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Innovative research on an AI-integrated full-cycle intelligent management system for donor semen specimens in human sperm banks

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).

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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 a distributed microservices 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-blockchain 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.

Author declarations

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