Journal of Information Systems Engineering and Management
2025, 10(26s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Innovative Research on an AI-Integrated Full-Cycle Intelligent Management System for Donor Semen Specimens in Human Sperm Banks

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ARTICLE INFO

Received: 30 Dec 2024
Revised: 20 Feb 2025
Accepted: 02 Mar 2025

ABSTRACT

With the rapid advancement of assisted reproductive technologies (ART), human sperm banks urgently require a transition from traditional management models to intelligent, data-driven systems. This study proposes a full-cycle status management system that deeply integrates artificial intelligence (AI) with an information platform. By combining machine learning, natural language processing (NLP), the Internet of Things (IoT), and blockchain technology, the system automates and optimizes the entire workflow from donor screening to clinical application. An AI-driven predictive model enhances semen quality assessment, dynamic data analysis improves follow-up efficiency, and multi-center clinical trials validate its effectiveness. Results demonstrate a 35% improvement in management efficiency, a 25% reduction in operational costs, and a 12% increase in pregnancy success rates. This research provides an innovative solution for intelligent management in reproductive medicine and highlights the broad potential of AI in biological specimen repository management.

Keywords: Artificial intelligence (AI), Full-Cycle Management, Sperm Banks, Predictive Modeling, Blockchain, Internet of Things (IoT)

INTRODUCTION

Human sperm banks, as critical infrastructure for ART, require efficient management to ensure specimen quality and patient safety. Traditional approaches relying on manual records and static data analysis suffer from fragmented data and delayed responses. Recent breakthroughs in AI applications (e.g., medical imaging diagnosis, supply chain optimization) inspire this study. By integrating AI with an advanced information platform, we aim to establish an intelligent management system covering the entire lifecycle of donor semen specimens, enabling real-time data processing, scientific decision-making and automated workflows.

METHODOLOGY AND TECHNICAL FRAMEWORK

System Architecture

The system adopts distributed micro services architecture, comprising four layers:

Data Acquisition Layer

Integrates RFID tags, optical character recognition (OCR), and IoT sensors to collect real-time donor information, semen parameters (e.g., motility, morphology), and cryopreservation environment data.

AI Analysis Layer

Deep Learning Model: A convolutional neural network (CNN)-based image analysis module achieves 98.7% accuracy in identifying abnormal sperm morphology from microscopic images.

Time-Series Prediction: Long short-term memory (LSTM) networks forecast long-term viability decay in cryopreserved specimens, optimizing storage strategies.

NLP Module: Automatically extracts key metrics (e.g., miscarriage rates, fetal health) from unstructured follow-

up reports

Security Layer

Employs blockchain for tamper-proof data storage and AES-256 dynamic encryption to ensure privacy.

AI-Driven Full-Cycle Management

Donor Screening: AI classification models (random forest algorithm) assess genetic and health data to flag high-risk donors (AUC=0.93).

Dynamic Semen Quality Monitoring: AI models generate real-time quality scores (e.g., motility ≥40% as qualified), minimizing human error.

Intelligent Follow-Up: NLP analyzes clinical outcomes (pregnancy rates, miscarriages) to produce multidimensional evaluation reports

EXPERIMENTAL RESULTS AND ANALYSIS

Management Efficiency

Pilot implementation at Chongqing Human Sperm Bank demonstrated:

Data Entry: OCR reduced manual error rates from 8% to 0.5%.

Cryopreservation Survival: LSTM-optimized storage improved 5-year survival rates to 92% (vs. 85% with traditional methods).

Follow-Up Response: AI automation increased patient response rates from 60% to 88%.

Clinical Validation

Multi-center trials (n=1,200 cases) revealed:

Pregnancy Success: 68% in AI-optimized groups vs. 56% in controls ($p<0.01$).

Abnormality Detection: CNN achieved 97.5% sensitivity in identifying morphological anomalies, surpassing manual screening (85%).

DISCUSSION AND INNOVATIONS

Technical Integration

First application of LSTM-block chain integration for dynamic traceability and secure data sharing.

NLP-driven follow-up system resolves challenges in processing unstructured clinical data.

Industry Impact

Provides a scalable AI framework for global sperm banks, particularly in resource-limited regions.

Ethics and Privacy

Federated learning enables collaborative modeling while preserving data confidentiality.

FUTURE DIRECTIONS

Technological Expansion: Integrate 5G and edge computing for real-time remote monitoring and dynamic AI updates.

Cross-Domain Applications: Extend the framework to oocyte banks, stem cell repositories, and other biobanking scenarios.

CONCLUSION

This study establishes the first AI-integrated, full-cycle intelligent management system for human sperm banks, significantly enhancing operational efficiency and clinical outcomes. The technical framework and empirical data offer critical insights for the intelligent transformation of reproductive medicine, with substantial academic and practical implications.

ACKNOWLEDGEMENT

We thank Chongqing Human Sperm Bank, Chongqing Maternal and Child Health Hospital, and the Second Affiliated Hospital of Chongqing Medical University for Clinical Data Support. We also acknowledge Chongqing Yunwen Technology Co., Ltd. for their technical collaboration.

Funding Project: Key Project of the Science and Health Joint Medical Research Program in Chongqing (Human Sperm Bank Donor Sperm Specimens Full-Cycle Status Follow-Up Management Platform Project, 2023ZDXM014).

Institutional Review Board Statement: Not Applicable

Informed Consent Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Data Availability Statement: The dataset used in this article is provided by the Human Sperm Bank of Chongqing Research Institute of Population and Family Planning Science and Technology and it is confidential.

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