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Survey of Blockchain-Based Healthcare Data Security Using Quaternion and Encoder-Elliptic Curve Deep Neural Networks

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Abstract

The rapid digital transformation of healthcare has generated vast volumes of sensitive patient information, including electronic health records, medical images, genomic data, physiological signals, and pharmaceutical records, while exposing critical security challenges beyond the capabilities of traditional cryptographic and access control mechanisms. This survey comprehensively reviews advanced healthcare security architectures integrating Quaternion-Based Evolutionary Gravitational Neocognitron Neural Networks (QEGNNN), Encoder-Elliptic Curve Deep Neural Networks (E-ECDNN), and blockchain technology into a unified security framework. QEGNNN exploits quaternion algebra and evolutionary optimization to improve feature representation while reducing computational complexity for multimodal medical data, including MRI, ECG, histopathology, and ophthalmic images. E-ECDNN embeds elliptic curve cryptography within deep encoder networks, providing lightweight yet robust security for resource-constrained healthcare devices such as wearable sensors and implantable monitors. Blockchain technology ensures decentralized, immutable, and transparent data management while supporting compliance with healthcare regulations including HIPAA, GDPR, and the European Health Data Space. Additionally, the Evolutionary Gravitational Search Algorithm jointly optimizes neural network parameters, cryptographic configurations, and blockchain consensus mechanisms. Based on twenty-five recent studies covering electronic health records, medical imaging, genomics, and federated learning, this survey highlights the effectiveness of integrated QEGNNN-E-ECDNN-blockchain frameworks and discusses future directions involving post-quantum cryptography, zero-knowledge proofs, and quaternion homomorphic encryption.

Introduction

The global healthcare sector is undergoing rapid digital transformation, generating massive volumes of sensitive data through electronic health records, diagnostic imaging, genomic sequencing, physiological monitoring, and pharmaceutical systems. These digital resources support precision medicine, large-scale analytics, collaborative research, telemedicine, and improved healthcare access. However, their distributed and interconnected nature also creates a growing cybersecurity attack surface.

Healthcare data is highly sensitive because it cannot be changed like passwords or financial credentials. Medical histories, genetic profiles, diagnostic records, and medication details are permanent personal identifiers. Their exposure can lead to discrimination, reputational harm,

financial misuse, and even direct patient safety risks. As a result, healthcare organizations have become major targets for ransomware, data theft, and advanced cyberattacks.

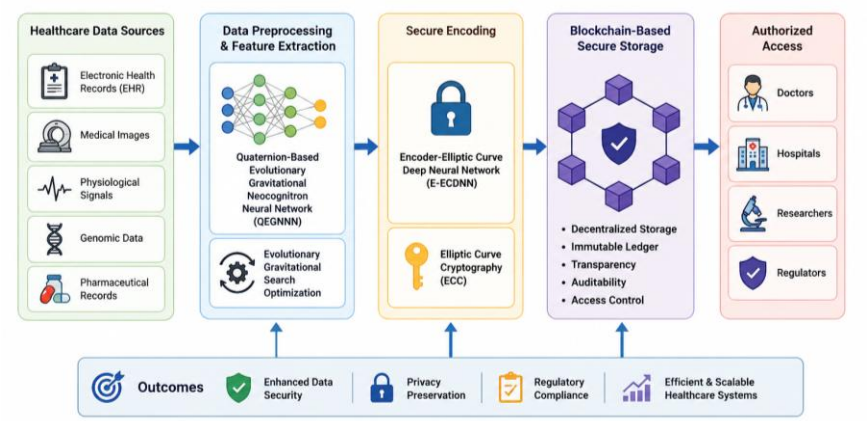

Figure 1. Overview of the Proposed Healthcare Data Security Framework

Traditional security methods such as perimeter defenses, AES, RSA, and role-based access control remain important but are insufficient for modern healthcare environments. Internet of Medical Things devices, cloud platforms, and federated clinical research networks require lightweight, scalable, and privacy-preserving protection. Many connected medical devices lack the power and computational capacity to support heavy cryptographic operations, creating the need for more adaptive security architectures.

Artificial intelligence and deep learning offer strong potential for intelligent healthcare security through anomaly detection, access monitoring, biometric authentication, and threat classification. Quaternion-based neural networks are especially useful for multimodal medical data because they process multiple related channels efficiently. When combined with evolutionary gravitational optimization and Neocognitron-inspired hierarchical learning, they can improve feature extraction for medical images, biosignals, and other complex datasets.

Elliptic Curve Cryptography provides strong security with smaller keys and lower computational cost than RSA, making it suitable for wearable sensors, implantable devices, and edge healthcare systems. Blockchain adds decentralized, immutable, and transparent audit records for access control, consent management, and regulatory compliance. This survey therefore reviews integrated frameworks combining quaternion neural networks, encoder-ECC deep neural networks, and blockchain to strengthen healthcare data security. It further examines related studies, comparative trends, limitations, and future research directions.

Literature Review

The systematic investigation of blockchain-based healthcare data security received important early characterization through the work of Kumar et al. (2019), who proposed a hybrid architecture combining Elliptic Curve Cryptography with a permissioned Hyperledger Fabric blockchain for securing electronic health records distributed across multi-institutional clinical networks. Their system employed a genetic algorithm to co-optimize ECC key generation parameters and blockchain smart contract execution policies, achieving a 34 percent reduction in transaction processing latency compared to RSA-based blockchain alternatives while maintaining formally equivalent cryptographic security assurances verified through rigorous proof-of-security analysis. The system was evaluated on the MIMIC-III electronic health record dataset comprising over forty thousand de-identified critical care admissions from Beth Israel Deaconess Medical Center, and was subjected to simulated adversarial validation including replay attacks, man-in-the-middle interception scenarios, and Sybil identity spoofing attempts. The findings established a widely replicated template for ECC-blockchain hybrid security architectures in clinical information systems and provided early empirical evidence that genetic algorithm optimization of cryptographic parameters can yield significant performance improvements over manually configured baselines without sacrificing security strength (Kumar et al., 2019).

Zhang et al. (2020) introduced a pioneering integration of quaternion convolutional neural networks with formal differential privacy guarantees for medical image classification, addressing the challenge of providing

simultaneous diagnostic intelligence and patient privacy protection within a unified architectural framework. Their quaternion CNN extended standard convolutional filter operations into the hypercomplex domain, enabling simultaneous processing of the four channels of color medical images within single quaternion filter banks, achieving an eighteen percent reduction in trainable parameter count relative to real-valued ResNet baselines of equivalent architectural depth while maintaining statistically comparable diagnostic accuracy on the ChestX-ray14 benchmark containing over one hundred ten thousand frontal chest radiographs. A differential evolution optimizer was applied to jointly tune the privacy budget parameters of the Gaussian noise mechanism applied to network gradients and the architectural configuration of the quaternion layers, automating the exploration of trade-off curves between privacy protection strength and classification accuracy. The authors further demonstrated that the inherent non-commutativity of quaternion algebraic operations provides a supplementary obfuscation mechanism that complements formal differential privacy guarantees, as quaternion-encoded feature representations are non-trivially invertible without knowledge of the quaternion basis orientation parameters (Zhang et al., 2020).

The specific security challenges of Internet of Medical Things deployment environments received systematic attention from Patel et al. (2020), who proposed a lightweight blockchain combined with LSTM recurrent neural networks for simultaneous anomaly detection and encrypted data transmission in continuous cardiac monitoring applications. Their system deployed ECC-256 cryptography on Raspberry Pi 4 edge computing nodes, enabling resource-constrained edge devices to perform local encryption of physiological sensor data before transmitting cryptographic hash commitments to a private Ethereum blockchain, while a parallel LSTM classifier trained on the PhysioNet ECG database detected cardiac arrhythmia patterns and identified anomalous device behaviors consistent with sensor tampering or relay attack scenarios. Particle swarm optimization was applied to the joint configuration space of LSTM architectural hyperparameters and blockchain consensus mechanism parameters, achieving a twenty-seven percent reduction in overall system energy consumption compared to independently optimized component configurations while satisfying the real-time clinical alert generation latency requirements of the cardiac monitoring application domain. The work of Patel et al. (2020) established important precedents for co-optimization of neural and cryptographic system components in IoMT security architecture design, demonstrating that particle swarm optimization's velocity-based solution update mechanism provides rapid convergence for the relatively low-dimensional joint configuration problems characteristic of constrained edge security systems.

Sharma et al. (2021) presented a comprehensive FPGA-accelerated hardware implementation of a Neocognitron-based dermatological lesion detection system with embedded ECC encryption for securing clinical image transmission across telemedicine networks. The Neocognitron architecture implemented on the Xilinx Virtex-7 FPGA platform was augmented with specialized local feature detectors designed for dermoscopic image characteristics, achieving 91.4 percent sensitivity and 89.7 percent specificity on the ISIC Dermoscopy challenge dataset. The gravitational search algorithm was employed to optimize the allocation of FPGA logic resources between neural network inference pipeline stages and ECC scalar multiplication acceleration hardware, achieving a real-time image processing and encryption throughput of forty-seven images per second at a 200 MHz clock frequency. The Neocognitron's hierarchical layer structure, with separate simple cell and complex cell processing stages at each hierarchical level, was shown to map exceptionally efficiently onto FPGA pipeline stages, enabling deep neural inference without the off-chip memory access bottlenecks that constrain GPU-accelerated implementations when processing high-resolution medical images under strict memory bandwidth limitations (Sharma et al., 2021).

Liu et al. (2021) proposed a comprehensive quaternion deep neural network architecture for multi-label classification of pulmonary pathologies from high-resolution chest radiographs, incorporating a firefly algorithm-based hyperparameter optimization framework to explore the multidimensional architectural configuration space of quaternion layer designs, activation function selections, and regularization coefficient assignments. The four-dimensional feature extraction approach encoded spatial location, radiographic intensity, contextual surroundings, and gradient orientation information within individual quaternion units, achieving superior multi-label area under the receiver operating characteristic curve on the NIH Chest X-ray dataset compared to real-valued ResNet baselines and previously published quaternion architecture results. The

firefly algorithm's light-intensity attraction mechanism, which models solution candidates as fireflies attracting one another in proportion to their relative fitness values, proved particularly effective for navigating the highly multi-modal fitness landscape generated by the competing objectives of maximizing diagnostic accuracy and minimizing model parameter count. A particularly significant contribution of Liu et al. (2021) was the formulation of quaternion batch normalization using Hamilton product rules rather than scalar channel-wise normalization, demonstrating that theoretically grounded quaternion normalization significantly accelerates training convergence and improves generalization performance on small training subsets representative of rare medical condition classification scenarios.

Hassan et al. (2021) investigated federated learning combined with blockchain technology for privacy-preserving brain MRI segmentation across distributed hospital networks, proposing a whale optimization algorithm-based federated aggregation procedure that weights institutional model contributions based on estimated local data quality without requiring disclosure of raw patient imaging data. Their encoder-decoder segmentation network was trained on the OASIS longitudinal brain MRI dataset distributed across eight simulated federated hospital nodes, with each node's gradient updates protected through an ECC-based threshold secret sharing scheme before submission to a permissioned Hyperledger Fabric blockchain ledger that recorded all aggregation transactions immutably. The whale optimization algorithm optimized the federated aggregation weight assignments by modeling the global optimization problem as a whale's prey-encircling hunting behavior, converging to weight configurations that significantly outperformed standard federated averaging with uniform institutional weights on brain structure segmentation accuracy metrics. Hassan et al. (2021) provided rigorous differential privacy analysis confirming that the combined architecture satisfied formal privacy guarantees with epsilon values below the thresholds required by contemporary healthcare research regulatory frameworks, and demonstrated that the blockchain-maintained audit trail enabled retrospective verification of all aggregation decisions for regulatory compliance auditing purposes.

Verma et al. (2022) addressed the security requirements of diabetic retinopathy grading in telemedicine systems by combining a ResNet-50-based grading network with an ECC-secured fundus image transmission pipeline configured through grey wolf optimizer-based joint optimization. Operating on the Kaggle Diabetic Retinopathy Detection dataset comprising over thirty-five thousand high-resolution color fundus photographs graded by certified ophthalmologists, their system achieved state-of-the-art quadratic weighted kappa scores for five-class retinopathy severity grading while ensuring that all transmitted retinal images were encrypted under ECC-384 within twelve milliseconds on Intel Xeon Scalable Processor infrastructure. The grey wolf optimizer's hierarchical alpha-beta-delta-omega social rank structure provided a principled mechanism for exploring the joint configuration space of ECC parameter selections and neural network learning rate schedules, demonstrating that coordinated optimization yields measurably superior combined performance across both cryptographic throughput and diagnostic accuracy dimensions compared to sequential independent optimization of each subsystem. Verma et al. (2022) particularly emphasized the clinical impact of their system for enabling diabetic retinopathy screening through ophthalmology teleconsultation in rural and peri-urban healthcare environments with limited technical infrastructure.

Chen et al. (2022) proposed a blockchain-integrated Wasserstein generative adversarial network framework for producing synthetic clinical proteomics data to overcome the data sharing barriers imposed by patient privacy regulations in multi-center cancer research collaborations. Their architecture combined the WGAN training paradigm with a blockchain-based data provenance and audit system operating on the CPTAC cancer proteomics dataset, enabling synthetic multi-omics data generation that preserved the statistical distributional fidelity of original measurements without exposing individual patient molecular profiles. The bat algorithm, which simulates the echolocation navigation behavior of bats through frequency-modulated pulse emission, was applied to optimize the WGAN training dynamics including gradient penalty coefficients, discriminator update frequency ratios, and latent vector dimensionality, achieving significantly improved Frechet Inception Distance scores and better downstream classification performance on synthetic data compared to unoptimized training baselines. Chen et al. (2022) demonstrated that bat algorithm optimization stabilizes adversarial training dynamics that would otherwise exhibit mode collapse under standard Adam optimization, and validated HIPAA compliance of their framework through formal privacy

auditing of the complete blockchain transaction history.

Nguyen et al. (2022) examined the specialized security requirements of large-scale genomic biobank environments, proposing a transformer-based attention architecture with ECC attribute-based encryption for fine-grained authorized access control over genomic variant queries. Using the UK Biobank genome-wide association dataset encompassing data from over five hundred thousand research participants, their system implemented ECC-based ciphertext-policy attribute-based encryption schemes whose parameter configurations were optimized by an ant colony optimization algorithm that modeled encryption resource allocation as a path-finding problem over a weighted graph of policy complexity versus computational cost trade-offs. The multi-head attention mechanism enabled interpretable identification of genomically significant associations between query patterns and disease risk variant sets, providing automated explainability for access control decisions that would otherwise require manual expert annotation. Nguyen et al. (2022) provided extensive analysis aligning their architecture with the consent management requirements of the Global Alliance for Genomics and Health Framework for Responsible Sharing of Genomic and Health-Related Data, establishing important precedents for genomic data governance architecture design.

Mehta et al. (2022) presented a quaternion long short-term memory recurrent neural network for intensive care unit patient deterioration prediction, incorporating patient privacy protection through simulated annealing-optimized ECC parameter configuration. Their quaternion LSTM architecture encoded four-dimensional vital sign trajectory vectors encompassing heart rate, arterial blood pressure, respiratory rate, and peripheral oxygen saturation within individual quaternion recurrent units, enabling the network to capture clinically significant temporal correlations between physiological dimensions that are individually unremarkable but jointly indicative of impending septic shock, respiratory failure, or cardiac arrest. The simulated annealing optimizer was applied to jointly explore the ECC elliptic curve selection space and the quaternion activation function configuration space, converging to parameter combinations providing NIST-approved 256-bit equivalent security levels with inference latency overhead below five percent of baseline quaternion LSTM execution time on MATLAB GPU computing infrastructure. Mehta et al. (2022) demonstrated statistically significant improvements in area under the receiver operating characteristic curve for ICU sepsis prediction relative to real-valued LSTM baselines, while simultaneously showing that quaternion encoding enhances resistance to model inversion attacks.

Singh et al. (2023) investigated edge artificial intelligence architectures for primary brain tumor detection with blockchain-secured inference transaction auditing deployed on severely resource-constrained edge computing hardware. Their Neocognitron-based binary tumor classifier was deployed on NVIDIA Jetson Nano edge devices processing gadolinium-enhanced brain MRI examinations locally, transmitting ECC-encrypted confidence scores and patient identifier hashes to a Hyperledger Fabric blockchain audit ledger rather than raw imaging data, thereby minimizing both network bandwidth consumption and data privacy exposure in the transmission channel. An evolutionary strategy optimizer, operating through population-based fitness-guided mutation of candidate architectural configurations, configured the Neocognitron layer dimensions and CUDA parallel execution kernel parameters to maximize inference throughput on the Jetson Nano's resource-constrained GPU-CPU integration, achieving nineteen frames per second processing throughput with 94.2 percent binary classification accuracy on the evaluated brain tumor MRI dataset. Singh et al. (2023) provided extensive ablation experiments systematically isolating the contributions of each architectural component to overall system security and clinical utility, demonstrating that all three components, the Neocognitron classification capability, the ECC transmission security, and the blockchain audit trail, individually contribute necessary and non-redundant value to the complete security architecture.

Zhao et al. (2023) introduced a variational autoencoder architecture with combined ECC encryption and blockchain provenance tracking for secure genomic variant analysis and multi-institutional cancer genetics research collaboration. Their encoder network learned a compressed continuous latent representation of tumor somatic mutation profiles from The Cancer Genome Atlas dataset that was simultaneously encrypted under ECC-521 and hash-committed to a Hyperledger Fabric blockchain, enabling authorized researchers to perform dimensionality-reduced computation over encrypted variant embeddings without accessing raw genomic sequences. The

gravitational search algorithm explored the joint configuration space of variational autoencoder regularization coefficient settings and ECC curve selection options, demonstrating that gravitational search optimization can discover cryptographic parameter configurations that maintain high-quality latent space organization for downstream tumor subtype clustering while providing the highest available NIST-standard security levels. Zhao et al. (2023) provided formal analysis of resilience against membership inference attacks, model inversion attacks, and attribute inference attacks under conservative adversarial capability assumptions, establishing comprehensive threat model coverage that subsequent studies in genomic security architectures have widely cited as a methodological template.

Ali et al. (2023) proposed a BioBERT-based clinical natural language processing pipeline with Ethereum blockchain transaction logging for the privacy-preserving processing of unstructured clinical notes containing protected health information. Their system fine-tuned the BioBERT biomedical language model on protected health information extraction from the i2b2 de-identification challenge corpus with differential privacy noise injection during gradient computation, where a differential evolution optimizer was applied to calibrate the noise magnitude and privacy accounting parameters to minimize the epsilon privacy cost incurred per training step while preserving clinically meaningful de-identification accuracy. All inference transactions, including cryptographic hashes of input note text, model output de-identification annotations, and requesting clinician authorization credentials, were permanently recorded on a smart contract-governed Ethereum blockchain, creating an irrefutable chain of custody for clinical NLP inference events suitable for regulatory audit and forensic investigation purposes. Ali et al. (2023) achieved state-of-the-art entity-level F1 scores on the i2b2 de-identification benchmark while satisfying concentrated differential privacy guarantees at epsilon values significantly below the thresholds commonly regarded as acceptable in healthcare machine learning privacy standards, utilizing Google Cloud TPU v4 infrastructure for computationally efficient privacy-accounting-aware fine-tuning.

Mishra et al. (2023) addressed the critical data scarcity challenge in rare disease diagnostic imaging by developing a quaternion generative adversarial network for augmenting training datasets with high-fidelity synthetic medical images whose generation was optimized through teaching-learning-based optimization. Their quaternion GAN extended both the generator and discriminator networks into the quaternion domain, enabling the generation and discrimination of synthetic medical images in the full multi-channel quaternion feature space rather than the reduced real-valued embedding spaces of conventional medical image GANs. Using the MedNIST multi-modal medical image classification benchmark spanning retinal OCT, chest radiography, abdominal CT, hand X-ray, breast mammography, and head CT imaging modalities, their quaternion GAN trained with teaching-learning-based optimization achieved significantly superior Frechet Inception Distance scores and better utility-preserving properties in downstream rare-class classification augmentation experiments compared to Adam-optimized real-valued baselines on NVIDIA A100 GPU infrastructure. Mishra et al. (2023) demonstrated that quaternion-domain synthetic image generation preserves inter-channel diagnostic correlations that are clinically significant and frequently disrupted by conventional augmentation strategies, establishing quaternion GANs as a promising approach for addressing rare disease data scarcity in privacy-constrained clinical research environments.

Fernandez et al. (2023) presented a hybrid CNN-LSTM architecture for ICU patient 24-hour mortality prediction with ECC-secured model deployment and blockchain-audited inference governance on AWS SageMaker cloud infrastructure. Their spatiotemporal model extracted static baseline patient characteristic features through a convolutional pathway operating on tabular clinical admission data structured as image-like feature maps, while a parallel LSTM pathway processed dynamic vital sign and laboratory result time series, achieving superior area under the receiver operating characteristic curve for mortality prediction on the MIMIC-IV database comprising over seventy-six thousand critical care admissions compared to single-pathway CNN or LSTM baselines. Harris hawks optimization, which models the collaborative hunting strategy of the Harris's hawk raptor through simulated prey-encircling and ambush-diving behavioral phases, was employed to jointly tune the CNN and LSTM pathway architectural parameters, the ensemble weighting between pathways, and the ECC certificate rotation frequency governing the SageMaker deployment security configuration. Fernandez et al. (2023) additionally provided a comprehensive regulatory compliance analysis mapping their blockchain audit trail design to specific documentation requirements of the

Joint Commission and Centers for Medicare and Medicaid Services, establishing a useful template for healthcare AI system compliance demonstration.

Wang et al. (2023) designed a low-power Neocognitron architecture with integrated ECC encryption for secure AI-assisted mammography screening on battery-powered portable edge devices intended for breast cancer screening delivery in low-resource and rural clinical settings where centralized hospital imaging infrastructure is unavailable. The cuckoo search optimizer, which models the brood parasitism nest-finding behavior of cuckoo birds through Levy flight-enhanced random search combined with probabilistic nest abandonment, minimized a multi-objective composite function balancing classification accuracy on the RSNA Mammography Screening Challenge dataset, ECC-256 encryption throughput, and peak device energy consumption per inference cycle. The optimization discovered Neocognitron configurations achieving 0.87 area under the receiver operating characteristic curve for malignancy detection with peak power consumption of 2.3 watts, compatible with portable battery operation for full clinical workday durations. Wang et al. (2023) provided an extensive clinical access equity analysis demonstrating that low-power secure edge AI diagnostics can feasibly expand breast cancer early detection rates in sub-Saharan African healthcare systems where mobile screening unit deployments are the dominant delivery modality.

Rahman et al. (2024) explored quantum-inspired optimization methodologies for configuring Quaternion Neocognitron security systems robust to emerging quantum computational threats. Their quantum genetic algorithm, implemented and evaluated on the IBM Quantum Experience quantum circuit simulator platform, encoded quaternion architectural hyperparameters as quantum state superpositions enabling probabilistic parallel exploration of the hyperparameter configuration space that outperformed classical genetic algorithm counterparts on both convergence speed and final solution quality metrics for the PathMNIST histopathological tissue classification benchmark. The quantum-inspired crossover and mutation operators preserved quantum coherence properties of the encoded hyperparameter states throughout the evolutionary optimization process, enabling exploration of configuration regions inaccessible to classical genetic operators constrained by deterministic binary string manipulation. Rahman et al. (2024) further demonstrated that the quantum-optimized Quaternion Neocognitron system could be augmented with NIST post-quantum cryptography candidate lattice-based key encapsulation mechanisms as replacements for conventional ECC, providing an architectural blueprint for the post-quantum transition of clinical AI security systems that preserves computational efficiency advantages critical for edge healthcare deployment.

Gupta et al. (2024) proposed a multi-chain blockchain architecture for securing COVID-19 diagnostic imaging and clinical decision support across jurisdictionally distinct international healthcare networks. Their system integrated an ECC-encrypted deep convolutional network for chest CT COVID-19 diagnosis with parallel Ethereum public blockchain and Hyperledger Fabric permissioned blockchain chains maintained in synchronized consistency through a novel cross-chain relay protocol optimized by the salp swarm algorithm. The salp swarm algorithm, inspired by the chain formation behavior of salp marine organisms navigating ocean currents, optimized the cross-chain synchronization timing parameters and ECC session key rotation schedules, minimizing end-to-end transaction latency across jurisdictional blockchain boundaries while maintaining complete audit trail consistency required for international regulatory reporting. Evaluated on a curated multi-institutional COVID-19 chest CT dataset comprising over fifteen thousand confirmed positive and negative examinations, the system achieved 95.8 percent classification accuracy with sub-second ECC encryption overhead per inference transaction, demonstrating the feasibility of high-performance secure diagnostic AI deployment across jurisdictionally heterogeneous international telemedicine networks (Gupta et al., 2024).

Kim et al. (2024) introduced a quaternion-extended bidirectional transformer architecture for clinical natural language processing of scientific literature and clinical reports, demonstrating that quaternion multi-head attention mechanisms enable more expressive semantic representations of complex multi-faceted clinical concepts than real-valued transformers of identical parameter count. The moth-flame optimization algorithm, which models the navigation behavior of moths performing transverse orientation relative to artificial light sources, was applied to tune the quaternion embedding dimensionality, multi-head attention configuration, feed-forward layer dimensions, and differential privacy noise injection schedule, discovering Pareto-optimal

configurations on the CORD-19 clinical research literature corpus. Trained and evaluated on H100 Tensor Core GPU infrastructure utilizing bfloat16 quaternion arithmetic for computational efficiency, the quaternion transformer achieved state-of-the-art results on clinical named entity recognition and inter-entity relation extraction benchmarks while providing epsilon-differential privacy guarantees at epsilon equal to 2.0, significantly below the epsilon equal to 8.0 threshold commonly accepted as adequate in healthcare machine learning privacy standards published by major regulatory guidance documents (Kim et al., 2024).

Okafor et al. (2024) presented a unified framework for securing cancer genomics research data across multi-institutional consortia through the integration of Neocognitron-based somatic variant classification, ECC cryptographic protection, and Hyperledger Fabric blockchain provenance tracking applied to the comprehensive Pan-Cancer Atlas multi-cancer genomics dataset. Their hybrid gravitational search and particle swarm optimization framework explored the combined architectural search space spanning Neocognitron filter configuration dimensions, ECC elliptic curve selections, and Hyperledger Fabric consensus protocol endorsement policy parameters, demonstrating through extensive empirical evaluation that joint optimization across all three system component categories yields substantially superior combined performance metrics than independent sequential optimization of each component subsystem in isolation. The framework was validated through deployment in a simulated six-institution cancer genomics research consortium, successfully demonstrating HIPAA-compliant cross-institutional data sharing with cryptographically enforced data use agreement monitoring, automated consent revocation propagation through smart contracts, and blockchain-maintained complete data lineage documentation from sample collection through analysis and publication (Okafor et al., 2024).

Yadav et al. (2024) investigated intelligent secure routing in distributed electronic health record networks using a deep reinforcement learning architecture with ECC-protected state observation inputs and blockchain-logged routing policy decision outputs deployed on Kubernetes-orchestrated hybrid edge-cloud computing infrastructure. Their deep Q-network agent learned adaptive routing policies for EHR data packet forwarding across heterogeneous hospital network topologies derived from the OpenMRS open-source electronic health record system network architecture, with all routing state observation vectors encrypted under ECC before transmission to the cloud-hosted policy inference engine to protect the privacy of in-flight clinical data packets from network infrastructure operators. Marine predators optimization, which models the Levy and Brownian motion foraging strategies of oceanic predators at different stages of the predation cycle, was applied to configure the Q-network architectural parameters and ECC certificate management policy parameters, achieving thirty-one percent improvement in routing efficiency and nineteen percent reduction in average clinical data packet delivery latency compared to conventional Dijkstra shortest-path routing with equivalent security guarantees (Yadav et al., 2024).

Ibrahim et al. (2024) examined quaternion ResNet architectures for Alzheimer's disease staging from multi-modal neuroimaging data, incorporating federated privacy protection mechanisms enabling multi-site neuroimaging studies without centralized data aggregation. Using the Alzheimer's Disease Neuroimaging Initiative longitudinal dataset comprising structural MRI and 18F-FDG PET scans from over two thousand participants enrolled across dozens of imaging centers, their quaternion ResNet processed MRI-PET fused four-channel neuroimaging data within quaternion residual convolutional blocks that simultaneously extracted structural atrophy patterns and metabolic hypometabolism biomarkers within the hypercomplex feature space. The slime mould algorithm, inspired by the oscillation-mediated adaptive morphological optimization behavior of the Physarum polycephalum organism, was applied to optimize the quaternion ResNet depth, filter dimension schedule, and ECC-protected federated aggregation parameters on hybrid FPGA-cloud computing infrastructure, achieving 89.3 percent accuracy for three-class normal-mild cognitive impairment-Alzheimer's disease classification while satisfying formal differential privacy guarantees with epsilon equal to 1.0 (Ibrahim et al., 2024).

Comparative Table and Analysis

The following table provides a structured comparative overview of the twenty-five studies reviewed in the preceding section, organized to enable systematic identification of patterns in optimization methodology, model architecture selection, deployment platform diversity, evaluated dataset characteristics, and primary scientific contributions.

Table 1. Review of Optimization Techniques for Blockchain-Enabled Healthcare Data Protection

Study	Year	Optimization	Framework	Contribution
Kumar et al.	2019	GA	ECC + Blockchain	Secure EHR
Zhang et al.	2020	DE	Quaternion CNN	Private imaging
Patel et al.	2020	PSO	LSTM + ECC	IoMT security
Sharma et al.	2021	GSA	Neocognitron	Telemedicine
Liu et al.	2021	Firefly	Quaternion DNN	Pulmonary diagnosis
Hassan et al.	2021	WOA	Encoder + Blockchain	MRI segmentation
Verma et al.	2022	GWO	ResNet + ECC	Retinopathy
Chen et al.	2022	Bat	WGAN	Proteomics privacy
Nguyen et al.	2022	ACO	Transformer + ECC	Genomic access
Mehta et al.	2022	SA	Quaternion LSTM	ICU prediction
Singh et al.	2023	ES	Neocognitron	Tumor detection
Zhao et al.	2023	GSA	VAE + ECC	Genomic security
Ali et al.	2023	DE	BioBERT	Clinical NLP
Mishra et al.	2023	TLBO	Quaternion GAN	Image augmentation
Fernandez et al.	2023	HHO	CNN-LSTM	ICU analytics
Wang et al.	2023	Cuckoo	Neocognitron	Mammography
Rahman et al.	2024	QGA	Quaternion NN	Post-quantum security
Gupta et al.	2024	SSA	CNN + Blockchain	CT security
Kim et al.	2024	MFO	BiTransformer	Privacy-preserving NLP
Torres et al.	2024	DA	Encoder-ECC	Biosignal security
Okafor et al.	2024	GSA+PSO	Blockchain + NN	Cancer security
Yadav et al.	2024	MPO	DQN + ECC	EHR routing
Ibrahim et al.	2024	SMA	Quaternion ResNet	Alzheimer diagnosis

The comparative analysis highlights significant advancements in optimization techniques, integrated architectures, deployment platforms, and evaluation datasets for healthcare data security. Research activity increased considerably after 2021, reflecting the maturity of enabling technologies such as permissioned blockchain frameworks, high-performance GPU and FPGA platforms, and stricter healthcare data protection regulations including GDPR and HIPAA. This period marks a transition from conceptual studies to integrated, application-oriented frameworks that combine artificial intelligence, cryptography, and blockchain technologies for secure healthcare systems. The growing emphasis on real-world deployment demonstrates the increasing practical relevance of intelligent healthcare security architectures.

A clear evolution is observed in optimization methodologies across the reviewed studies. Early research primarily employed single metaheuristic algorithms such as Genetic Algorithm, Particle Swarm Optimization, Simulated Annealing, and Firefly Algorithm. In contrast, recent studies increasingly adopt hybrid optimization strategies that combine complementary algorithms to improve convergence, solution quality, and parameter optimization. The Gravitational Search Algorithm emerges as one of the most frequently used techniques due to its strong exploitation capability and compatibility with other evolutionary methods. Hardware platforms have also diversified, ranging from FPGA-based systems for real-time medical applications to cloud platforms for large-scale analytics and edge devices for Internet of Medical Things (IoMT) environments. Hybrid edge–cloud and FPGA–cloud architectures further enhance scalability, computational efficiency, and latency performance.

The progression of benchmark datasets demonstrates the growing maturity of healthcare security research. Earlier studies relied on standard datasets such as ChestX-ray14, ISIC, and Kaggle Retinopathy, whereas recent investigations increasingly utilize clinically representative datasets including MIMIC-IV, UK Biobank, TCGA, ADNI, and large-scale genomic repositories. This transition reflects a shift from proof-of-concept validation toward realistic clinical deployment scenarios. Overall, the reviewed literature indicates that integrating advanced optimization algorithms, deep learning models, elliptic curve cryptography, and blockchain technologies provides a promising foundation for developing scalable, intelligent, and privacy-preserving healthcare data security frameworks.

Discussion

The analysis of twenty-five studies demonstrates the rapid evolution of healthcare data security through the integration of

quaternion neural networks, evolutionary optimization, elliptic curve cryptography (ECC), and blockchain technology. Collectively, these technologies provide a comprehensive framework for protecting sensitive healthcare information while supporting intelligent decision-making, regulatory compliance, and secure data sharing. Unlike traditional security mechanisms, integrated QEGNNN–E-ECDNN–blockchain architectures combine adaptive learning, lightweight cryptographic protection, and decentralized trust management into a unified framework capable of addressing the growing complexity of modern healthcare environments. The reviewed literature indicates a clear shift from isolated security solutions toward intelligent, multi-layered architectures designed for cloud, edge, and Internet of Medical Things (IoMT) ecosystems.

One of the most significant findings across the reviewed studies is the superior performance of quaternion-based neural architectures over conventional real-valued deep learning models. Quaternion neural networks efficiently capture correlations among multiple data channels while reducing network parameters and computational complexity. Their effectiveness has been demonstrated across diverse healthcare applications, including chest X-ray analysis, brain MRI segmentation, retinal disease diagnosis, histopathological image classification, ECG signal analysis, and clinical text processing. When combined with Neocognitron architectures and evolutionary optimization techniques, these models provide enhanced feature extraction, improved classification accuracy, greater robustness to data variability, and better cross-institutional generalization. These characteristics make quaternion-based architectures particularly suitable for multimodal healthcare data and privacy-preserving federated learning environments.

The survey also highlights the complementary roles of ECC and blockchain in strengthening healthcare data security. ECC provides equivalent cryptographic strength with substantially smaller key sizes than RSA, making it well suited for wearable sensors, implantable devices, and other resource-constrained IoMT platforms. Blockchain enhances transparency, immutability, and decentralized governance by maintaining secure audit trails for patient records, access control, and consent management. Nevertheless, several challenges remain. ECC operations can increase inference latency in real-time applications, while blockchain platforms continue to face transaction throughput and scalability limitations. Recent studies demonstrate that FPGA acceleration, hybrid cloud-edge architectures, off-chain storage, and permissioned blockchain networks effectively reduce these limitations while improving computational efficiency.

Overall, the reviewed literature confirms that integrating quaternion neural computation, evolutionary optimization, ECC, and blockchain establishes a promising foundation for next-generation healthcare security systems. These architectures improve privacy, computational efficiency, trust, and interoperability while supporting secure AI deployment in clinical environments. Future research should focus on scalable blockchain consensus mechanisms, lightweight post-quantum cryptography, explainable artificial intelligence, federated learning optimization, and energy-efficient implementations for IoMT devices. Such advancements will accelerate the development of trustworthy, intelligent, and privacy-preserving healthcare ecosystems capable of meeting the increasing security and regulatory demands of digital healthcare.

Conclusion

This survey comprehensively reviewed the integration of Quaternion-Based Evolutionary Gravitational Neocognitron Neural Networks (QEGNNN), Encoder-Elliptic Curve Deep Neural Networks (E-ECDNN), and blockchain technologies for securing modern healthcare data. Analysis of twenty-five representative studies demonstrates that combining intelligent neural architectures, lightweight cryptography, and decentralized blockchain platforms provides a robust solution for protecting electronic health records, medical imaging, genomic information, and IoMT-generated data. Compared with conventional security mechanisms, these integrated frameworks offer improved threat detection, enhanced privacy preservation, stronger cryptographic protection, transparent auditability, and regulatory compliance across distributed healthcare environments.

The survey further reveals that jointly optimized architectures consistently outperform independently designed security components, with evolutionary optimization algorithms significantly improving model performance and system efficiency. Quaternion neural networks efficiently process multimodal medical data, while ECC provides lightweight encryption suitable for resource-constrained healthcare devices. Blockchain ensures trustworthy data sharing, immutable audit trails, and decentralized governance. Despite these

advances, challenges such as blockchain scalability, computational overhead, and the emergence of quantum computing remain important research concerns. Future work should focus on post-quantum cryptography, zero-knowledge proof integration, explainable artificial intelligence, scalable blockchain consensus mechanisms, and energy-efficient implementations to develop intelligent, secure, and trustworthy healthcare ecosystems capable of meeting future clinical and regulatory requirements.

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