particularly vulnerable to a range of threats—such as data breaches, Distributed Denial of Service (DDoS) attacks, and man-in-the-middle exploits that span across different layers of the IoT architecture. At the perception layer, risks include physical tampering, fake node injection, and side-channel attacks. The network layer faces issues like eavesdropping, spoofing, and routing manipulation, while the application layer remains exposed to malware, weak authentication mechanisms, and API-level attacks.

To address these threats, a wide spectrum of security strategies has emerged over the past decade. Research has focused on lightweight encryption protocols, anomaly-based and machine learning-enhanced intrusion detection systems (IDS), blockchain-enabled trust models, and decentralized access control mechanisms.

However, despite these advances, critical limitations remain in areas such as scalability, energy efficiency, standardization, and adaptability to evolving threats (Bera et al., 2020). This review consolidates research findings from 2015 to 2025, with the goal of offering a comprehensive perspective on IoT security threats, mitigation strategies, and technological advancements. It further evaluates the effectiveness of proposed solutions in sector-specific contexts—particularly in sensitive domains such as healthcare and Industrial IoT (IIoT). Lastly, this review identifies unresolved research gaps and outlines future directions, advocating for adaptive, context-aware, and interoperable security architectures that can ensure long-term sustainability and trust in IoT ecosystems.

## LOT Applications and the Rise of smart environments

IoT enables smart environments by connecting a wide range of devices, from simple sensors to complex embedded systems. In smart cities, for instance, IoT facilitates intelligent traffic management, energy-efficient lighting, and real-time environmental monitoring. In healthcare, wearable devices and remote monitoring solutions enable better patient care and early detection of health issues. IIoT offers Predictive automation of manufacturing maintenance processes. These diverse submissions power revolutions across domains, creating a more allied and efficient world. Be that as it may, the widespread deployment of IoT Devices introduce exclusive challenges. The variety of devices, tied with their variable computational power, resources, leads to uneven networks where the old-style Security measures may not be sufficient. Moreover, the dynamic and distributed nature of IoT systems requires particular tactics to guarantee confidentiality, integrity, and availability (Das et al., 2017). IoT's versatility enables applications across multiple domains, improving system responsiveness and user experience. The table below summarizes key IoT use cases:

**Table 1.**
**Applications of IoTs in Smart Environments**

| Domains | Applications |
|---|---|
| Healthcare | Remote patient monitoring, wearable health trackers, telemedicine systems |
| Smartcities | Traffic control, smart lighting, waste management, pollution monitoring |
| Agriculture | Precision farming, irrigation monitoring, livestock tracking |
| Manufacturing | Predictive maintenance, asset tracking, process automation |
| Transportation | Fleet management, real-time tracking, smart parking |
| Energy | Smart grids, energy consumption monitoring, automated billing |

These systems depend heavily on data accuracy and reliability, making **security** a critical concern.

## Security Threats in LOT Environments

As IoT networks grow, there is a numeral of security challenges arising, Intimidating the security and consistency of smart environments are at stake. Some of the prominent intimidations to include are as follows:

- Data Breach and Unauthorized Access: IoT devices frequently grip delicate information, therefore, making them the key goal for attackers who aim to steal or manipulate it. Weak validation mechanisms and poor encryption worsen these risks (Ammar et al., 2018).
- Devices with Default or Weak Passwords: Most IoT devices are set at the factory with effortlessly predicted passwords, this leaves them vulnerable to brute-force attacks.

- API Security: Unsecured APIs are able to expose devices to unauthorized access or handling.

## SECURITY ATTACKS IN LOT ENVIRONMENTS

**Malware and Ransomware Attacks:** Malware infections can destruct normal functions of IoT devices, triggering data loss, system outages, or even physical damage, particularly when acute infrastructure is involved (Conti et al., 2021).

- Distributed Denial of Service (DDoS) Attacks: The interrelated nature of IoT systems makes them vulnerable to DDoS attacks, where attackers use frequent compromised devices to overflow a target system with traffic, upsetting services (Bian et al., 2022).

- Man-in-the-Middle (MITM) Attacks: In this type of attacks, an invader interrupts communication among devices, moving or stealing data during transmission (El Bekkali et al., 2022).

To counter these intimidations, a multifaceted method is required, highlighting robust encryption, access control mechanisms, and real-time threat detection systems.

### Deference Mechanism for LOT security

Several strategies have been advanced to strengthen the security landscape of IoT environments. Major defense mechanisms include:

- Intrusion Detection Systems (IDS): IDSs monitor network traffic for abnormal patterns that could indicate security breaches. Techniques such as anomaly detection, signature-based detection, and machine learning enhance IDS accuracy in IoT networks (Elhoseny et al., 2022).
- Encryption Techniques: Lightweight encryption methods are essential for securing communications in resource-constrained IoT devices. These techniques protect data confidentiality while minimizing computational overhead (Brown & White, 2023).
- Blockchain Solutions: Blockchain offers a decentralized and tamper-proof method for managing data, securing transactions, maintaining data integrity, and fostering trust within IoT networks.
- Artificial Intelligence and Machine Learning: AI-driven solutions enable real-time threat detection and the prediction of security risks through historical data analysis. Machine learning algorithms improve IDS by adapting to evolving threats and enhancing overall effectiveness.

Integrating multiple layers of defense from physical security to network and application-level protection creates a robust and resilient IoT ecosystem. These frameworks enhance threat detection and mitigation across various levels of IoT architecture. Security threats in IoT can be analyzed effectively using the OSI (Open Systems Interconnection) model. Attacks can occur at any layer, from physical device tampering to application-level exploits.

**Table 2.**
**Security Attacks in IoTs with Respect to OSI Layers**

| OSI Layer | Common Attacks |
|---|---|
| Physical Layer | Device tampering, jamming, side-channel attacks |
| Data link Layer | MAC spoofing, traffic analysis, replay attacks |
| Network Layer | IP spoofing, sinkhole, selective forwarding, DDoS |
| Transport Layer | SYN flooding, UDP flooding |
| Session Layer | Session hijacking, unauthorized session interception |
| Presentation Layer | Data format manipulation, malicious payload injection |
| Application Layer | Malware, ransomware, insecure APIs, firmware manipulation |

# LITERATURE REVIEW

The rapid expansion of the Internet of Things has spawned many studies centering on applications, security challenges, and mitigation strategies. Research has highlighted a diversity of results that address the weaknesses of IoT systems.

## IoT Security Challenges

Inherent characteristics, such as heterogeneity and resource constriction, offer exclusive challenges from the IoT security perception. As Mishra and Pandya asserted, IoT devices are basically dynamic in nature; that is, their environment of operation can be utterly unpredictable-thereby vulnerable to threats on various dimensions. Generally speaking, these threats come in different levels categorized into physical attacks, namely the tampering of the devices, while network-related threats include DDoS and eavesdropping. It's a broad threat landscape that requires good knowledge of vulnerabilities both on the device and network. IoT security is hindered by several unique challenges that differentiate it from traditional IT environments:

**Table 3.**
**Security Challenges in IoTs**

| Challenges | Description |
|---|---|
| Device Heterogeneity | Devices differ in hardware, OS, and protocols, complicating uniform security |
| Resource Constraints | Limited memory, processing power, and battery restrict advanced encryption |
| Weak Authentication Mechanisms | Many devices use default or weak credentials |
| Insecure Communication Channels | Lack of end-to-end encryption exposes data in transit |
| Firmware Vulnerabilities | Devices often lack timely firmware updates, exposing them to known exploits |
| Scalability | Security models must scale with billions of interconnected devices |
| Intermittent Connectivity | Devices may not always be online, making real-time monitoring difficult |

## Defensive Measures

An increasing number of studies are dedicated to developing defensive approaches to tackle IoT security challenges. Abosata et al. focus on security mechanisms specifically designed for industrial IoT (IIoT) applications. They highlight that traditional IT security solutions are often incompatible with IIoT due to different operative contexts and constraints. To address this, they propose context-aware security strategies custom-made to the unique requirements of industrial environments, which often demand real-time data processing and automation.

## Vulnerability Analysis

Ikrissi and Mazri highlight the vulnerabilities present in smart environments, noting that many IoT devices are equipped with insufficient security features.One major concern is the extensive use of default authorizations, which are rarely updated, leaving these devices extremely vulnerable to cyberattacks. Their study highlights the acute need for manufacturers to prioritize security during the proposal phase by integrating built-in securities against unlawful access and tampering.

## Intrusion Detection and Prevention

Their study presents a framework for intrusion detection that controls machine learning algorithms to observe traffic patterns and classify anomalies revealing potential attacks.They argue that the flexibility of machine learning models makes them predominantly effective in dynamic IoT networks, where traditional signature-based methods often fall short Roman et al. (2013).

## IoT in Healthcare

Advancements in IoT have altered healthcare, enabling the development of "smart healthcare" systems that improve patient monitoring, data collection, and communication efficiency Xu et al. (2014). A 2022 study examines IoT applications in healthcare, showcasing noteworthy benefits in dealing chronic diseases and refining patient engagement.

## Blockchain Integration

The integration of blockchain technology into IoT security has appeared as a swiftly growing research focus. Abiodun et al. (2023) define blockchain as a decentralized framework that enhances data integrity and security.Their review highlights its applications in IoT, including decentralized identity management and secure data-sharing protocols. This approach eases risks related with centralized control while nurturing transparency and confidence among users and devices. These findings underline the necessity for constant innovation and devoted strategies to address IoT's growing challenges and prospects. Challenges still exist in areas related to data security, interoperability of devices, and reliable values for data that allow for continuous integration within healthcare environments (Yang et al., 2017).

## IoT Security and Privacy

Increased utilization of IoT in various fields has resulted in making security issues related to IoT devices and networks one of the crucial concerns (Zhang et al., 2019). Recent SLRs strongly indicated that robust security frameworks covering key aspects, such as authentication, encryption of data, and detection of threats in real time, are an urgent need.In particular, researchers have called for adaptive security mechanisms that automatically use machine learning to respond dynamically to threats, which is especially crucial in environments with high-risk devices or sensitive data, such as healthcare and industrial IoT Suo et al. (2012). IoT systems are operating in various dynamic environments, where real-time responsiveness to changes is needed, for instance, network congestion or device availability. The work gives more emphasis on the contribution of self-adaptive architectures, especially in fog and edge computing, toward the delivery of scalable and resilient IoT deployments. These adaptive architectures enhance QoS by better distribution of computational loads and flexible responses to changes in the environment (Zhou, Cao, Dong, & Vasilakos, 2022). Future research directions indicate further development in edge computing frameworks that can manage resources better and assure consistent service delivery.

## Policy and Regulatory Considerations

Besides purely technical solutions, the role of policy and regulatory frameworks in shaping security practices of IoT is also considered (Zhou, Tang, Li, & Zhang, 2023). According to researchers, developing comprehensive policies could set minimum standards for security that may encourage manufacturers to adopt best practices in device security. This kind of collaboration by industry stakeholders and government agencies can result in guidelines that enforce security across the IoT ecosystem.

# METHODOLOGY

## Research Design

This study follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 guidelines to conduct a systematic literature review on security attacks and mitigation strategies in the Internet of Things (IoT) from 2015 to 2025. The methodology includes identifying relevant studies, applying inclusion/exclusion criteria, screening and selecting studies, and synthesizing findings.

## Research Question (Using PICO Framework)

**Population/Problem (P):** Internet of Things (IoT)

**Intervention (I):** Security mitigation strategies

**Comparison (C):** Not applicable

**Outcome (O):** Protection from security attacks

*What security attacks target IoT systems and what mitigation strategies are used to address them?*

## Search Strategy

A structured search was conducted using major academic databases including **IEEE Xplore, Scopus, ACM Digital Library, SpringerLink, and ScienceDirect**. The search covered publications between **2015 and 2025**, in English, and included journal articles, conference papers, and reviews.

## Search Keywords & Synonyms

**IoT:** "Internet of Things", IoT, "smart devices", "cyber-physical systems"

**Security Attacks:** "security attacks", threats, vulnerabilities, "cyber attacks", "malicious attacks"

**Mitigation Strategies:** "mitigation strategies", "security solutions", "defense mechanisms", countermeasures, protection

### Boolean Search Query:

("Internet of Things" OR IoT OR "smart devices" OR "cyber-physical systems")

AND

("security attacks" OR threats OR vulnerabilities OR "cyber attacks" OR "malicious attacks")

AND

("mitigation strategies" OR "security solutions" OR "defense mechanisms" OR countermeasures OR protection)

## Inclusion and Exclusion Criteria

### Inclusion Criteria:

✓ Published between 2015 and 2025

- ✓ Written in English
- ✓ Related to IoT security attacks and mitigation strategies
- ✓ Peer-reviewed articles and conference papers

**Exclusion Criteria**

- ✓ Studies not directly related to IoT security
- ✓ Non-English publications
- ✓ Grey literature, editorials, and non-peer-reviewed articles

### Study Selection Process

The search yielded 1,360 records. After removing 290 duplicates, 1,070 records were screened by title and abstract. 760 records were excluded for irrelevance. The full texts of the remaining 310 articles were assessed, with 230 excluded for not meeting inclusion criteria. Ultimately, 60 articles were included for final qualitative synthesis.

**PRISMA Flow Summary**

**Table 4.**
**Prisma Flow Summary**

| Stage | Count |
|---|---|
| Records Identified | 1360 |
| Duplicates Removed | 290 |
| Records Screened | 1070 |
| Records Excluded | 760 |
| Full Text Articles Assessed | 310 |
| Full Text Articles Excluded | 230 |
| Studies Included in Final Review | 60 |

## Analysis

Artificial Intelligence has become a cornerstone in advancing IoT security due to its ability to learn from data and adapt to dynamic environments. In particular:

**Intrusion Detection Systems (IDS):** According to Shinde et al. (2023) AI, especially machine learning and deep learning algorithms (e.g., SVMs, CNNs, LSTMs), enhances the detection of real-time anomalies in IoT traffic. These models outperform static signature-based methods, offering adaptability and faster response times.

**Anomaly and Behavior-Based Detection:** AI models can learn normal behavior patterns of IoT devices and flag deviations, which is particularly useful in environments where fixed rules fail due to heterogeneous device behaviors

.**Context-Aware Security Mechanisms:** AI enables systems to factor in environmental, behavioral, and temporal context for more accurate threat detection and access control.

**AI-Driven Authentication:** Behavioral biometrics, usage pattern analysis, and continuous identity verification, powered by AI, offer scalable and user-friendly authentication in constrained devices.

Despite its promise, the application of AI in IoT security is limited by resource constraints, lack of transparency, and vulnerability to adversarial attacks. These limitations highlight the need for robust, lightweight, and explainable AI frameworks tailored for IoT ecosystems.

## FUTURE DIRECTIONS

In spite of substantial advancements, numerous gaps persist that future research must address:

**Explainable AI (XAI) for IoT Security:** There is a growing demand for AI models that are both understandable and explainable, enabling humans to justify their decisions, specifically in areas that are highly sensitive such as healthcare and smart cities. Research should put an effort into employing XAI techniques so as to build stronger trust and ensure accountability Sicari et al. (2015).

**Edge AI and Federated Learning**: The augmentation of federated and low power edge AI models that keep the privacy of data, as well as reduce the load on IoT nodes, is the need of the hour Islam et al. (2015).

**AI Model Resilience and Robustness:** One of the future directions of research can include the study on how the AI models can be made more resilient by adopting the right security measures to protect themselves from the adversarial attacks and the challenges that they will encounter by the dynamically changing threat landscapes Miraz et al. (2015). This would require, among other things, the fight against adversarial examples and self-healing algorithms implementation Moosavi et al. (2015).

**Lightweight Security Protocols:** The innovative moves should still continue in the creation of extremely lightweight Algorithms that zero in on resource-scarce devices, particularly, the wearable/electronic devices of IoT, etc., for real-time security enforcement Smith and Johnson (2023).

**Cross-Layer AI Security Frameworks:** According to Gupta et al. (2023) holistic frameworks that apply AI across multiple IoT layers (network, application, perception) are underexplored. Future research should design integrated frameworks for comprehensive threat mitigation Lee and Kim (2023).

**AI and Regulatory Compliance:** As AI becomes central to IoT security, it is crucial to align AI-powered solutions with evolving legal and regulatory standards, such as GDPR, HIPAA, and industry-specific compliance frameworks Rathore et al. (2021).

**Benchmarking and Standardization:** The lack of standardized datasets and benchmarking protocols hinders the comparative evaluation of AI models. Future work must focus on developing publicly available benchmarks for consistent and reproducible research Ferrag et al. (2020).

## CONCLUSION

The development of Internet of Things (IoT) technologies has opened up exciting opportunities in many areas, but it has also created severe security issues. This systematic literature review has assessed the state of IoT security and identified ongoing challenges including data compromise, DDoS attacks, ineffective authentication mechanisms, and other malicious thrusts as results of the complex resourceless nature of IoT devices. With regards to these issues, the literature shows an increasing interest in, for example, advanced machine learning techniques for dynamic intrusion detection, as well as in the use of blockchain technology for establishing trust and control over data. Also, the review identifies the importance of new artificial intelligence, edge computing, and decentralized systems for the development of stronger and more flexible self-learning security systems. These solutions meet the system requirements of IoT technology concerning lightweight design and scalability. Context-driven and domain-specific instructions, particularly in industrial and healthcare sectors, reveal further evidence of the need for tailored security solutions.

Despite notable advancements, the findings reveal several research gaps, including the need for standardized protocols, improved interoperability, efficient key management, and context-driven, self-adaptive security frameworks. Future research should prioritize lightweight yet resilient architectures capable of real-time threat mitigation, while also addressing regulatory, ethical, and privacy concerns. A collaborative effort between academia, industry, and policy-makers will be crucial to establish a secure and resilient IoT ecosystem that can scale sustainably in the face of evolving cyber threats.

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**Consent to Participate:** Yes

**Consent for publication and Ethical approval:** Because this study does not include human or animal data, ethical approval is not required for publication. All authors have given their consent.

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