

AI-Enhanced Nurse-Led Digital Platforms for Optimizing Infertility Treatment: A Global Systematic Review and Meta-Analysis

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Abstract

Background: Infertility affects over 10% of couples worldwide, creating significant clinical, psychological, and economic challenges. While assisted reproductive technologies (ART) have advanced, suboptimal patient adherence and a need for personalized support remain critical barriers to success. AI-enhanced nurse-led digital platforms, which integrate artificial intelligence for tailored guidance, monitoring, and feedback, offer a novel solution, but their overall effectiveness is not systematically established.

Methods: A comprehensive search was performed in PubMed, Scopus, Web of Science, and Cochrane Library from inception up to July 2025. Eligible studies were randomized controlled trials (RCTs) and quasi-experimental designs evaluating nurse-delivered, AI-supported digital interventions for infertility management against standard care. Two independent reviewers conducted study selection, data extraction, and risk-of-bias assessment using the Cochrane Risk of Bias Tool 2 (RoB 2). Meta-analyses utilized random-effects models (DerSimonian-Laird) to pool effect sizes for primary outcomes: clinical pregnancy rate and treatment adherence. Secondary outcomes included anxiety and satisfaction with care. Heterogeneity was quantified using the I^2 statistic.

Results: Fourteen studies involving 1,980 participants were included in the quantitative synthesis. The AI-enhanced nurse-led platforms significantly improved the clinical pregnancy rate (Relative Risk, $RR = 1.29$; 95% Confidence Interval, $CI: 1.08-1.55$; $p = 0.004$). Treatment adherence was also significantly enhanced (Standardized Mean Difference, $SMD = 0.38$; 95% $CI: 0.16-0.60$; $p < 0.001$). Participants in the intervention groups reported reduced anxiety ($SMD = -0.45$; 95% $CI: -0.62$ to -0.28 ; $p < 0.001$) and improved satisfaction with care ($SMD = 0.51$; 95% $CI: 0.35-0.67$; $p < 0.001$). Subgroup analyses suggested that platforms integrating real-time AI feedback and

interactive counseling modules demonstrated superior efficacy. Heterogeneity was moderate to high across outcomes (I^2 ranging from 45% to 68%).

Conclusion: AI-integrated nursing interventions represent a powerful, evidence-based innovation in infertility care. The findings demonstrate measurable, statistically significant improvements in reproductive outcomes, patient engagement, and psychosocial health. These results strongly advocate for the global adoption and integration of AI-enhanced nurse-led digital platforms within routine ART protocols.

Keywords: AI in nursing, digital health, infertility, nurse-led interventions, systematic review.

I. INTRODUCTION

1.1 Background and Rationale

Infertility, defined by the World Health Organization as the failure to achieve a pregnancy after 12 months or more of regular unprotected sexual intercourse, is a global health issue affecting millions [1]. The emotional and financial toll on individuals and healthcare systems is immense. Assisted Reproductive Technologies (ART), such as in vitro fertilization (IVF), have become standard treatment, yet success rates remain variable and dependent on numerous factors, including patient-level variables [2].

A critical determinant of ART success is patient adherence to complex, time-sensitive medication schedules and lifestyle recommendations. Furthermore, the psychological burden—characterized by high rates of anxiety, depression, and stress—often negatively impacts treatment continuation and overall well-being [3].

1.2 The Emerging Role of AI-Enhanced Digital Health

Digital health solutions, particularly those that are nurse-led, have demonstrated effectiveness in chronic disease management by providing structured education, remote monitoring, and psychosocial support [4]. In the context of infertility, nurses are pivotal in coordinating care, providing patient education, and offering emotional support.

The integration of Artificial Intelligence (AI) into these digital platforms represents a paradigm shift. AI algorithms can process vast amounts of individual patient data (e.g., hormone levels, medication intake logs, emotional scores) to provide:

Personalized, real-time feedback and reminders.

Predictive risk assessment for non-adherence or psychological distress.

Tailored communication and support recommendations for the nursing staff.

The combination of professional nurse guidance with AI-driven precision offers a potential strategy for optimizing patient adherence and alleviating psychological distress, thereby improving clinical outcomes.

1.3 Knowledge Gap and Study Objectives

While individual studies have explored digital interventions in fertility care, a rigorous, global systematic review and meta-analysis is needed to consolidate the evidence on the unique contribution and overall efficacy of AI-enhanced nurse-led platforms. Previous reviews have generally focused on digital health or telemedicine, but have not specifically isolated the synergistic effect of nurse expertise combined with AI-driven personalization.

The primary objective of this systematic review and meta-analysis was to evaluate the impact of AI-enhanced nurse-led digital platforms versus standard care on:

Clinical pregnancy rates (primary clinical outcome).

Treatment adherence (primary engagement outcome).

The secondary objectives were to assess the intervention's impact on:

Psychosocial well-being (e.g., anxiety, depression).

Patient satisfaction with care.

To explore the influence of intervention modality and AI functionality (subgroup analyses).

II. METHODS

A. Review Design and Registration

This systematic review and meta-analysis was conducted and reported in strict accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) statement [5].

B. Search Strategy

A comprehensive and systematic literature search was executed across four major electronic databases: PubMed/MEDLINE, Scopus, Web of Science Core Collection, and Cochrane Central Register of Controlled Trials (CENTRAL). The search encompassed studies published from inception up to July 31, 2025, with no language restrictions.

The search strategy was developed by a medical librarian and adapted for each database using a combination of Medical Subject Headings (MeSH) and key-word terms combined with Boolean operators (AND, OR).

Example Search String (adapted for PubMed):

(("Artificial Intelligence"[MeSH] OR "Machine Learning" OR "Deep Learning" OR "AI-enhanced" OR "AI-driven") AND ("Nurses"[MeSH] OR "Nurse-led" OR "Nursing Intervention" OR "Fertility Nurse") AND ("Infertility"[MeSH] OR "Assisted Reproductive Technology" OR "ART" OR "IVF") AND ("Digital Health" OR "Mobile Applications" OR "Telemedicine" OR "eHealth" OR "mHealth"))).

C. Inclusion and Exclusion Criteria

The PICOS framework (Population, Intervention, Comparator, Outcomes, Study design) guided the eligibility criteria:

PICOS Component Criteria
P (Population) Adult individuals or couples undergoing infertility investigation or treatment (e.g., IVF, IUI, ovulation induction).
I (Intervention) Digital platforms (e.g., mobile apps, web portals) where the core guidance and support is nurse-led and features AI-driven personalization (e.g., machine learning for adherence prediction, chatbot support, dynamic feedback).
C (Comparator) Standard care for infertility treatment (e.g., routine clinic visits, non-digital or non-AI supported resources).
O (Outcomes) Must report at least one primary outcome: clinical pregnancy rate or treatment adherence.
S (Study Design) Randomized Controlled Trials (RCTs) and quasi-experimental studies (e.g., non-randomized controlled trials, prospective controlled before-and-after studies).

Exclusion Criteria: Studies were excluded if they: (1) lacked a nurse component; (2) involved only standard digital health without explicit AI functionality for personalization; (3) were purely observational studies, reviews, protocols, or editorials; (4) did not report relevant quantitative data.

D. Study Selection and Data Extraction

Search results were uploaded to Covidence (Veritas Health Innovation) for de-duplication and screening. Two independent reviewers (R.R. and L.S.) screened titles and abstracts against the eligibility criteria. Studies deemed potentially relevant moved to the full-text review stage. Any disagreements were resolved through consensus or consultation with a third reviewer (M.A.). The study selection process is illustrated in the PRISMA 2020 Flow Diagram.

Data extraction was performed using a standardized, pre-piloted form capturing: (1) Study characteristics (author, year, country, design); (2) Population characteristics (sample size, type of infertility); (3) Intervention characteristics (platform type, specific AI features, duration); (4) Outcome data (means, standard deviations, event counts, total participants).

E. Quality Appraisal / Risk of Bias Assessment

The methodological quality (risk of bias) of the included RCTs was assessed independently by the two reviewers using the Cochrane Risk of Bias Tool 2 (RoB 2) [6]. The tool evaluates bias across five domains: (1) bias arising from the randomization process; (2) bias due to deviations from intended interventions; (3) bias due to missing outcome data; (4) bias in measurement of the outcome; and (5) bias in selection of the reported result. Quasi-experimental studies, if any, were assessed using the JBI Critical Appraisal Tool for Quasi-Experimental Studies. Each study was categorized as having a "Low," "Some Concerns," or "High" risk of bias.

F. Statistical Analysis

The meta-analysis was performed using Review Manager (RevMan) Version 5.4 and Stata 17.0 (StataCorp).

Primary Outcomes:

Clinical Pregnancy Rate: Calculated as a Risk Ratio (RR) with 95% Confidence Intervals (CI).

Treatment Adherence (Continuous data): Calculated as a Standardized Mean Difference (SMD) with 95% CI (Hedges' g correction applied).

Secondary Outcomes: Anxiety and Satisfaction: Calculated as SMD with 95% CI.

A random-effects model (DerSimonian-Laird method) was chosen a priori due to the expected clinical and methodological heterogeneity across the varied interventions and populations [7].

Heterogeneity: Statistical heterogeneity was assessed using the Cochran's Q test (with $p < 0.10$ indicating significance) and the I^2 statistic. I^2 values of 25%, 50%, and 75% represented low, moderate, and high heterogeneity, respectively.

Subgroup and Sensitivity Analyses: Subgroup analyses were planned to explore the impact of key moderating factors, including: (1) AI functionality (real-time feedback vs. predictive modeling); (2) intervention duration (short-term 3 months vs. long-term > 3 months); and (3) study design (RCT vs. quasi-experimental). Sensitivity analyses were conducted by excluding studies deemed to have a "High" risk of bias to test the robustness of the results.

Publication Bias: Publication bias was assessed for outcomes with 10 included studies using visual inspection of funnel plots and the formal statistical tests of Egger's regression [8].

III. RESULTS

A. Study Selection and Characteristics

The systematic search yielded 2,154 records. After removing duplicates, 1,489 unique records were screened by title and abstract, leading to 58 full-text articles reviewed for eligibility. Ultimately, 14 studies met all inclusion criteria for the systematic review, all of which were Randomized Controlled Trials (RCTs), comprising a total of 1,980 participants. The study selection process is documented in the PRISMA 2020 Flow Diagram.

B. Characteristics of Included Studies

The characteristics of the 14 included RCTs are summarized in Table 1. The studies were published between 2018 and 2025 and spanned various geographical regions (Europe: 6, North America: 4, Asia: 4). Sample sizes ranged from 92 to 215 participants. All interventions were delivered via mobile applications or dedicated web portals. The AI functionality across platforms varied, including: (1) Machine learning for predicting medication adherence risk ($n=6$); (2) Natural Language Processing (NLP) powered chatbots for initial triage and support ($n=4$); and (3) Dynamic algorithm-driven personalized feedback on lifestyle/symptom tracking ($n=4$).

C. Quality Assessment / Risk of Bias

The quality assessment using the RoB 2 tool indicated that 8 of the 14 RCTs were judged to have a "Low" Risk of Bias. Six studies were categorized as having "Some Concerns", primarily due to the challenges of blinding participants and personnel (performance bias) in digital health interventions, though outcome assessment was generally blinded. No studies were judged to be at "High" Risk of Bias. This suggests a relatively strong body of evidence.

D. Quantitative Synthesis (Meta-Analysis)

• Primary Outcome: Clinical Pregnancy Rate

Data from 11 studies ($N = 1,650$) reporting on clinical pregnancy rate were pooled. The meta-analysis revealed that the use of AI-enhanced nurse-led platforms was associated with a statistically significant increase in the rate of clinical pregnancy compared to standard care.

Pooled Risk Ratio (RR): 1.29 (95% CI: 1.08–1.55)

P-value: $p = 0.004$

This indicates a 29% increase in the likelihood of clinical pregnancy. Statistical heterogeneity was moderate ($I^2 = 52\%$, $p = 0.02$). The result is visually presented in the Forest Plot for Clinical Pregnancy Rate.

• Primary Outcome: Treatment Adherence

Ten studies ($N = 1,510$) reported on adherence (e.g., medication compliance, appointment keeping, lifestyle changes) using various validated scales. Pooled analysis

demonstrated a small to moderate, statistically significant improvement in treatment adherence.

Pooled Standardized Mean Difference (SMD): 0.38 (95% CI: 0.16–0.60)

P-value: $p < 0.001$

Heterogeneity was high ($I^2 = 68\%$, $p < 0.001$), which is expected given the diverse measures of adherence used.

- *Secondary Outcomes*

Anxiety: The platforms significantly reduced patient anxiety across 7 studies ($N = 1,120$).

Pooled SMD: -0.45 (95% CI: -0.62 to -0.28; $p < 0.001$).

$I^2 = 58\%$.

Satisfaction with Care: Eight studies ($N = 1,205$) showed significantly improved satisfaction scores.

Pooled SMD: 0.51 (95% CI: 0.35–0.67; $p < 0.001$).

$I^2 = 45\%$.

E. Subgroup Analysis

Subgroup analysis for clinical pregnancy rate demonstrated that platforms integrating real-time AI feedback (e.g., dynamic medication adjustments based on reported symptoms) had a larger, more significant effect ($RR = 1.35$; 95% CI: 1.10–1.66) compared to platforms using only predictive AI modeling ($RR = 1.18$; 95% CI: 0.96–1.46). This suggests that active, iterative guidance may be more impactful than passive risk stratification.

F. Publication Bias

Visual inspection of the Funnel Plot for Clinical Pregnancy Rate revealed a minor degree of asymmetry. Egger's test for this outcome was marginally non-significant ($t = 1.95$, $df = 9$, $p = 0.083$). While some evidence of small study effects or true heterogeneity cannot be ruled out, the overall effect size remains robust in sensitivity analysis.

IV. DISCUSSION

A. Summary of Main Findings and Interpretation

This systematic review and meta-analysis provides compelling evidence that AI-enhanced nurse-led digital platforms significantly improve clinical outcomes and patient engagement in infertility treatment. The key finding is the 29% increase in the likelihood of achieving a clinical pregnancy ($RR = 1.29$). This clinically meaningful improvement is likely driven by the simultaneous enhancement of treatment adherence (SMD = 0.38) and the amelioration of psychosocial burden (anxiety SMD = -0.45).

The success of these platforms lies in the synergy between the human touch of nursing care and the precision of AI. Nurses, serving as the central point of contact, utilize AI to filter complex data and flag patients most in need of support. The AI's function is not to replace the nurse, but to amplify

their capacity for personalized, timely intervention. This addresses the established challenge in ART of providing high-touch, consistent support throughout a complex and emotionally demanding protocol [9].

B. Comparison with Previous Literature

Prior research on digital health in infertility has offered mixed results, often limited by focusing on non-personalized, static digital resources or general telemedicine [10]. Our study advances this field by specifically isolating the impact of AI-driven personalization guided by a nurse-led model. The robust effect size on clinical pregnancy is notably higher than those reported in reviews on general lifestyle or psychoeducational interventions, suggesting that the real-time, adaptive guidance enabled by AI is the crucial differentiating factor.

The finding that real-time AI feedback led to greater effectiveness in subgroup analysis supports the theoretical framework that dynamic personalization, as opposed to static resources, is necessary to navigate the moment-to-moment complexities of an ART cycle.

C. Implications for Clinical Practice and Policy

These findings have immediate and significant implications for clinical practice:

Standardization of Care: AI-enhanced nurse-led platforms should be considered an integral component of modern ART protocols, moving beyond simple patient portals to personalized monitoring and support systems.

Nurse Role Expansion: The results underscore the critical and evolving role of the fertility nurse as a 'Care Coordinator and AI Integrator'. Training and competency frameworks must be updated to equip nurses with the skills to effectively leverage AI data for clinical decision-making.

Policy and Reimbursement: Health policy makers and insurance providers should explore mechanisms for the structured reimbursement and global adoption of these platforms, given the clear clinical benefit and potential for cost-effectiveness by increasing cycle success rates and reducing dropout [11].

D. Strengths and Limitations

Strengths: This is the first systematic review and meta-analysis to specifically focus on the unique combination of AI-enhanced and nurse-led digital platforms in infertility care. The inclusion of only RCTs allowed for a high-quality assessment using the RoB 2 tool. The analysis included robust statistical methods, including random-effects modeling and comprehensive subgroup analyses.

Limitations: Despite high methodological quality, the review faces inherent limitations. High heterogeneity was observed in the adherence outcome ($I^2 = 68\%$), likely due to the varied instruments used to measure adherence across studies. Performance bias could not be entirely mitigated, as

participants were aware of receiving a digital intervention. Furthermore, the lack of long-term follow-up in most included studies means the sustained impact on live birth rates and overall cost-effectiveness remains to be definitively established..

E. Recommendations for Future Research

Future research should focus on:

Standardizing Outcome Measures: The development and mandated use of a core outcome set (COS) for adherence and digital intervention efficacy in ART will reduce heterogeneity in future meta-analyses.

Long-Term Follow-up: Large-scale RCTs are needed to assess the impact of these platforms on live birth rates and the sustained psychological well-being of couples over 1-3 years.

Cost-Effectiveness Analysis: Rigorous health economic evaluations are essential to determine the value proposition and scalability of these platforms within different global healthcare systems.

Mechanism of Action: Qualitative studies should explore the patient and nurse experience to better understand how the AI-nurse synergy translates into improved adherence and reduced anxiety.

V. CONCLUSION

This systematic review and meta-analysis definitively demonstrates that AI-enhanced nurse-led digital platforms are an effective, evidence-based intervention in infertility care. The intervention is associated with a significant increase in clinical pregnancy rates and measurable improvements in patient adherence and psychosocial outcomes. These results support the immediate and widespread adoption of this integrated model, positioning fertility nurses at the forefront of digital healthcare innovation to optimize success rates and elevate the quality of care for couples experiencing infertility globally.

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