Digital Food Traceability and Risk Control in Smart Canteens: Implications for Hospital Food Services

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Abstract

Smart canteen systems enabled by IoT, blockchain, and AI offer new opportunities for digital food traceability and risk control, but their implications for hospital food services remain unclear. This review aims to synthesize theoretical insights from existing research on digital food traceability and risk management in smart canteen systems and discuss their implications for hospital food services. Literature (2020-2026) from Web of Science, PubMed, Scopus and Food Science & Technology Abstracts was searched with keywords on smart canteens, clinical gastronomy, IoT, blockchain, AI and therapeutic diets. After duplicate removal, title/abstract and full-text reviewing, 29 scholarly sources focusing on institutional catering, hospital food safety or intelligent food supervision were retained. Integrative synthesis and framework construction were employed, without empirical data. The reviewed literature suggests that smart canteen systems can integrate IoT real-time sensing, tamper-proof blockchain recording and AI risk prediction to support end-to-end traceability from procurement to sample retention. Three core obstacles hinder hospital adoption: uneven digital infrastructure investment, severe clinical-catering data fragmentation, and insufficient algorithm customization for therapeutic diet matching. Hospital catering presents unique risks including nutritional imbalance, therapeutic diet errors, allergen residues, food-drug interactions and digital system vulnerabilities. Intelligent technologies carry inherent limitations-sensor drift, algorithm bias, false warnings, high cost, poor interoperability and privacy risks-that cannot be eliminated by technical iteration alone. The hierarchical closed-loop framework proposed may mitigate multidimensional hospital food safety risks, but requires empirical verification.

Keywords: Smart canteen, Food traceability, Hospital food services, Food safety risk management, Clinical gastronomy.

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1. Introduction

Clinical catering and hospital dietary safety constitute core components of modern public health management and inpatient rehabilitation nursing, undertaking core responsibilities of nutritional support and safe dietary supply for patients during treatment (Bond et al., 2023). Distinct from ordinary commercial catering that merely satisfies basic appetite demands, hospital gastronomy services carry rigorous professional thresholds: they must comply with universal food hygiene standards while matching individualized clinical treatment plans, chronic disease intervention, postoperative rehabilitation protocols and dietary contraindications for vulnerable patient groups (Lopez et al., 2026).

Hospitalized patients generally stay in sub-health or pathological conditions with suppressed immune function, rendering them far more susceptible to microbial contamination, deteriorated ingredients, dietary allergen residues and non-standard cooking procedures than ordinary diners (Lebelo et al., 2021). In this high-risk catering scenario, traditional manual governance relying on on-site supervision, paper-based archives and periodic sampling inspection cannot satisfy the ultra-stringent safety demands of clinical gastronomy (Chen et al., 2021). Practically, most public hospitals still face persistent governance defects: discontinuous supervision across catering links, opaque ingredient source information, delayed risk early warning, and ambiguous responsibility confirmation after food safety accidents. These loopholes accumulate hidden risks throughout

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procurement, storage, processing, distribution and inpatient dining procedures (Mu et al., 2024).

Driven by smart hospital construction and catering industry digital transformation, intelligent canteen governance models have been widely deployed in institutional catering sites including schools, enterprises and medical facilities (Liang et al., 2025). Supported by multi-dimensional digital technologies-real-time sensor perception, distributed blockchain storage, AI image recognition and big data cloud analysis, smart canteen systems can help overcome the temporal and spatial limitations of manual management. Such systems can automatically collect, continuously monitor, archive and intelligently analyze full-chain catering data, thereby providing a technical basis for precise risk tracing and proactive hazard prevention (Müller et al., 2026; Yu et al., 2024).

Existing academic literature mainly focuses on technical application effects of intelligent catering in commercial scenarios or safety management of school canteens (Liang et al., 2025). Few studies systematically integrate the unique clinical attributes of hospital gastronomy and the vulnerability of inpatient populations to explore the internal logic, practical constraints and optimization paths of smart traceability and risk control targeting medical catering environments (Mu et al., 2024). Current literature also suffers from two obvious limitations: first, most technical studies only discuss general food safety monitoring without incorporating hospital-specific topics such as HACCP implementation, therapeutic diet formulation, allergen control and immunocompromised patient risk prevention (Bond et al., 2023; Lebelo et al., 2021); second, digital technology research largely emphasizes technical advantages while ignoring hardware defects, algorithmic flaws, data privacy risks and cross-system interoperability barriers (Rugji et al., 2025; Thakkar et al., 2023).

Relevant to this review, Erazo-Perez et al. (2025) also recognized the lag in the digital transformation of hospital catering, proposed a three-layer architecture of perception-processing-display, and took patient safety and clinical outcomes as core concerns. However, as a single-technology implementation study, it does not cover blockchain-AI integration, hospital-specific clinical risks (e.g., therapeutic diet errors, food-drug interactions), nor governance-level barriers such as data silos and capacity gaps (Erazo-Perez et al., 2025). This review extends their work by constructing a multi-technology closed-loop governance framework that addresses these missing dimensions.

The academic contribution of this study to gastronomy research lies in systematically articulating how digital food traceability reshapes institutional and hospital catering governance. By integrating IoT-blockchain-AI technologies into a closed-loop data chain, digital traceability can elevate gastronomy from a culinary service discipline toward a clinically integrated safety science-bridging upstream ingredient provenance with downstream therapeutic diet prescriptions, allergen controls, and drug-food interaction alerts. This conceptual reframing advances gastronomy scholarship by shifting the analytical focus from general catering hygiene to patient-specific, risk-precise, and digitally traceable dietary governance, thereby addressing a critical theoretical gap at the intersection of food science, clinical nutrition, and digital health systems.

Accordingly, this review examines digital food traceability and risk control in smart canteen systems, integrating theoretical insights to explore their potential applications in hospital food safety governance.

2. Review methodology

2.1. Review type definition

This is a conceptual theoretical review, not a systematic or scoping review. Its aim is not exhaustive evidence synthesis but to integrate disconnected findings, reorganize theoretical logic, identify bottlenecks, and construct an original whole-process governance framework for hospital smart catering safety (Mu et al., 2024). Methodologically, it follows integrative literature review principles (Elsbach & van Knippenberg, 2020) and conceptual article design logic (Jaakkola, 2020). A conceptual review suits a fragmented, interdisciplinary field requiring theoretical consolidation; theory is advanced through structured abduction and synthesis, not mere description or aggregation. It does not follow PRISMA standards: the literature search assembles representative interdisciplinary theoretical insights for theoretical synthesis and framework construction, not exhaustive identification/appraisal of all studies (Whittemore & Knafl, 2005). Therefore, full PRISMA-compliant screening documentation and formal risk-of-bias appraisal are not performed.

2.2. Literature retrieval strategy

2.2.1. Databases

Four authoritative databases were selected for unified retrieval: Web of Science Core Collection, PubMed, Scopus, Food Science & Technology Abstracts (Gu et al., 2026; Singh, 2025).

2.2.2. Search time window

The literature search covered publications from January 2020 to July 2026 (approximately six and a half years), consistent with the scope of the review (Huang et al., 2026; Yu et al., 2024).

2.2.3. Keyword combination

Four groups of retrieval keywords were used in parallel combination:

1-Smart catering dimension: smart canteen, intelligent cafeteria, digital food supervision, IoT food monitoring (Müller et al., 2026; Yu et al., 2024).

2-Institutional catering service dimension (non-hospital): institutional food service, school canteen, food processing kitchen, commercial catering traceability, cold chain management, HACCP catering, food service digitalization (Liang et al., 2025).

3-Hospital clinical dimension: hospital catering, clinical gastronomy, therapeutic diet, inpatient food safety, immunocompromised patients, food allergen management, food-drug interaction (Bond et al., 2023; Lebelo et al., 2021).

4-Digital technology dimension: food traceability, blockchain food record, artificial intelligence risk early warning, big data food safety, medical data interoperability, data privacy, cybersecurity (Rugji et al., 2025; Thakkar et al., 2023).

2.3. Literature sampling boundaries

2.3.1. Literature type

Priority was given to peer-reviewed journal articles, review papers and book chapters (Gu et al., 2026; Singh, 2025), while conference abstracts and editorials (Schiro et al., 2020) were generally not considered for theoretical synthesis.

2.3.2. Thematic scope

Priority research themes include intelligent monitoring, food traceability, risk control, and data management in catering service systems, including but not limited to hospital, school, or commercial catering scenarios (Mu et al., 2024). Agricultural food production, food processing factory research without a catering service link (Jimoh & Hashim, 2025) and food detection technology research without any discussion of traceability or risk management frameworks (Osemwowa, 2026) were generally not considered for theoretical synthesis.

2.3.3. Analytical and conceptual contribution

Sources were prioritized based on their capacity to offer substantive theoretical insights, transparent analytical frameworks, or actionable evidence for the proposed framework (Huang et al., 2026).

2.4. Literature reviewing and synthesis process

Initial retrieval obtained 682 records; 206 duplicate records were removed via database deduplication. After title and abstract review, 381 records not relevant to the thematic scope were filtered out. The remaining 95 sources entered full-text reading, 66 sources were not retained and 29 were retained as the final sources, as shown in Table 1 below. The final 29 sources comprise 11 empirical journal articles, 15 review papers, and 3 book chapters. Themes involved: 16 focus on catering-safety digital technology; 4 focus on hospital dietary risk; 2 focus on data interoperability/privacy; 7 focus on smart-catering governance bottlenecks.

Reviewing was conducted thematically by the author to identify texts relevant for theoretical synthesis; formal independent quality appraisal of each candidate paper was not undertaken. The 66 sources not retained at the full-text stage were discarded on thematic grounds (e.g., lacking actionable theoretical insights for the proposed framework). Consistent with the logic of theoretical sampling in integrative reviews (Whittemore & Knafl, 2005), these exclusions were not granularly catalogued, as the aim was to assemble conceptually relevant inputs rather than exhaustively account for all retrieved records (Elsbach & van Knippenberg, 2020).

Literature synthesis adopted thematic classification: documents were divided into four categories: digital technology application in catering safety, hospital clinical dietary risk management, data interoperability and privacy protection, and intelligent catering governance bottlenecks (Mu et al., 2024). Based on categorized literature findings, this paper sorts out the operation logic of smart traceability mechanisms, summarizes multi-dimensional governance dilemmas, and constructs an optimized closed-loop risk control theoretical framework.

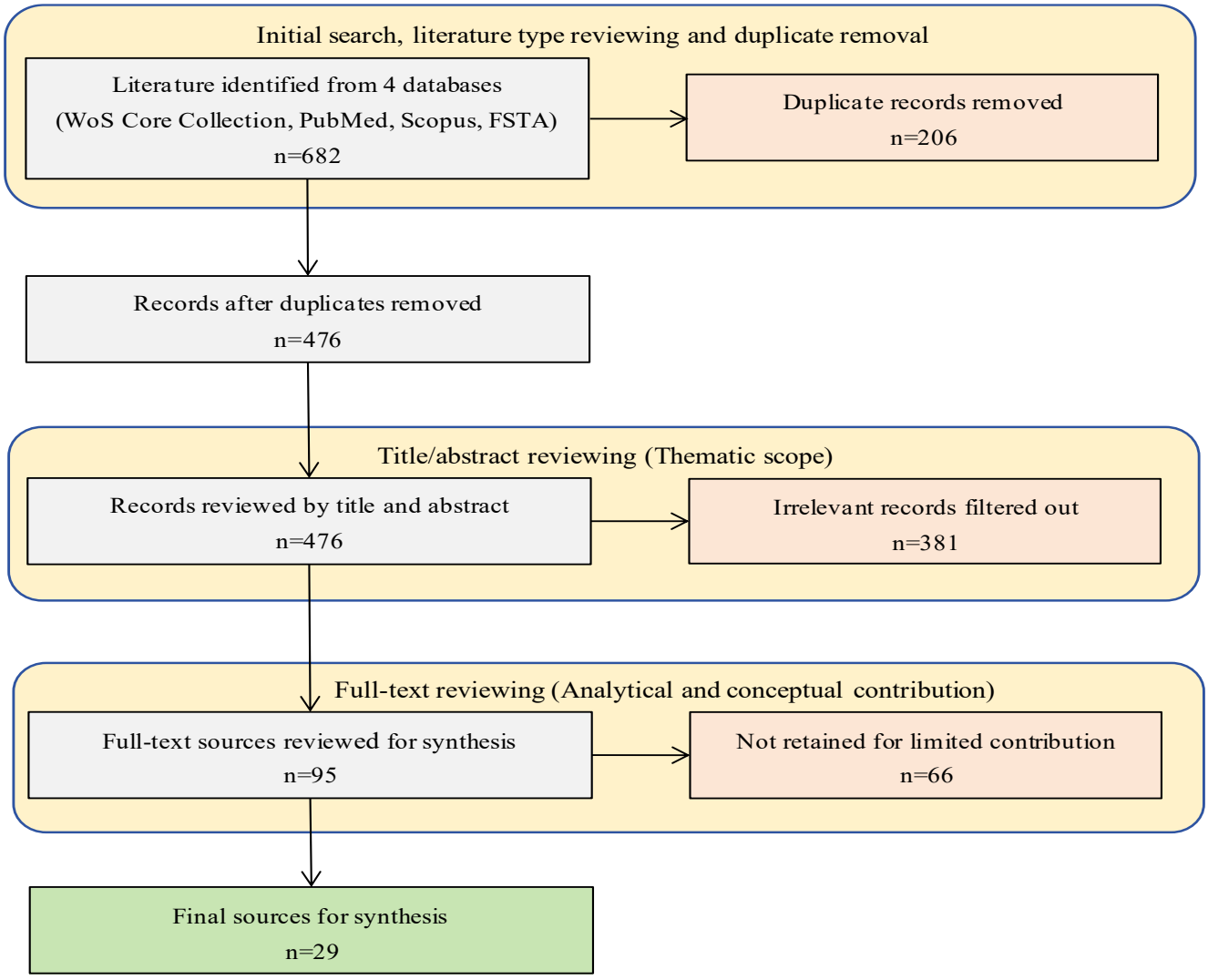


Figure 1. Literature sampling and synthesis workflow

Note: This workflow illustrates the thematic sampling of literature for conceptual synthesis. It is not a PRISMA-compliant systematic review flow diagram, and formal risk-of-bias appraisal was not performed.

Source: Drawn by the author.

Table 1. Overview of 29 key literature sources used for theoretical synthesis (2020-2026)

Author & Year	Research scenario	Core technology	Research focus	Key research conclusions	Research Limitations	Source type	Thematic category
Bond et al. (2023)	AI in clinical nutrition practice	AI, machine learning, deep learning	AI applications, personalized interventions, and clinical decision support	AI can transform clinical nutrition through personalized interventions	Ethical concerns, data privacy, bias, and need for clinical validation	Review papers	Hospital dietary risk
Chen et al. (2021)	Food service establishment supervision in China	Mobile Internet and 2D barcode technology	Addressing regulatory implementation barriers via smart supervision	Identified regulatory challenges and designed a smart supervision solution	Without personalized patient-diet matching module design	Empirical journal articles	Smart-catering governance bottlenecks
Corradini et al. (2024)	Food supply chain virtualization for food safety	Digital twins, IoT, nondestructive sensing, multiscale modeling	Defining requirements and future trends for virtual food systems and digital twins	Virtualization enables simulation and prediction of safety risks, improving resource use and decision-making	Data integration gaps and insufficient technical skills for virtualization	Book chapters	Catering-safety digital technology

Table 1. (cont.)

Author & Year	Research scenario	Core technology	Research focus	Key research conclusions	Research Limitations	Source type	Thematic category
Gbonyea et al. (2025)	On-site rapid food detection	Smartphone-integrated nanozyme technologies (S-INTs)	S-INTs for rapid pathogen/contaminant detection and AI/ML integration	Mobile equipment realizes low-cost raw material traceability	Sensitivity, multiplexing, and field validation challenges remain	Review papers	Catering-safety digital technology
Gu et al. (2026)	Food chemical safety detection	spectroscopic analysis, chromatography, mass spectrometry, and sensor technology	food quality control, identification of bioactive constituents, contaminant detection	AI enhances analytical efficiency and accuracy	Unable to link detection results with patient clinical dietary restrictions	Review papers	Catering-safety digital technology
Hornback et al. (2026)	Biomedical data harmonization for intelligent healthcare	HL7 FHIR standard	Systematically mapping FHIR's applications across clinical care, research, and public health domains	FHIR effectively integrates EHRs and enables decision support, precision medicine, and AI	No hospital catering scenario validation	Review papers	Data interoperability/privacy
Huang et al. (2026)	Food packaging whole life cycle	IoT packaging monitoring tags	Safety traceability of food packaging materials	Intelligent labels record full storage and transportation environment	Not applicable to short-cycle hospital prepared meals	Review papers	Catering-safety digital technology
Jimoh & Hashim (2025)	Non-invasive food quality assessment	Spectroscopy, imaging, sensor arrays, chemometrics	principles and applications of non-invasive techniques across food matrices	Non-invasive methods enable rapid, real-time quality monitoring; miniaturization, fusion, and AI integration are key future directions	No batch traceability binding function for hospital supplier archives	Book chapters	Catering-safety digital technology
Khan et al. (2022)	Inpatient therapeutic diet service	Sequential explanatory mixed-methods design	Measuring dietary-error prevalence and tracing human-factor causes along the meal-flow process	Error rate was low but mostly critical; organizational-behavior strategies could reduce errors and improve wellbeing	No digital traceability integration discussed	Empirical journal articles	Hospital dietary risk
Ku et al. (2021)	Bubble tea food safety management	An FSMS service platform with lightweight computing	Modularizing HACCP principles to increase data transparency and traceability	IF4BT integrates HACCP with IOTA Tangle, using deep learning to detect high-risk factors and reduce food safety issues	No empirical validation or deployment testing reported	Empirical journal articles	Catering-safety digital technology
Lebelo et al. (2021)	Chemical contamination in food production stages	Bioremediation of pollutants	Tracing contamination from agriculture to consumer, including pesticides and antibiotics	Consumer protection from chemical toxicity relies on stringent regulatory efforts	No targeted discussion of allergic hazards for hospitalized sensitive groups	Review papers	Smart-catering governance bottlenecks
Liang et al. (2025)	School smart canteen	Digital behavior intervention	Digital nudge intervention in smart school canteens	Smart canteens improve adolescents' healthy dietary choices	Research objects exclude immunocompromised hospitalized patients	Empirical journal articles	Catering-safety digital technology
Lopez et al. (2026)	AI applications in food safety	Neural networks and sensing data	Detecting chemical hazards, not biological or physical	AI in food safety focuses on chemical hazards, using neural networks and sensing data, with limited unstructured data use	Lack of unstructured data algorithms; limited biological hazard detection	Review papers	Catering-safety digital technology
Ma et al. (2022)	Smartphone-based food safety and nutrition	Smartphone sensing, imaging, apps, traceability	Smartphones in rapid detection, traceability systems, and personalized diet guidance	Smartphones enable low-cost rapid screening, transparent traceability, and personalized guidance	Sensor accuracy, calibration, data privacy, weak clinical validation	Review papers	Catering-safety digital technology

Table 1. (cont.)

Author & Year	Research scenario	Core technology	Research focus	Key research conclusions	Research Limitations	Source type	Thematic category
Mu et al. (2024)	Global food safety early warning system	IoT + big data early warning model	Systematic framework for intelligent food risk prevention	Multi-dimensional data fusion realizes proactive risk assessment rather than post-hoc investigation	Rarely incorporates clinical medical data of hospital inpatient populations	Review papers	Catering-safety digital technology
Müller et al. (2026)	Catering cold chain management	IoT + cloud data storage	Real-time monitoring, predictive risk assessment, and logistics optimization	IoT sensors monitor in real time; AI predicts temperature deviations, assesses safety, optimizes logistics, reducing spoilage and contamination	Does not involve personalized therapeutic diet matching logic	Review papers	Catering-safety digital technology
Osemwowa (2026)	Food adulteration identification	AI spectral discrimination model	Intelligent identification of food adulterants	AI outperforms traditional chemometrics for subtle adulteration	Ignore allergen residue risks of hospital therapeutic meals	Review papers	Catering-safety digital technology
Palomares et al. (2026)	CKD patients receiving AI-based personalized nutrition	Machine learning, CDSS, generative AI tools	AI personalizes diet, monitors parameters, predicts complications	AI-tailored nutrition advice reduces complications (e.g., hyperkalemia) and improves adherence	LLM inaccuracies, hallucination risks, need clinical validation	Review papers	Hospital dietary risk
Rugji et al. (2025)	Agricultural & catering industry	Comprehensive AI food risk model	Universal food safety, food security risk identification	Algorithms can identify multiple hidden hazards in mass catering	Algorithm bias exists for rare special medical food combinations	Review papers	Catering-safety digital technology
Schiro et al. (2020)	Digital food safety and nutrition communication	Search engines, apps, social media, digital analytics	Harnessing digital tools for engaging food safety/nutrition communications	Digital tools can enhance food safety/nutrition communication reach	GDPR, practical, philosophical, and policy challenges	Review papers	Smart-catering governance bottlenecks
Singh (2025)	Global food quality and safety	Machine learning, computer vision, NLP	AI integration for real-time monitoring, prediction, contaminant detection, and traceability	AI reduces human error and speeds threat response	No targeted development for hospital kitchen standardized processing	Review papers	Catering-safety digital technology
Thakkar et al. (2023)	Food & drug safety supervision	AI and real-world data analysis	AI/RWD applications, readiness, and regulatory integration	AI and RWD advance drug/food safety assessment, but regulatory science requires ongoing fit-for-purpose evaluation	Insufficient discussion of medical data privacy and cybersecurity risks	Empirical journal articles	Smart-catering governance bottlenecks
Tripathi et al. (2023)	Smart city food supply chains	EOSIO-based Blockchain and IoT (BIoT)	BIoT layered framework for food traceability	Proposed EOSIO system achieves 0.5s block production and 1s confirmation, outperforming Ethereum	Lacks real-world deployment and empirical validation	Empirical journal articles	Catering-safety digital technology
Wang et al. (2026)	Hospital therapeutic diet nutrient assessment	RGB-D imaging, SAM segmentation, SE_ResNet50_vd classification	Developing and validating an AI system for real-time hospital nutrient intake assessment	AI system achieves 99.2% food recognition accuracy, enabling real-time hospital nutrient monitoring superior to traditional dietary surveys	Volume estimation accuracy varies (≥80% threshold) across diverse food items	Empirical journal articles	Hospital dietary risk
Yadegari & Asosheh (2025)	Smart hospital IoT integration	Unified multi-layer IoT architecture	Enhancing CIS interoperability, security, and efficiency via IoT	Unified model improves interoperability, security, and operational efficiency	Simulation-only design, lacks real-world clinical deployment validation	Empirical journal articles	Data interoperability/privacy

Table 1. (cont.)

Author & Year	Research scenario	Core technology	Research focus	Key research conclusions	Research Limitations	Source type	Thematic category
Yan & Kan (2022)	Salmonella outbreak response and control	Whole-genome sequencing and multi-sector collaboration	Strengthening cross-sector collaboration and surveillance networks for outbreak detection and control	Multi-sector collaboration, genomic surveillance, and information sharing are essential for timely Salmonella outbreak detection, prevention, and control in China	Commentary lacking empirical validation and implementation details for resource-limited settings	Empirical journal articles	Smart-catering governance bottlenecks
Yu et al. (2024)	Food safety inspection and monitoring	AI-enhanced nanosensor arrays with machine learning	Enhancing detection sensitivity, speed, and accuracy via pattern recognition	Integration of artificial intelligence with nanosensor arrays holds promise for enhancing food safety monitoring	Data dimensionality, algorithm reliability, and practical deployment challenges	Book chapters	Catering-safety digital technology
Zheng et al. (2026)	Donated medical equipment idling in remote areas	Time-Driven Activity-Based Costing (TDABC) model	Quantifying hidden lifecycle O&M costs and analyzing policy failure mechanisms	Long-term O&M costs comprise 30.19% of total investment; policy must shift from equipment delivery to sustainable service capacity building	Single extreme case; analytical rather than statistical generalization	Empirical journal articles	Smart-catering governance bottlenecks
Zhou & Yin (2026)	County-hospital digital managemen t center construction	Integrated health big-data platforms	Applying SWOT to county-hospital digital-management-center implementation	Digital centers integrate data for unified monitoring; policy reforms address talent, silo, and operational gaps	Qualitative SWOT-only design; no empirical validation or quantitative metrics	Empirical journal articles	Smart-catering governance bottlenecks
Total number of sources = 29							

Note: This table presents key sources drawn upon for conceptual framework building, and does not represent a complete systematic review evidence table. Formal quality appraisal of individual studies was not performed.

The conceptual framework (Figure 2) was not preconceived but emerged iteratively by mapping the mechanisms and bottlenecks extracted from each thematic cluster onto the specific risk dimensions of clinical catering. Each component of the final framework is thus directly anchored in one or more of the 29 retained studies, as detailed in the literature-framework mapping table (Table 2).

2.5 Transparent process of framework development

The conceptual framework presented in Figure 2 was developed through a four-phase iterative process:

- Topic classification: Based on research focuses, the 29 retained papers are divided into the four major theme clusters mentioned in 2.4.
- Mechanism extraction: Within each cluster, key operational mechanisms (e.g., IoT real-time sensing, blockchain tamper-proofing, AI risk prediction) and recurring governance dilemmas (e.g., data islands, algorithmic bias, professional-capacity gaps) were extracted.
- Cross-theme synthesis: By mapping the extracted mechanisms onto the identified clinical catering risks, we iteratively linked technical capabilities to hospital-specific safety hazards (therapeutic diet errors, allergen residues, food-drug interactions). This phase involved abductive reasoning to align general digital food safety solutions with the unique constraints of clinical gastronomy.
- Framework construction: The synthesized insights were organized into a hierarchical closed-loop architecture spanning source procurement, processing/production, terminal dining, and post-event traceability, with data interoperability and human-resource capacity as cross-cutting enablers. The final framework (Figure 2) was refined through multiple rounds to ensure internal coherence and logical completeness.

This transparent process ensures that the framework is not an arbitrary assemblage but a systematically derived theoretical model grounded in the literature and oriented toward solving a practical governance problem. Unlike systematic reviews that synthesise empirical findings from eligible studies, this iterative framework construction maps themes extracted from key literature sources onto clinical catering risks to generate new theoretical structure.

3. Operating logic and systematic framework of smart traceability mechanism in hospital catering safety

The food safety traceability mechanism based on smart canteens can form a digital governance chain covering all hospital catering links. It has the potential to transform the traditional post-hoc investigation mode and to support a governance shift from passive post-event rectification toward proactive prevention and real-time in-process supervision (Chen et al., 2021). Different from isolated digital equipment deployment, the smart traceability system integrates multi-source digital technologies to build an interconnected, tamper-proof and fully traceable catering safety data ecosystem, covering raw material procurement, warehouse preservation, standardized kitchen processing, finished meal distribution, personalized inpatient dietary matching and standardized meal sample retention (Yu et al., 2024).

Centered on data solidification and information transparency, the system is designed to establish a collaborative supervision logic comprising real-time perception, dynamic early warning, precise traceability and standardized management through the coordinated operation of three layers: an IoT sensing layer, a blockchain data storage layer and an AI intelligent analysis layer (Müller et al., 2026).

3.1. IoT real-time sensing layer: basic automatic data collection

The IoT sensing system undertakes real-time collection of environmental and operational indicator data for hospital catering. High-precision sensors for temperature, humidity, microbial environment and cold chain operation are deployed in core functional areas: ingredient cold storage warehouses, kitchen processing workshops, finished meal heat preservation zones and food distribution vehicles (Müller et al., 2026). All environmental parameters and equipment operation data can be automatically uploaded to cloud platforms at high frequency, potentially replacing error-prone, incomplete and falsifiable manual timing records (Yu et al., 2024).

For hospital-specific therapeutic ingredients and high-risk raw materials requiring constant temperature and humidity storage, 24-hour uninterrupted monitoring is realized. The system automatically triggers early warning alarms once environmental indicators exceed threshold limits, forcing management staff to dispose risks immediately and prevent food deterioration and microbial growth caused by improper storage conditions (Huang et al., 2026). Nevertheless, the sensing layer carries inherent defects: sensor drift, delayed data transmission and equipment failure often generate distorted input data, leading to false alarms or missed risk reminders, which reduce the reliability of automatic supervision (Thakkar et al., 2023).

3.2. Blockchain data layer: tamper-proof whole-process traceable ledger

Built on continuously collected sensing data, blockchain technology constructs credible, unalterable archives for full-process hospital catering information (Gbonyea et al., 2025). This integration of HACCP-based critical control points with blockchain ledgers has been operationalized in service platforms such as IF4BT, which modularizes HACCP principles and uses deep learning to flag high-risk factors while ensuring tamper-resistant data transparency (Ku et al., 2021). Each batch of raw materials, auxiliary materials and therapeutic ingredients is bound to a unique electronic identification code containing supplier qualification, ingredient origin, production batch, incoming inspection results, storage duration, operator information, cooking parameters, distribution time and corresponding ward dining information (Ma et al., 2022).

All data can be stored on distributed blockchain nodes, which makes unauthorized modification or deletion difficult and helps preserve the authenticity, integrity and traceability of catering records (Gbonyea et al., 2025). This architecture has been empirically benchmarked in smart-city food supply chains (Tripathi et al., 2023). When inpatient foodborne adverse reactions or dietary safety incidents occur, administrators can rapidly locate problematic ingredient batches, abnormal processing links and responsible subjects through traceability codes, avoiding inefficient blind large-scale investigations under traditional management modes (Chen et al., 2021). However, distributed blockchain storage expands data volume exponentially, increasing operation costs and raising risks of patient dietary privacy leakage if access authorization mechanisms are not strictly designed (Thakkar et al., 2023).

3.3. AI big data analysis layer: intelligent risk prediction and proactive prevention

On the basis of perceived and archived data, the AI big data analysis layer is intended to provide active risk warning for hospital catering safety (Gu et al., 2026; Singh, 2025). The system accumulates long-term catering safety records, seasonal ingredient risk rules, high-risk cooking characteristics, inpatient dietary

allergy archives and disease-based dietary contraindication data to build a clinical gastronomy-oriented risk identification model (Bond et al., 2023).

Machine learning and correlation analysis enable the system to automatically identify potential hazards such as incompatible high-risk ingredients, non-standard cooking techniques and mismatched therapeutic diet collocations before meal preparation, reminding nutritionists and catering staff to optimize menus and processing workflows, lowering accident risks caused by professional mismatches and irregular operations (Rugji et al., 2025). Notably, AI algorithms face prominent limitations: existing models are trained on general catering datasets, generating algorithm bias for rare therapeutic diet combinations. Frequent false early warnings increase management workload, while insufficient training samples for special patient groups weaken the accuracy of personalized risk assessment (Thakkar et al., 2023). The three-tier technical system of perception, storage and analysis jointly forms the core operation framework of hospital smart catering traceability, yet its actual governance effects are restricted by multi-dimensional practical dilemmas unique to medical catering scenarios.

4. Core risks and practical governance dilemmas of hospital smart canteen food safety

Although smart canteen systems possess technical advantages in full-chain traceability and intelligent supervision, their integration with clinical diet management in hospital settings remains limited (Erazo-Perez et al., 2025). Hospital catering risks differ significantly from commercial catering, featuring strong professionalism, high concealment and severe hazard consequences, which cannot be fully covered by universal intelligent catering supervision models (Bond et al., 2023). This section first categorizes six distinct hospital catering risk types, then summarizes multi-dimensional governance bottlenecks of smart canteen deployment.

4.1. Classified hospital catering safety hazards

4.1.1. Conventional foodborne microbial hazards

As in other catering settings, raw material deterioration, cross-contamination between raw and cooked foods, inadequate tableware disinfection, and microbial overgrowth caused by improper cold-chain storage may lead to infectious diarrhea among immunocompromised inpatients (Lebelo et al., 2021).

4.1.2. Nutritional inadequacy risks

Unbalanced macronutrient and micronutrient combinations fail to match rehabilitation demands of chronic disease, postoperative and tumor patients, causing malnutrition and delayed clinical recovery (Bond et al., 2023).

4.1.3. Therapeutic diet matching errors

Errors in the formulation or provision of low-sodium, low-protein, semi-liquid, and other therapeutic diets may conflict with clinical treatment plans (Khan et al., 2022). For example, providing excessive sugar to patients with diabetes or high-potassium meals to patients with renal failure may pose serious risks. Such dietary mismatches may be particularly concerning for patients with chronic kidney disease, for whom appropriate nutritional management is essential (Palomares et al., 2026).

4.1.4. Food allergen residue risks

Undeclared egg, seafood, nut and dairy residues in therapeutic meals induce severe allergic reactions in sensitive hospitalized populations (Lebelo et al., 2021).

4.1.5. Food-drug interaction risks

Dietary ingredients counteract oral and injectable medicines, weakening therapeutic efficacy or triggering adverse drug reactions, a risk of particular concern in hospital catering settings (Thakkar et al., 2023).

4.1.6. Digital information system risks

Digital information system risks include network attacks on catering data platforms, system crashes suspending traceability functions, inconsistent data standards causing information disconnection, and excessive reliance on intelligent systems leading to weakened manual supervision awareness (Rugji et al., 2025).

4.2. Practical governance dilemmas restricting smart canteen application

4.2.1. Lack of targeted functional design for hospital therapeutic diet scenarios

Most existing intelligent catering algorithms and supervision modules are developed for mass commercial catering, focusing only on conventional hygiene indicators such as ingredient freshness and processing environment cleanliness (Osemwowa, 2026). They ignore hospital-exclusive professional risks: chronic disease dietary restrictions, unbalanced therapeutic meal nutrition, allergen residues and incompatible special ingredient combinations. Current intelligent systems cannot automatically identify or warn against hazards arising from mismatched clinical diets, failing to satisfy personalized safety management

demands of inpatients and limiting the practical value of smart traceability technology (Bond et al., 2023).

4.2.2. Severe hospital internal data island barriers

In most public hospitals, smart canteen management systems, clinical diagnosis hospital information systems, nursing information platforms and pharmacy contraindication databases operate as independent closed platforms without unified data interfaces and authorized sharing mechanisms (Ma et al., 2022). Catering intelligent systems cannot obtain real-time patient diagnosis records, dietary restriction records and postoperative rehabilitation dietary standards, disabling personalized risk early warning and precise diet matching for different patient groups.

The separation of clinical medical data and catering data confines intelligent traceability to basic raw material safety monitoring, unable to exert professional governance advantages integrating clinical medicine and nutritional catering. Meanwhile, cross-system data transmission also brings hidden dangers of medical privacy leakage and cybersecurity attacks (Thakkar et al., 2023).

4.2.3. Uneven digital construction investment across hierarchical hospitals

Tertiary public hospitals with sufficient operational funds and technical support can deploy complete IoT monitoring equipment, blockchain traceability platforms and AI analysis systems to realize full-link intelligent catering supervision. By contrast, grassroots and county-level public hospitals face constraints of insufficient financial budgets, shortage of professional technical personnel and incomplete digital supporting facilities, resulting in simplified smart canteen construction, idle core intelligent functions and mixed coexistence of intelligent equipment and manual management modes (Zhou & Yin, 2026).

Uneven digital capacity makes standardized and replicable intelligent risk control impossible across the whole public hospital industry, failing to fundamentally resolve persistent food safety hazards in hospital catering (Chen et al., 2021).

4.2.4. Inherent technical limitations of digital supervision tools

Prior literature mostly regards IoT, blockchain and AI as universal solutions while insufficiently discussing their inherent defects (Rugji et al., 2025):

- Sensing hardware defects: sensor measurement errors, cold chain equipment failures and delayed data upload generate inaccurate raw data (Thakkar et al., 2023);
- Algorithm defects: training set bias, frequent false risk alarms and insufficient identification accuracy for rare therapeutic diet combinations increase management burden (Gu et al., 2026);
- Interoperability barriers: inconsistent data coding standards between different brand intelligent systems hinder cross-platform data interconnection (Hornback et al., 2026);
- Cost pressure: full-set intelligent equipment and long-term operation and maintenance fees form heavy financial burdens for grassroots medical institutions (Zheng et al., 2026);
- Cybersecurity and privacy risks: centralized storage of patient dietary and disease data faces hacking threats; unauthorized access to blockchain traceability records may leak sensitive medical information (Thakkar et al., 2023);
- Human supervision substitution risks: catering staff overly depend on automatic alarms, reducing active manual inspection frequency, forming governance blind spots when intelligent systems malfunction (Schiro et al., 2020).

4.2.5. Insufficient professional capability of catering operators and imperfect operation mechanisms

Most hospital catering employees are accustomed to traditional manual management modes, lacking operational proficiency and initiative to conduct standardized self-inspection through intelligent systems (Chen et al., 2021). Hospitals generally lack dedicated daily operation and maintenance teams for smart equipment, alongside independent assessment and supervision systems targeting intelligent catering management. Low staff literacy and imperfect institutional mechanisms lead to disconnection between advanced digital tools and on-site safety governance effects (Schiro et al., 2020).

5. Optimization of closed-loop traceability and risk control mechanism for hospital food safety based on smart canteen systems

Targeting the aforementioned dilemmas-insufficient clinical adaptation of intelligent systems, fragmented internal data, unbalanced digital construction and inherent technical defects-this study proposes a full-process closed-loop optimization framework covering source prevention, real-time process supervision, terminal patient-diet matching and post-event traceability (see Figure 2 Conceptual framework of farm-to-patient closed-loop risk governance).

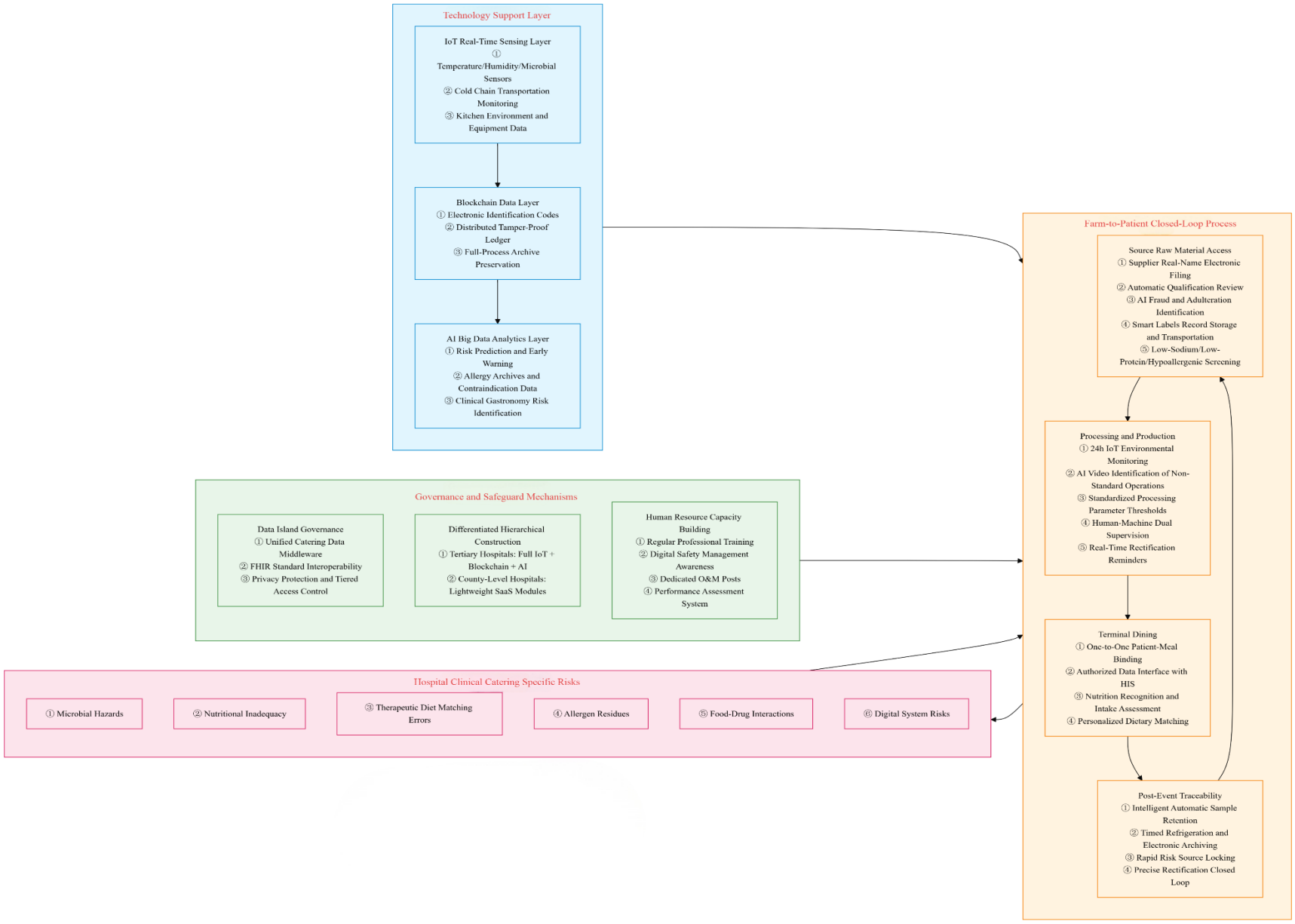


Figure 2. Conceptual framework of farm-to-patient closed-loop food safety traceability and risk control under smart canteen system

Source: Drawn by the author.

The proposed governance system takes digital full-chain traceability, multi-dimensional precise early warning, clinical professional adaptation and standardized dual human-machine supervision as core objectives, aiming to address technical and institutional bottlenecks in hospital catering digital transformation and to improve refined clinical dietary safety governance (Mu et al., 2024). All reviewed and finally retained sources are summarized in Table 1.

5.1. Source raw material access: digital supplier filing and clinical ingredient screening mechanism

Public hospital catering suppliers shall complete real-name electronic filing and automatic qualification review on the smart canteen platform. AI-powered analytical techniques can detect, predict, and prevent food fraud and adulteration across the food supply chain, thereby supporting supplier risk identification and contributing to safer procurement decisions (Osemwowa, 2026). For all incoming ingredients, IoT-enabled intelligent labels can record the full storage and transportation environment, supporting food safety traceability (Huang et al., 2026).

For hospital therapeutic diet demands, customized screening modules for low-sodium, low-protein, hypoallergenic and special medical food are embedded in the system, ensuring raw materials comply with differentiated clinical dietary safety standards for diabetic, renal failure, allergic and postoperative patients (Wang et al., 2026).

5.2. Processing and production links: IoT-AI driven full-process dynamic supervision

IoT intelligent sensing systems realize 24-hour automatic supervision of kitchen processing environments, cold storage temperature and food preservation status, recording all abnormal data and triggering real-time alarms (Müller et al., 2026). AI-based video analytics systems automatically detect non-standard operations including raw-cooked cross-contamination, substandard tableware disinfection, irregular staff protective clothing and insufficient cooking temperature, pushing rectification reminders to catering managers (Singh, 2025). Combined with clinical catering professionalism, the system sets standardized processing parameter thresholds for high-risk therapeutic meals, restricting irregular cooking behaviors damaging nutritional efficacy or triggering safety hazards (Khan et al., 2022). Manual regular inspection mechanisms are retained to form human-machine dual supervision, making up for blind spots of intelligent equipment such as sensor errors and algorithmic errors (Thakkar et al., 2023).

5.3. Terminal dining and post-event traceability: one-to-one patient-meal binding closed-loop disposal

The smart canteen platform opens authorized data interfaces to connect with hospital inpatient management systems, realizing one-to-one matching between individual patient identity information and corresponding meal production batches, processing operators and ingredient source records (Hornback et al., 2026). When patients suffer adverse dining reactions or dietary safety incidents, management teams can rapidly trace risk sources, accurately lock affected meal scopes and abnormal links, and implement targeted rectification (Khan et al., 2022).

Intelligent automatic sample retention equipment replaces manual sample storage, realizing timed automatic refrigeration, electronic record archiving and regular cleaning reminders for meal samples, standardizing post-event evidence preservation and forming a complete closed-loop governance logic: source supervision→process monitoring→terminal personalized matching→post-event precise traceability (Khan et al., 2022; Ma et al., 2022).

5.4. Data island governance: standardized privacy-preserving data sharing authorization mechanism

On the premise of medical data privacy protection, a unified hospital catering data middleware platform is constructed to realize secure authorized data interconnection between smart canteen systems, clinical diagnosis platforms, nursing information systems and dietary contraindication databases (Hornback et al., 2026).

The intelligent supervision system dynamically adjusts risk early warning thresholds and menu safety matching schemes according to patients' disease types, treatment stages and personalized dietary restrictions, realizing professional customized safety supervision for inpatients and fundamentally resolving insufficient clinical adaptation of traditional intelligent catering systems (Wang et al., 2026). Strict data access authority classification is set to prevent unauthorized access to sensitive patient information and mitigate cybersecurity and privacy leakage risks (Yadegari & Asosheh, 2025).

5.5. Differentiated hierarchical digital construction and human resource capacity building

Hierarchical differentiated smart canteen construction standards are formulated for hospitals at different levels to balance uneven digital development:

- Tertiary hospitals: deploy full-coverage integrated supervision systems integrating IoT, blockchain and AI to realize high-precision whole-chain intelligent governance (Yadegari & Asosheh, 2025).
- Grassroots county-level hospitals: adopt lightweight cloud-based SaaS intelligent catering modules (Zhou & Yin, 2026), prioritizing core functions including ingredient traceability, environmental safety monitoring and intelligent sample retention to reduce construction and operation costs, realizing basic intelligent safety supervision popularization.

Regular professional training targeting catering managers and frontline operators is carried out to improve proficiency in intelligent system operation and digital safety management awareness, ensuring long-term stable operation of smart traceability and risk control mechanisms (Khan et al., 2022). Meanwhile, dedicated equipment operation and maintenance posts and intelligent catering performance assessment systems are established to solve the problem of idle intelligent functions caused by imperfect institutional guarantees (Zheng et al., 2026).

Table 2. Mapping Table of Framework Components to Key Literature Sources

Closed-loop framework component	Reference	Main Contributions
Source raw material access	(Huang et al., 2026; Osemwowa, 2026; Wang et al., 2026)	Adulteration prevention, intelligent traceability label, therapeutic diet evaluation
Processing and production links	(Khan et al., 2022; Müller et al., 2026; Singh, 2025; Thakkar et al., 2023)	Cold chain real-time monitoring, AI visual violation recognition, lower processing errors for therapeutic meals, Manual-AI dual supervision
Terminal dining and post-event traceability	(Hornback et al., 2026; Khan et al., 2022; Ma et al., 2022)	Patient-meal traceability, Dietary error analysis, mobile terminal traceability
Data island governance	(Hornback et al., 2026; Wang et al., 2026; Yadegari & Asosheh, 2025)	FHIR interoperability, Clinical-adaptive smart supervision, Tiered data access control
Differentiated hierarchical digital construction and human resource capacity building	(Khan et al., 2022; Yadegari & Asosheh, 2025; Zheng et al., 2026; Zhou & Yin, 2026)	Whole-chain intelligent governance, lightweight SaaS, digital safety training, Catering O&M governance

6. Future research prospects and development trends

With continuous digital technology iteration and disciplinary development of clinical gastronomy, hospital food safety intelligent governance will evolve toward high precision, personalized clinical adaptation and cross-scenario multi-party linkage, presenting broad application prospects in public health and hospital catering service management. Three core research directions deserve attention in subsequent studies.

6.1. Deep integration of digital twin technology and hospital smart canteens

Digital twin technology will become a key research hotspot for clinical gastronomy safety governance. Virtual simulation models covering full catering links can be constructed to conduct pre-simulation and risk assessment for new menus and innovative processing techniques, potentially transforming traditional passive post-hoc traceability into more proactive whole-process risk prevention (Corradini et al., 2024). Subsequent empirical research can focus on constructing hospital catering digital twin simulation frameworks and verifying their risk prediction accuracy through on-site hospital data.

6.2. Cross-department and cross-institution collaborative supervision mechanism improvement

Future hospital intelligent catering safety platforms are expected to enable data interconnection with market supervision bureaus, food safety testing institutions and regional public health service platforms, potentially forming a multi-party collaborative governance pattern covering suppliers, hospital production terminals, patient dining terminals and government supervision terminals. Multi-sector collaborative mechanisms and surveillance networks can strengthen information sharing and collaboration among clinical medicine, disease control, and food safety institutions, thereby improving the timely detection, prevention, and control of foodborne disease outbreaks and enhancing the overall public health emergency response capacity of medical institutions (Yan & Kan, 2022). Relevant research needs to further explore standardized data sharing protocols balancing supervision efficiency and medical data privacy.

6.3. Personalized precision nutrition intelligent management and low-cost lightweight digital popularization

Supported by deep mining of clinical patient data and customized therapeutic diet algorithms, smart canteen systems are expected to achieve ultra-fine dietary safety matching based on individual patient differences including disease types, physical biochemical indicators and rehabilitation cycles (Wang et al., 2026), forming integrated intelligent governance systems combining safety supervision, nutritional matching and clinical treatment adaptation.

Lightweight low-cost SaaS intelligent catering models are likely to be widely promoted in grassroots medical institutions, effectively alleviating the imbalance of digital construction resources between hierarchical hospitals and comprehensively upgrading intelligent food safety governance capacity of all public hospitals. Follow-up research can carry out cost-benefit empirical analysis of lightweight intelligent systems in grassroots hospitals to provide practical construction reference.

In general, smart canteen-based food safety traceability and closed-loop risk control mechanisms represent an inevitable innovative direction for modern hospital clinical gastronomy safety management. Optimized digital supervision systems, improved cross-department data linkage mechanisms and breakthroughs in clinical professional adaptation bottlenecks may alleviate long-standing hospital catering safety governance pain points, deliver safer and more targeted dietary services for immunocompromised inpatient groups, and enrich the theoretical system of digital intelligent governance in medical catering public health fields (Chen et al., 2021).

Limitations of this review

Firstly, this research is a pure conceptual theoretical review without original field investigation or experimental data; all constructed governance frameworks and optimization paths require subsequent empirical research, hospital case studies and quantitative verification (Mu et al., 2024).

Secondly, the literature retrieval scope is limited to four mainstream English databases, failing to fully cover regional non-English grey literature on hospital catering safety. Thirdly, existing targeted empirical research focusing on therapeutic diet safety, hospital catering cybersecurity and food-drug interaction intelligent early warning remains scarce, restricting the sufficiency of literature support for partial arguments. Subsequent research can expand retrieval channels and carry out field empirical studies to supplement relevant evidence.

Finally, this is a conceptual-integrative rather than systematic review; literature sampling is thematic rather than exhaustive, without PRISMA-standardised screening and formal quality appraisal; exclusion reasons for the 66 full text screened articles were not granularly catalogued, limiting full reproducibility of literature sampling procedures.

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Declarations

Competing Interests

The author has no relevant financial or non-financial interests to disclose.

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Ethics Statement

This study is a conceptual literature review based on previously published research and did not involve human participants, animals, or primary data collection. Therefore, ethics committee approval and informed consent were not required.

Data Availability Statement

No original data were generated or analyzed; this review is based on previously published literature.

AI statement

The generative AI tool ChatGPT (OpenAI) was used only in a limited and controlled manner to improve the language clarity and readability of the manuscript. All content was reviewed and approved by the author.

Author Contributions

B. Hu: Conceptualization, Methodology, Validation, Formal analysis, Writing – original draft, Writing – review and editing.

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