International Journal of Scientific Research and Modern Technology (IJSRMT) ijsrmt.com
Volume 2, Issue 4, 2023
DOI: https://doi.org/10.38124/ijsrmt.v2i4.746

Explainable Risk Controls for Digital Health Payments: SHAP-Constrained Gradient Boosting with Policy-Based Access, Audit Trails, and Chargeback Mitigation

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Publication Date 2023/04/28

Abstract

The rapid expansion of digital health payments has introduced new opportunities for efficiency, accessibility, and innovation in healthcare financing. However, this evolution also brings heightened exposure to fraud, data misuse, and systemic vulnerabilities that can undermine trust in digital health ecosystems. Ensuring that risk controls are not only effective but also explainable is increasingly vital for fostering accountability and regulatory compliance. This study explores a framework that integrates explainable machine learning, particularly SHAP-constrained gradient boosting, with layered governance mechanisms such as policy-based access control, audit trails, and chargeback mitigation. The objective is to balance predictive accuracy with interpretability, providing healthcare providers, regulators, and financial intermediaries with transparent insights into payment risk patterns. By embedding explainability into fraud detection and transaction monitoring, stakeholders can enhance decision-making, ensure fairness, and strengthen patient and provider trust. Furthermore, the inclusion of auditability and traceability supports compliance with evolving data protection regulations, while policy-driven access management reduces insider threats. Chargeback mitigation mechanisms provide an additional safeguard for consumers and healthcare organizations, reducing financial losses and disputes. Together, these risk controls contribute to a secure, transparent, and resilient digital health payment infrastructure. The paper highlights the potential of explainable, policy-driven systems to redefine risk management in healthcare finance and to foster sustainable digital adoption.

Keywords: *Explainable Artificial Intelligence (XAI), Digital Health Payments, Risk Controls, Policy-Based Access, Chargeback Mitigation*

I. INTRODUCTION

➢ *Evolution of Digital Health Payments*

The Evolution of Digital Health Payments has been driven by a convergence of technological innovation, consumer expectations, and rising healthcare costs. Ononiwu et al. (2023) highlights how legacy paper billing and manual workflows, which once dominated healthcare administration, have been steadily replaced by automated billing engines powered by artificial intelligence and machine learning. As healthcare spending surged billing administration alone accounting for nearly $300 billion of the U.S. healthcare spend organizations adopted digital tools to reduce inefficiencies and accelerate payment cycles. Embedded finance tools such as mobile platforms, digital wallets, and "buy-now-pay-later" plans have become increasingly attractive as patients face escalating out-of-pocket burdens and seek more flexible, retail-like payment experiences (Ononiwu et al., 2023).

Furthermore, Teker et al. (2022) trace key milestones in the broader digital payment ecosystem that underpin these healthcare trends. From the first ATM in 1967 to contactless credit card innovations in 1999, the emergence of blockchain in 2009, Google Wallet in 2011, and Visa's Click-to-Pay in 2020, these developments collectively forged the infrastructure and user familiarity that now extend into digital health payments. The proliferation of smart cards, mobile apps, and biometric authentication in mainstream finance has created both the technological foundation and the user trust necessary for digital health payment solutions to flourish (Teker et al., 2022).

➢ *Challenges in Risk Management and Trust*

Challenges in Risk Management and Trust in digital health payments are fundamentally tied to the complexities of implementing large-scale, interoperable systems within a highly regulated environment. Scheibner et al. (2021) delineate how eHealth implementations face significant legal, ethical, and socio-technical hurdles, including fragmented policy landscapes, heterogeneous technical platforms, and insufficient standardization each of which elevates systemic risk and undermines stakeholder confidence. The lack of cohesive interoperability frameworks and unified governance adds friction to secure payment reconciliation, heightens susceptibility to fraud, and hampers seamless auditability, all of which are critical to risk control and trust in financial transactions (Scheibner et al., 2021).

Beyond structural factors, challenges in end-user trust are deeply rooted in technical reliability and perceptions of data misuse. The scoping review published in the Journal of Medical Internet Research identifies trust-impeding elements such as information misuse fears, defective technologies, poor information quality, and inadequate transparency on who accesses patient data. These concerns are amplified when financial and health data converge, raising the stakes for both institutions and individuals. The anxiety that personal or payment data may be exploited especially without clear safeguards or visible accountability erodes user confidence and poses a material threat to adoption and system integrity (Elements of Trust in Digital Health Systems: Scoping Review, 2018).

➢ *Importance of Explainable and Transparent Controls*

Importance of Explainable and Transparent Controls frames the essential role that interpretability and openness play in fostering confidence in digital health payment systems. As Amann et al. (2020) emphasize, in healthcare contexts where decisions have critical financial and clinical implications black-box models undermine user trust and impede accountability. Explainability mechanisms such as SHAP, LIME, or saliency maps provide end users with concrete, intelligible rationales behind each decision. For example, when a flagged payment transaction is accompanied by a clear breakdown of feature contributions such as anomalous billing amounts, provider location, or mismatch with diagnostic codes clinicians and financial officers are better equipped to validate and accept the system's risk assessment (Amann et al., 2020).

Equally, transparent controls serve as guardrails for model governance and auditability. Markus, Kors, and Rijnbeek (2020) argue that without transparent model design and explanation strategies, clinicians and regulators cannot assess algorithmic fidelity or detect hidden biases. Transparent systems allow for traceability from data inputs to model outputs thus underpinning external validation and compliance. For instance, when a chargeback case arises, audit trails enriched with explainable annotations make it possible to reconstruct the decision path, evaluate fairness, and refine system parameters. In the domain of digital health payments, such capabilities are indispensable for establishing institutional trust and operational resilience (Markus et al., 2020).

➢ *Objective and Scope of the Study*

The primary objective of this study is to examine the integration of explainable risk controls into digital health payment systems, with a particular focus on SHAP-constrained gradient boosting, policy-based access management, audit trails, and chargeback mitigation. The study seeks to highlight how the combination of explainability and governance mechanisms can strengthen risk detection, promote accountability, and enhance trust across healthcare financial transactions. By focusing on interpretability, the research underscores the importance of providing stakeholders patients, providers, financial institutions, and regulators with transparent insights that support informed decision-making and regulatory compliance.

The scope of the study extends across multiple dimensions of digital health payments, encompassing technical, regulatory, and operational perspectives. It addresses both systemic risks, such as fraud and insider threats, and user-centric concerns, including data misuse, financial disputes, and trust erosion. The analysis situates explainable machine learning within a broader risk management framework that integrates governance policies, transaction traceability, and consumer protection mechanisms. By doing so, the study not only evaluates the current state of digital health payments but also proposes a resilient model capable of supporting sustainable adoption and long-term digital transformation in healthcare finance.

➢ *Structure of the Paper*

The structure of this paper is organized to provide a coherent and logical flow of ideas, beginning with the introduction, which outlines the background, objectives, and scope of the study. Following this, the literature review critically examines existing scholarship and frameworks relevant to digital payment systems, governance, and dispute management, highlighting gaps that this research seeks to address. The methodology section details the analytical approach and frameworks used to evaluate payment risks and safeguard mechanisms. The subsequent sections present the findings, focusing on key dimensions such as reducing patient disputes, integrating chargeback safeguards, and aligning payment systems with policy-driven governance. Each thematic area is discussed with supporting evidence, drawing on best practices and contemporary challenges. The discussion then synthesizes these findings to illustrate their broader implications for patients, providers, and regulators. Finally, the paper concludes by offering future directions for resilient digital payment systems, emphasizing pathways toward building trust, ensuring compliance, and fostering sustainable innovation in healthcare finance.

II. LANDSCAPE OF DIGITAL HEALTH PAYMENT RISKS

➢ *Fraud and Transactional Vulnerabilities*

Fraud and Transactional Vulnerabilities within digital health payment systems arise from intricate sociotechnical interdependencies and legacy infrastructure gaps. Ewoh and Vartiainen (2023) as presented in figure 1 expose how healthcare networks, burdened by outdated systems and insufficient endpoint governance, become prime targets for cyberattacks. The proliferation of interconnected devices often unpatched and unmanaged creates multiple ingress points for attackers, putting payment systems at risk through lateral movement and data exfiltration. For example, compromised imaging systems or smart medical devices can facilitate unauthorized billing access or manipulation of financial records, undermining the integrity of transactional flows and precipitating both financial leakage and operational disruptions (Akinleye et al., 2023).

Meanwhile, Atalor et al. (2023) illustrate how the lack of transparent and accountable claim submission processes enables sophisticated fraud schemes such as phantom billing, upcoding, and unbundling. Their proposed blockchain-enabled, smart contract architecture with multisignature verification by patients, providers, and payers demonstrates how immutable records and distributed validation can thwart fraudulent claims. Without such mechanisms, conventional systems remain vulnerable to denial-of-service attacks, internal collusion, and post-payment disputes. In sum, the absence of hardened, auditable controls and distributed validation pathways in existing digital health payment workflows amplifies both technical and opportunistic vulnerabilities, demanding layered, resilient countermeasures aligned with contemporary threats (Okoh & Grace, 2022).

Fig 1 Picture of Digital Financial Ecosystem and Fraud Vulnerabilities (Ewoh and Vartiainen, 2023)

Figure 1 illustrates a digital financial ecosystem, highlighting interconnected platforms, transactions, and virtual assets, which directly relates to Fraud and Transactional Vulnerabilities. In such a system, the multiple layers of digital wallets, mobile banking applications, and blockchain-based transaction flows present potential entry points for fraudsters to exploit. Risks include identity theft, unauthorized access, phishing attacks, and manipulation of digital payment processes, as criminals may exploit weaknesses in authentication, system integration, or user awareness. The visual emphasis on currency tokens and transaction nodes underscores how the increasing complexity of financial technologies, while improving efficiency, also magnifies exposure to fraudulent activities if not supported by robust cybersecurity measures, regulatory oversight, and real-time monitoring.

➢ *Data Privacy and Misuse Concerns*

Data Privacy and Misuse Concerns are paramount in digital health payment systems, where sensitive financial and clinical data intersect and transparency is essential. Grande et al. (2020) as represented in table 1 highlight critical threats arising from the "digital health footprint," noting features such as invisibility users' unawareness of tracking practices and immortality data persisting indefinitely and identifiability easy re-identification of individuals even from aggregated data. These characteristics not only facilitate unwanted profiling but also create lucrative avenues for misuse in digital payment contexts, where identity-linked transaction trails might be monetized without user consent or awareness (Ijiga et al., 2021).

Equally troubling are the findings of Cory, Rieder, and Huynh (2023), who analyzed 152 mHealth apps and uncovered pervasive vulnerabilities in privacy design. They document widespread leakage of protected health and personally identifiable information to third-party trackers, coupled with neglect of transparency and "privacy by design" principles. When such breaches occur in payment-enabled health apps, they can expose financial identifiers, behavioral patterns, or health conditions to unauthorized actors raising risks of discriminatory pricing, identity theft, or stigmatization. These dual pressures opaque data capture and unchecked external sharing underscore the urgent need for robust, explainable, and enforceable privacy controls within digital health payment infrastructures.

Table 1 Summary of Data Privacy and Misuse Concerns

Key Issue	Description	Implications	Possible Mitigation Strategies
Unauthorized Access	Occurs when sensitive patient data is accessed without proper authorization.	Leads to breaches of confidentiality, reputational damage, and potential legal penalties.	Implement strong authentication protocols and role-based access controls.
Data Misuse	Involves the exploitation of patient information for unauthorized financial, commercial, or personal gains.	Can undermine trust in digital payment systems and increase regulatory scrutiny.	Enforce strict data governance policies and continuous monitoring of data handling.
Inadequate Consent	Patients may not fully understand how their data is collected, stored, and used.	Raises ethical concerns, compliance risks, and possible disputes with regulators.	Enhance transparency with clear consent mechanisms and patient education.
Weak Data Protection	Insufficient encryption or outdated security practices increase vulnerability to cyberattacks.	May cause large-scale data leaks and financial losses.	Adopt advanced encryption standards, regular audits, and compliance with global data protection regulations.

- *Regulatory and Compliance Pressures*

Regulatory and Compliance Pressures exert profound influence on the deployment of digital health payment systems, where innovation often outpaces regulatory frameworks. Atalor et al. (2023) describe how health care artificial intelligence exists in a liminal regulatory space, frequently falling outside the jurisdiction of traditional oversight bodies like the FDA or agencies governing privacy or quality of care. This ambiguity complicates compliance, as developers grapple with navigating fragmented mandates that may not clearly encompass emerging technologies. Digital payment modules embedded within health platforms risk operating without established safety or fairness thresholds, creating potential for audit failures or unchecked risk exposure (Ijiga et al., 2021).

Simultaneously, Ebrahim (2023) underscores how the explosive growth of healthcare regulations ueled by proliferation of state, federal, and data protection mandates poses operational burdens. He notes that compliance systems remain largely manual and resource-intensive, with manual tracking of hundreds of evolving regulatory mandates per year. This state impairs scalability, delays innovation cycles, and increases exposure to costly penalties and disruptions. Particularly for digital health payments, which cross technical, financial, and patient domains, institutions must continually monitor shifting frameworks (e.g., HIPAA, GDPR, AI Act) while remaining agile highlighting the imperative for explainable, automated, and policy-aligned risk controls embedded within payment infrastructures.

III. ROLE OF EXPLAINABLE MACHINE LEARNING IN RISK CONTROL

- *Importance of Interpretability in Financial Decisions*

Importance of Interpretability in Financial Decisions becomes paramount when AI-driven models impact high-stakes financial outcomes such as credit approval, fraud detection, or transaction adjudication. Černevičienė and Kabašinskas (2023) as represented in table 2 systematically analyze diverse XAI applications and conclude that interpretability tools such as SHAP-based feature importance are critical in justifying model decisions. These tools enable financial practitioners and auditors to trace outputs back to specific variables such as claim amount anomalies, provider geolocation, or patient profile deviations which is essential when evaluating flagged health payment transactions. Without this transparency, institutions are exposed to model opacity risks, including unchallenged biases and decision leakage (Ijiga et al., 2022).

AlSaleh and Mazhar (2023) reinforce that model-agnostic principles, like local surrogate models or rule-based explanations, support interpretability across varied algorithmic frameworks. They emphasize that such transparency is not merely desirable it is integral for building stakeholder trust and ensuring regulatory compliance in financial contexts. For instance, when a digital health payment is flagged for risk, interpretable explanations can guide financial officers or compliance teams to assess fairness, detect bias, and satisfy audit requirements. In the ecosystem of healthcare finance, interpretability thus underpins the credibility, accountability, and resilience of automated decision systems (Atalor, 2019).

Table 2 Summary of Importance of Interpretability in Financial Decisions

Key Aspect	Description	Implications	Possible Approaches
Transparency	Ensures that financial models and payment algorithms can be understood by stakeholders.	Builds confidence among patients, providers, and regulators, reducing skepticism about automated decisions.	Use explainable AI frameworks and provide clear model documentation.
Accountability	Helps trace the reasoning behind financial decisions such as billing or chargebacks.	Strengthens compliance with regulations and reduces disputes related to opaque decision-making.	Incorporate audit trails and decision-logging systems.
Trust	Patients and providers are more likely to accept financial outcomes if decisions are explainable.	Enhances adoption of digital payment systems and lowers resistance to automation.	Provide user-friendly explanations of payment decisions in real-time dashboards.
Risk Management	Interpretability allows for early detection of anomalies or unfair financial practices.	Reduces financial fraud, regulatory penalties, and systemic vulnerabilities.	Apply interpretable machine learning models and regular stress-testing of payment systems.

- *SHAP-Constrained Gradient Boosting for Transparency*

The integration of SHAP-constrained gradient boosting into financial decision-making frameworks has emerged as a vital approach for enhancing transparency and accountability. Gradient boosting algorithms, while powerful in capturing complex nonlinear relationships in digital payment risk assessments, often function as "black-box" systems, limiting interpretability (Ijiga et al., 2023). By applying SHAP (Shapley Additive Explanations) constraints, decision pathways become more intelligible, enabling stakeholders to trace how features such as transaction amount, geolocation, and device identifiers contribute to fraud detection and chargeback predictions. This transparency fosters greater trust in automated systems and reduces regulatory challenges in highly sensitive domains like digital health payments, where accuracy and explainability are equally critical (Lundberg et al., 2020).

Moreover, the combination of SHAP explanations with gradient boosting enhances compliance by aligning machine learning outcomes with policy-driven risk controls. For example, when unusual payment behavior triggers a fraud alert, SHAP values can highlight the most influential factors, making it possible for auditors and compliance officers to verify algorithmic reasoning. This ensures not only technical soundness but also ethical accountability, as decision-making logic is explicitly documented. In financial ecosystems where policy adherence, user protection, and chargeback mitigation are paramount, SHAP-constrained gradient boosting provides an advanced yet interpretable pathway for balancing efficiency with transparency (Zhang et al., 2022).

- *Enhancing Stakeholder Trust through Explainable AI*

The increasing integration of Artificial Intelligence into high-stakes domains such as finance and healthcare has amplified concerns about transparency and accountability. Stakeholders including regulators, investors, patients, and clients require assurance that AI-driven decisions are not only accurate but also understandable and justifiable. Explainable AI (XAI) frameworks provide interpretability by making complex models comprehensible, thereby fostering trust and acceptance. For instance, techniques such as Local Interpretable Model-agnostic Explanations (LIME) and SHapley Additive Explanations (SHAP) allow stakeholders to see which variables influence predictions, ensuring alignment with ethical and legal expectations as presented in figure 2 (Ribeiro et al., 2016). By contextualizing AI outcomes in familiar business or clinical reasoning, organizations enhance transparency and demonstrate a commitment to fairness.

Moreover, stakeholder trust extends beyond technical transparency to include perceived reliability and fairness in AI deployment. XAI addresses these concerns by integrating ethical dimensions into algorithmic accountability, ensuring that decision-making processes are not biased or opaque. This is particularly critical in finance, where credit scoring must avoid discriminatory patterns, and in healthcare, where patient safety depends on clear clinical justifications. By embedding explainability, firms move closer to responsible AI practices that strengthen long-term relationships with regulators and clients (Arrieta et al., 2020). As a result, explainability not only mitigates risk but also becomes a strategic asset for enhancing credibility and sustainable innovation.

Figure 2 shows business professionals attentively engaging with a humanoid robot, symbolizing the growing role of artificial intelligence in decision-making. In the context of Enhancing Stakeholder Trust through Explainable AI, it highlights how transparency and clarity in AI systems are essential for building confidence among diverse stakeholders whether they are regulators, providers, or clients. Just as the individuals in the image seek to understand and evaluate the robot's input, stakeholders in real-world applications expect AI systems to justify their outcomes in an interpretable manner. Explainable AI ensures that decisions are not seen as "black box" outputs but rather as transparent, accountable processes, thereby fostering collaboration, trust, and acceptance across different sectors.

Fig 2 Picture of Building Trust Through Transparent AI Decisions (Ribeiro et al., 2016).

IV. POLICY-BASED ACCESS CONTROL IN DIGITAL HEALTH SYSTEMS

➢ *Reducing Insider Threats with Access Governance*

Insider threats remain one of the most critical challenges in cybersecurity because they exploit legitimate access rights to compromise systems. Access governance plays a pivotal role in mitigating these risks by establishing clear oversight mechanisms that define, monitor, and enforce access privileges. By aligning access controls with the principle of least privilege, organizations can minimize opportunities for misuse while ensuring accountability. For example, role-based access control (RBAC) and attribute-based access control (ABAC) models provide structured frameworks for granting permissions based on contextual needs, thereby limiting the scope of insider-driven data breaches (Alneyadi et al., 2016). Such governance mechanisms ensure that only authorized individuals interact with sensitive datasets, reducing the likelihood of accidental or malicious misuse.

Furthermore, access governance incorporates periodic audits, continuous monitoring, and anomaly detection to identify suspicious activities that may indicate insider threats. This includes detecting irregular login behaviors, privilege escalations, or unauthorized data transfers. Embedding access governance into organizational information security management systems not only prevents data leakage but also strengthens compliance with regulatory requirements (Coles-Kemp & Hansen, 2017). For instance, financial institutions and healthcare organizations use access governance solutions to maintain strict oversight of sensitive information, balancing operational efficiency with robust protection. By integrating proactive monitoring with adaptive access policies, organizations foster a resilient defense posture against insider threats.

➢ *Role-Based vs. Attribute-Based Access Models*

Role-based access control (RBAC) and attribute-based access control (ABAC) represent two foundational paradigms for managing user permissions in complex systems. RBAC assigns access rights based on organizational roles, ensuring consistency and simplicity in environments with stable hierarchies as presented in figure 3 (Sandhu et al., 1996). For example, in digital health payment systems, clinicians, auditors, and administrators may each receive predefined roles that restrict their access to only relevant data. This reduces administrative complexity and enforces the principle of least privilege. However, RBAC can become rigid when organizations require more dynamic access decisions, particularly in sectors where contextual variables such as time, location, or transaction risk must be considered (Ajayi et al., 2019).

ABAC, by contrast, enhances flexibility by granting access based on attributes tied to users, resources, and the environment (Hu et al., 2015). In practice, ABAC allows digital health platforms to enforce fine-grained policies, such as permitting a medical officer to approve transactions only during working hours or restricting

cross-border payment approvals based on jurisdictional regulations. This adaptability is critical in mitigating fraud while ensuring compliance with evolving standards. By integrating ABAC with RBAC, organizations can balance operational efficiency with nuanced access governance, thereby strengthening digital health payment ecosystems against insider and external threats (James et al., 2023).

Figure 3 illustrates a healthcare ecosystem where multiple stakeholders patients, physicians, insurance companies, pharmacies, hospitals, and agents interact through digital records, ID cards, electronic prescriptions, and medical certificates. In this context, Role-Based Access Control (RBAC) would restrict access according to predefined roles, such as physicians accessing medical records or pharmacies viewing prescriptions, ensuring that only those with specific job functions can interact with sensitive data. In contrast, Attribute-Based Access Control (ABAC) provides more flexibility by considering attributes like time, location, or patient consent in addition to roles; for example, an emergency responder could gain temporary access to a patient's health records based on the urgency of the situation. While RBAC offers simplicity and efficiency in routine operations, ABAC ensures dynamic, context-aware decision-making, which is especially valuable in complex healthcare scenarios where multiple entities require conditional access to sensitive information.

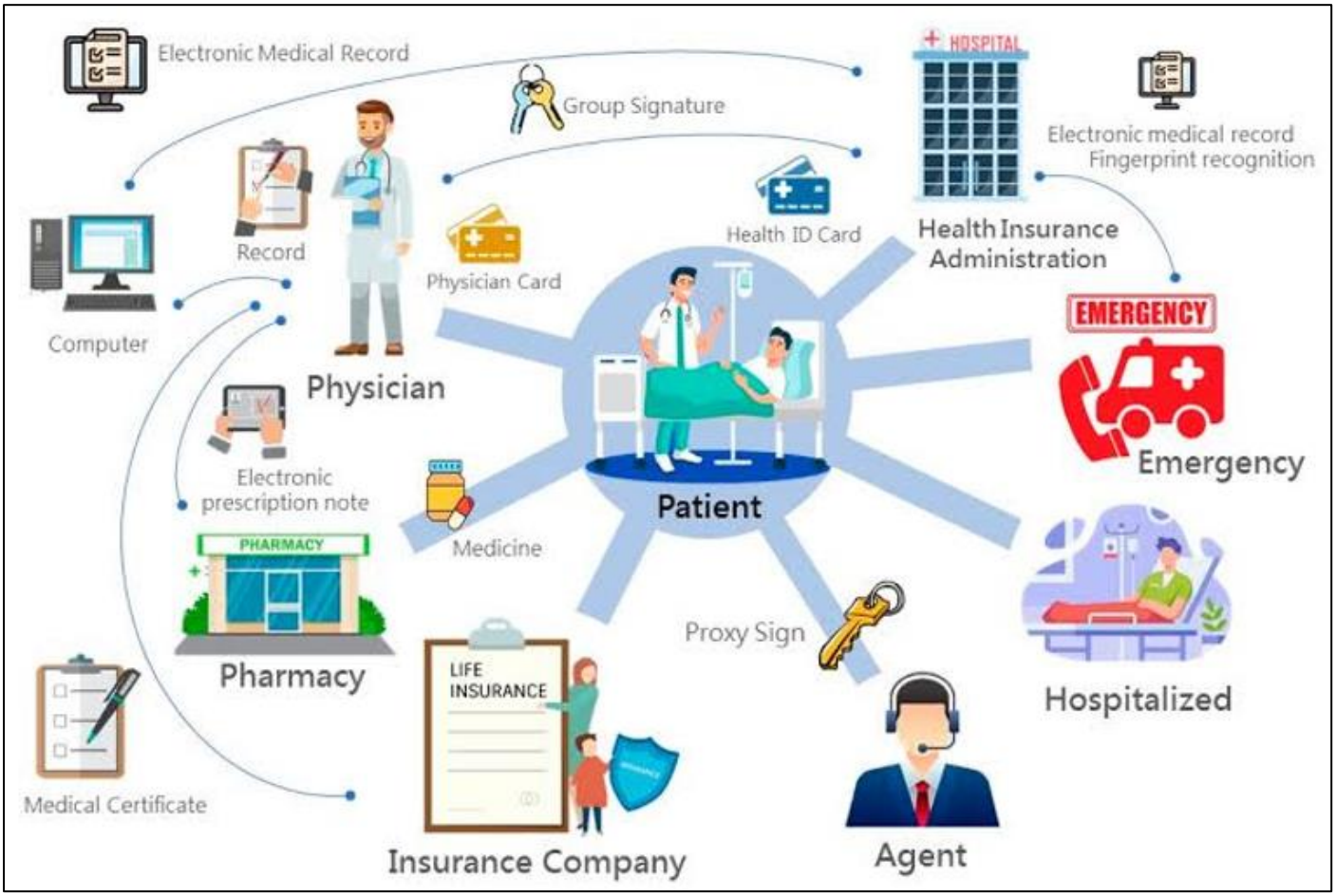

Fig 3 Picture of Balancing Roles and Attributes in Healthcare Data Access (Sandhu et al., 1996).

➢ *Alignment with Healthcare Data Protection Standards*

Ensuring compliance with healthcare data protection standards such as the General Data Protection Regulation (GDPR) and the Health Insurance Portability and Accountability Act (HIPAA) is central to safeguarding digital health payments. These regulations establish robust frameworks for protecting sensitive patient data, mandating mechanisms such as encryption, anonymization, and stringent access controls. Within the context of explainable risk controls, alignment with these standards enhances not only the security of health payment infrastructures but also patient trust in digital financial transactions (Ihimoyan et al., 2022). By embedding compliance-driven policies into access management and audit trail systems, organizations can proactively mitigate risks associated with data breaches and unauthorized disclosures as represented in table 3 (Dehling et al., 2020).

In practice, this alignment demands harmonizing technical safeguards with regulatory imperatives. For instance, integrating role-based and attribute-based controls with GDPR's data minimization principle ensures that only necessary health data is processed in payment workflows. Similarly, HIPAA's emphasis on auditability aligns well with transparent chargeback mitigation strategies that document every transaction event. Such convergence of explainable AI models with global standards enables healthcare payment systems to achieve accountability and resilience while minimizing litigation and reputational risks. Ultimately, adhering to GDPR and HIPAA within risk control architectures strengthens interoperability and fosters cross-border digital health trust (Alahmadi et al., 2022).

Table 3 Summary of Alignment with Healthcare Data Protection Standards

Key Aspect	Description	Implications	Possible Approaches
Regulatory Compliance	Ensuring digital health payment systems adhere to frameworks such as HIPAA, GDPR, and local health data laws.	Reduces legal liabilities and strengthens stakeholder confidence.	Conduct regular compliance audits and integrate policy-based access controls.
Patient Privacy	Safeguarding sensitive medical and financial data during payment transactions.	Builds trust among patients and prevents misuse of personal health information.	Apply strong encryption, tokenization, and anonymization techniques.
Security Integration	Embedding data protection within payment platforms to minimize breaches.	Protects against cyberattacks and data leakage that could disrupt healthcare delivery.	Deploy multi-factor authentication, intrusion detection systems, and real-time monitoring.
Interoperability Standards	Aligning with global healthcare data exchange protocols for seamless payments.	Enhances system efficiency, reduces operational risks, and promotes cross-border healthcare transactions.	Implement HL7/FHIR standards and secure APIs for data sharing.

V. STRENGTHENING ACCOUNTABILITY WITH AUDIT TRAILS

- *Transaction Traceability and Verification*

Transaction traceability and verification are critical components of safeguarding digital health payment systems. Traceability ensures that every transaction from initiation to settlement can be monitored and validated, thereby reducing opportunities for fraud and unauthorized activities (Atalor, 2022). Blockchain-based architectures have gained prominence as effective tools for ensuring immutable and verifiable transaction histories. These distributed ledgers provide a transparent and tamper-resistant record of financial exchanges, enabling healthcare institutions to reconcile accounts while maintaining compliance with global data security regulations as presented in figure 4 (Casino et al., 2019). For example, in digital health insurance claims, blockchain enables stakeholders to track the status of a payment in real time, ensuring accountability across insurers, providers, and patients.

Verification mechanisms complement traceability by authenticating the integrity of each transaction. Cryptographic hashing, consensus algorithms, and smart contracts enable automated verification, reducing reliance on third-party intermediaries and minimizing delays (Atalor et al., 2023). In healthcare payments, these features strengthen fraud prevention while enhancing trust among stakeholders who handle sensitive medical and financial data. Additionally, integration with sustainable digital infrastructures allows traceability solutions to scale efficiently in complex ecosystems such as multi-provider health networks, ensuring both security and interoperability (Kouhizadeh et al., 2021).

Figure 4 illustrating the 20 components of Transaction Traceability and Verification would present them as interconnected layers within a secure payment ecosystem. At the core, elements like unique IDs, real-time verification, and audit trails ensure every transaction is recorded and verifiable. Surrounding this core, features such as blockchain integration, AML compliance, fraud detection, and standardized monitoring provide the structural safeguards needed for reliability and security. The outer layer emphasizes outcomes, including customer trust, accountability, dispute resolution, and consumer protection, which highlight the practical value of these mechanisms. Together, the diagram shows how technical measures, regulatory alignment, and user-focused safeguards integrate to create a transparent, accountable, and resilient digital payment framework.

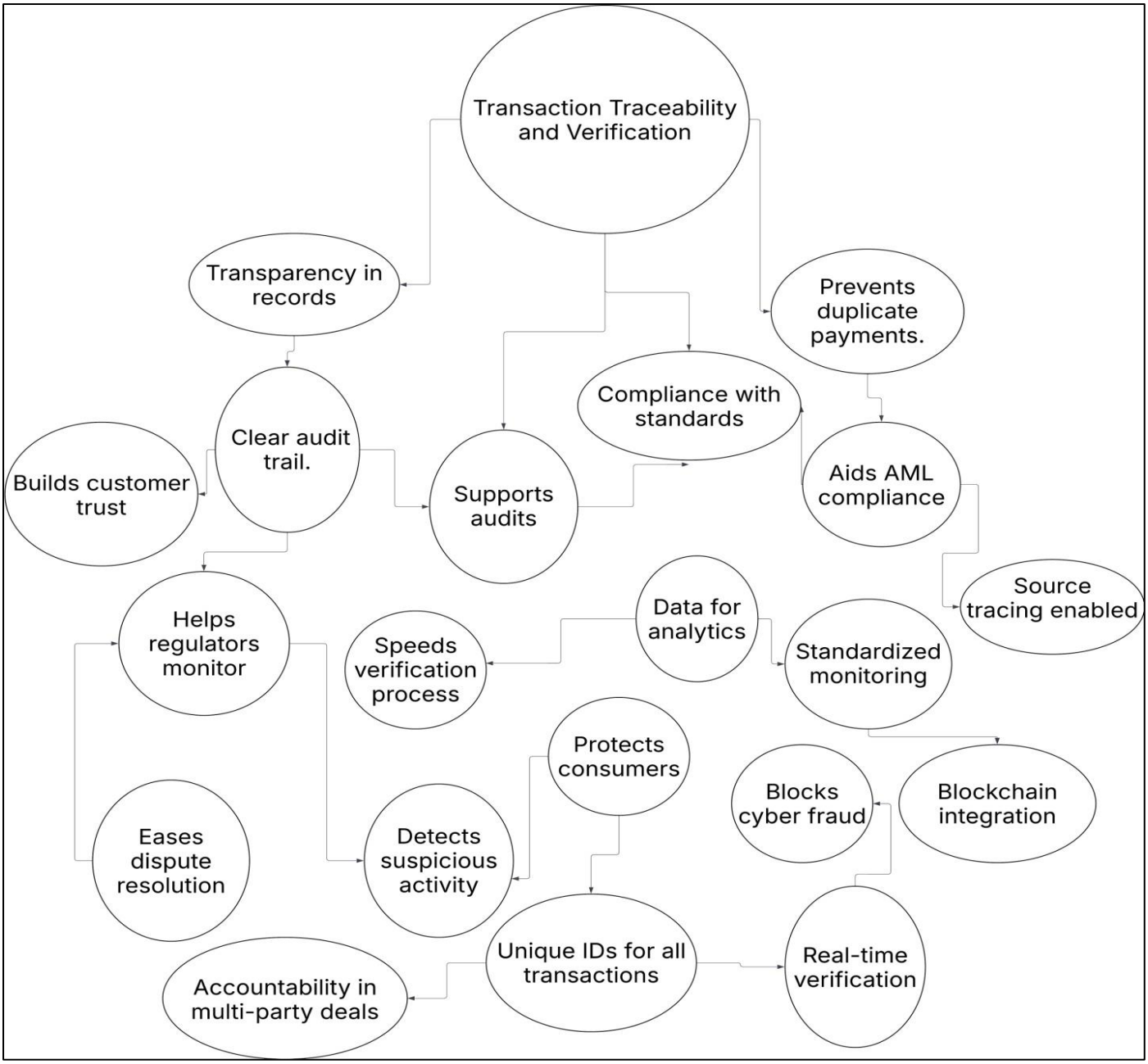

Fig 4 Diagram of Integrated Framework for Transaction Traceability and Verification

➢ *Regulatory Compliance through Auditability*

Ensuring regulatory compliance through auditability is a cornerstone in safeguarding digital health payment systems. As payment infrastructures expand to accommodate electronic transactions in healthcare, regulators increasingly demand transparent, immutable, and verifiable records to deter fraud and enhance accountability. Blockchain-enabled audit trails provide a secure environment where every transaction is time-stamped, cryptographically sealed, and permanently recorded, ensuring non-repudiation and reducing compliance risk. For instance, integrating auditability with artificial intelligence allows regulators to trace irregular payment flows while simultaneously monitoring for anomalies in near real-time, creating an ecosystem where compliance enforcement is embedded into the payment architecture (Chiu & Greene, 2019).

Furthermore, healthcare payments involve complex regulatory frameworks such as HIPAA in the U.S. and GDPR in the EU, which require rigorous protection of sensitive data alongside financial integrity. Smart contracts play a pivotal role in strengthening auditability by automating compliance checks, ensuring that contractual obligations are executed transparently without manual intervention (Atalor, 2022). This improves not only operational efficiency but also regulatory trustworthiness. In healthcare supply chains, smart contracts linked with audit trails have already demonstrated significant improvements in minimizing procurement irregularities and ensuring contractual adherence, which directly translates into higher resilience of digital health payment systems (Omar et al., 2021).

➢ *Supporting Investigations and Dispute Resolution*

Supporting investigations and dispute resolution in digital health payments requires mechanisms that provide transparency, accountability, and verifiability across the payment chain. By embedding detailed audit trails, healthcare institutions and payment providers can reconstruct disputed transactions to identify inconsistencies or fraudulent activities. Such mechanisms

not only facilitate timely resolution of chargebacks but also strengthen trust among patients, providers, and insurers. Blockchain-based frameworks, for example, have been highlighted as effective tools for dispute resolution by ensuring immutability and decentralized verification of financial records as represented in table 4 (Chen et al., 2022). These systems reduce reliance on third parties while providing regulators and investigators with reliable evidence to mediate conflicts.

Moreover, audit trails serve as the backbone of investigative protocols by capturing time-stamped logs of all payment activities. This traceability enables regulators to cross-reference disputed claims against verifiable system records, minimizing delays in settlement processes. In the context of digital health payments, where errors or intentional manipulations can compromise patient trust, robust audit trails create enforceable accountability structures. Studies have shown that institutions leveraging auditability frameworks experience faster dispute closure rates and improved compliance in investigations (Manski & Molnar, 2021). Consequently, the integration of structured audit logs and transparent dispute mechanisms ensures both operational resilience and enhanced consumer confidence.

Table 4 Summary of Supporting Investigations and Dispute Resolution

Key Aspect	Description	Implications	Possible Approaches
Transparent Audit Trails	Maintaining detailed logs of digital health payment transactions.	Facilitates quick identification of irregularities and supports accountability.	Implement immutable ledger systems such as blockchain for tamper-proof records.
Evidence for Disputes	Providing verifiable transaction data to support patient, provider, and regulator claims.	Reduces conflict escalation and strengthens trust in the payment system.	Integrate structured reporting tools that generate real-time case evidence.
Collaboration Mechanisms	Enhancing cooperation between payment processors, healthcare institutions, and regulators.	Improves resolution timelines and reduces operational bottlenecks.	Establish cross-institutional protocols and secure communication channels.
Chargeback Management	Addressing erroneous or fraudulent chargebacks through risk-aware frameworks.	Minimizes financial losses while protecting patient rights.	Deploy automated chargeback monitoring and AI-driven pattern recognition systems.

VI. CHARGEBACK MITIGATION AS A CONSUMER PROTECTION TOOL

- *Financial Loss Prevention for Healthcare Providers*

Financial loss prevention is a critical concern for healthcare providers navigating digital health payment systems. Providers are increasingly exposed to risks from fraudulent transactions, chargeback disputes, and unauthorized access to sensitive financial data. Implementing robust digital payment controls, such as multi-layered authentication, anomaly detection, and policy-based access restrictions, can significantly mitigate these risks. Nguyen and Klein (2021) argue that advanced fraud detection systems leveraging machine learning enhance the ability of healthcare organizations to prevent revenue leakage by identifying irregular billing activities in real-time. For example, predictive analytics can flag suspicious claim submissions, reducing the likelihood of costly reimbursement errors.

Moreover, effective financial loss prevention strategies extend beyond technology to include resilient frameworks that ensure business continuity. Alharthi et al. (2022) as presented in figure 5 highlight that integrating secure and transparent payment infrastructures within digital health ecosystems fosters trust among patients, insurers, and regulators. Healthcare providers adopting such frameworks not only reduce financial exposure but also strengthen compliance with regulatory standards. For instance, maintaining immutable audit trails provides verifiable evidence for disputed claims, thereby lowering the incidence of chargeback-related losses. Thus, financial loss prevention in digital health payments combines proactive technological safeguards with governance practices that reinforce provider sustainability in an increasingly digital healthcare economy (Gracea & Okohb, 2022).

Fig 5 Picture of Healthcare Meets Finance: Safeguarding Against Financial Loss (Alharthi et al., 2022)

Figure 5 illustrate a stethoscope placed over U.S. dollar bills symbolizes the intersection of healthcare and finance, highlighting the critical need for financial loss prevention among healthcare providers. In this context, the stethoscope represents medical practice, while the money underscores the significant costs involved, including equipment, staff, and patient care. Financial loss prevention is essential to safeguard against revenue leakage from billing errors, insurance fraud, or inefficient resource management. Healthcare providers must implement robust systems to monitor claims, reduce waste, and ensure compliance with regulations, thereby protecting their financial stability and enabling continued delivery of quality care.

- *Reducing Patient Disputes and Payment Conflicts*

Reducing patient disputes and payment conflicts is essential to strengthening trust and ensuring efficiency in digital health payment systems. As healthcare transactions increasingly rely on digital platforms, disputes often arise from billing inaccuracies, lack of transparency, or delayed chargeback resolutions. Liu, Chen, and Xu (2021) emphasize that digital technologies can enhance transparency in financial interactions by providing patients with real-time access to itemized billing records and payment histories. This transparency mitigates conflicts by enabling patients to verify service charges before authorization, thereby minimizing post-treatment disputes. For example, blockchain-enabled audit trails in payment processing can offer tamper-proof evidence in cases of contested transactions, creating a neutral basis for conflict resolution.

Additionally, advanced financial technologies such as explainable artificial intelligence (XAI) can detect and address discrepancies in billing, reducing disputes between patients and providers. Gai, Qiu, and Sun (2018) argue that FinTech applications, when combined with machine learning models like SHAP-constrained gradient boosting, allow patients to understand how charges are computed, reducing perceptions of unfairness. Such models improve communication between healthcare providers and patients by ensuring that disputed claims are addressed with data-driven justifications. In turn, this reduces administrative costs and strengthens patient-provider relationships, promoting a more equitable and sustainable healthcare payment ecosystem.

- *Integrating Chargeback Safeguards into Risk Frameworks*

Integrating chargeback safeguards into risk frameworks is critical to maintaining trust and minimizing financial losses in digital health payment systems. Chargebacks, which are often triggered by disputed or fraudulent transactions, pose significant operational risks to healthcare providers and payment processors. By embedding automated safeguards into risk frameworks, organizations can proactively identify high-risk transactions before settlement. Chen, Wu, and Yang (2019) highlight that FinTech innovations, particularly real-time fraud detection algorithms, enable providers to

assess transaction legitimacy dynamically, reducing the frequency of chargebacks. For example, implementing predictive analytics and anomaly detection within digital health platforms allows providers to flag irregular payment patterns such as duplicate claims or abnormally high charges before they escalate into disputes.

Furthermore, machine learning models enhance the adaptability of risk frameworks by continuously learning from new transaction data, thereby strengthening defense mechanisms against evolving fraud schemes. Jagtiani and Lemieux (2019) emphasize that the use of alternative data sources and predictive modeling supports more precise risk classification, minimizing false positives that often frustrate patients. In healthcare, such systems can integrate medical billing histories with payment records to differentiate genuine disputes from fraudulent activities. This dual-layered approach not only reduces revenue leakage but also safeguards patient trust by ensuring that legitimate claims are resolved swiftly and transparently (Grace & Okoh, 2022).

Table 5 Summary of Integrating Chargeback Safeguards into Risk Frameworks

Key Aspect	Description	Implications	Possible Approaches
Risk Identification	Detecting patterns of fraudulent or recurring chargebacks in digital health payments.	Early detection prevents systemic financial risks and patient-provider disputes.	Use predictive analytics and anomaly detection to flag suspicious transactions.
Policy Alignment	Embedding chargeback controls within institutional risk management frameworks.	Ensures compliance with financial regulations and healthcare standards.	Develop standardized policy rules that integrate payment dispute protocols.
Financial Protection	Reducing the impact of unjustified chargebacks on healthcare providers and payment platforms.	Safeguards revenue flow and maintains operational stability.	Implement reserve funds, insurance coverage, or real-time validation checks.
Stakeholder Trust	Enhancing confidence of patients, providers, and regulators in the payment ecosystem.	Builds long-term trust and promotes adoption of digital health payment solutions.	Provide transparent dispute handling processes and periodic performance audits.

VII. TOWARD A SECURE AND SUSTAINABLE DIGITAL HEALTH PAYMENT ECOSYSTEM

- *Integrating Explainability with Policy-Driven Governance*

Integrating explainability into policy-driven governance ensures that the decision-making processes behind digital payment systems in healthcare are transparent, auditable, and aligned with regulatory requirements. As artificial intelligence and automated algorithms increasingly influence financial transactions and fraud detection in digital health, explainability provides the foundation for trust and accountability. By embedding clear, human-understandable reasoning within governance structures, stakeholders such as healthcare providers, patients, and regulators can better understand how automated decisions are made. This not only enhances compliance with data protection laws but also mitigates the risk of bias, unfair treatment, or disputes that could undermine the integrity of digital payment systems.

Policy-driven governance frameworks become more effective when they incorporate explainability as a core principle, ensuring that rules are not only enforced but also communicated in a way that stakeholders can validate (Amebleh, & Omachi, 2022). For example, when policies mandate transparent reporting of flagged or rejected transactions, explainability mechanisms provide the rationale for these actions, reducing ambiguity and reinforcing institutional credibility. In healthcare finance, this integration fosters confidence in both technological systems and regulatory oversight, ensuring that innovation in digital payments advances without compromising fairness, security, or ethical standards.

- *Building Trust Among Patients, Providers, and Regulators*

Building trust among patients, providers, and regulators is fundamental to the adoption and sustainability of digital health payment systems. Patients need assurance that their financial transactions are secure, transparent, and protected against unauthorized access or disputes. Providers, on the other hand, must trust that digital systems will guarantee timely reimbursements, minimize fraud, and offer recourse in case of chargebacks (Amebleh, & Omachi, 2023). Regulators seek confidence that governance frameworks adequately protect public interests while ensuring compliance with healthcare and financial standards. Establishing this tripartite trust requires a balance of technological safeguards, ethical standards, and transparent communication across all parties.

A strong foundation of trust is reinforced through consistency, accountability, and fairness in the operation of digital health payment infrastructures. Patients are more likely to embrace digital platforms when they see clear explanations of charges and policies, while providers gain confidence through predictable reimbursement structures and fraud-prevention measures. Regulators, in turn, view these systems as reliable when they align with established compliance frameworks and are supported by audit trails that verify integrity (Amebleh, & Okoh, 2023). By aligning the interests of patients, providers, and regulators, trust becomes a driving force that enhances adoption, reduces resistance to innovation, and strengthens the long-term resilience of digital payment ecosystems in healthcare.

➢ *Future Directions for Resilient Digital Payment Systems*

Future directions for resilient digital payment systems in healthcare will increasingly focus on embedding adaptive technologies that respond to evolving risks while maintaining patient-centered efficiency. Emerging tools such as artificial intelligence, blockchain, and predictive analytics are set to play a critical role in detecting fraudulent transactions, securing sensitive data, and ensuring transparent payment trails. As the volume of healthcare transactions grows, resilience will hinge on developing interoperable platforms that seamlessly connect providers, insurers, and regulators, thereby reducing inefficiencies and enhancing oversight. Furthermore, systems must integrate mechanisms that account for regulatory updates and market shifts to remain agile in a dynamic healthcare environment.

Resilient digital payment systems will also move toward personalization and inclusivity, ensuring accessibility for diverse patient populations across urban and rural settings. User-friendly interfaces, multilingual support, and mobile-based solutions will help overcome barriers to participation while expanding trust and adoption. Additionally, embedding sustainability principles such as energy-efficient data management and cost-effective scalability will be central to ensuring that digital payment infrastructures remain viable in the long term. These forward-looking strategies will not only strengthen resilience but also promote equity, innovation, and sustainable growth in the global healthcare payment ecosystem.

VIII. CONCLUSION AND FUTURE RECOMMENDATION

➢ *Conclusion*

This study demonstrates that the sustainability of digital health payment ecosystems depends on embedding explainable, transparent, and policy-driven risk controls that address technical, regulatory, and trust-related vulnerabilities. By integrating SHAP-constrained gradient boosting with layered governance mechanisms—such as policy-based access controls, immutable audit trails, and robust chargeback mitigation—healthcare stakeholders can achieve a balance between predictive accuracy and interpretability. These measures not only strengthen fraud detection and dispute resolution but also ensure compliance with global standards such as GDPR and HIPAA, thereby minimizing systemic risks and reinforcing accountability. Furthermore, embedding explainability into financial decision-making processes fosters trust among patients, providers, and regulators by making automated outcomes intelligible and ethically grounded. In doing so, digital health payment infrastructures can transition from being perceived as opaque and risk-prone to becoming secure, transparent, and resilient systems that protect financial integrity while promoting equitable healthcare access. Ultimately, the convergence of explainable AI, governance frameworks, and consumer protection safeguards represents a critical pathway toward building future-ready digital health payment platforms capable of withstanding evolving threats while supporting long-term innovation and adoption

➢ *Future Research Recommendations*

Future research should focus on advancing the scalability and adaptability of explainable AI in digital health payment infrastructures, particularly in high-volume, multi-jurisdictional contexts. Comparative studies between SHAP-constrained models and other emerging interpretability frameworks, such as counterfactual explanations or causal inference models, would deepen understanding of their relative effectiveness in fraud detection and regulatory compliance. Additionally, there is a need to investigate the integration of blockchain-enabled auditability with machine learning–driven risk scoring to create hybrid systems that maximize transparency and resilience. Cross-cultural and cross-border analyses could also reveal how variations in regulatory environments (e.g., GDPR in Europe versus HIPAA in the U.S.) impact trust and adoption of digital health payments. Finally, future work should explore patient-centered design of payment interfaces and dashboards, ensuring that explainability extends beyond technical stakeholders to empower end-users with clear, accessible, and ethically aligned financial insights

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