



Letter to Editor

Asian Pacific Journal of Reproduction

Journal homepage: <https://journals.lww.com/apjr/>

doi: 10.4103/apjr.apjr_59_25

Emerging frontiers in assisted reproductive technology: Balancing innovation and ethics in AI-driven embryo selection and personalized medicine

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The rapidly evolving environment of assisted reproductive technology (ART) requires consideration of how new innovations are reshaping clinical practice as much as research. In particular, there are three key areas that, while full of promise, also present significant challenges: the use of artificial intelligence (AI) in embryo selection, the impact of personalized medicine on ART success rates, and the ethical considerations of genetic screening of embryos[1]. This letter is meant to provoke further discussion and highlight the need for harmonized global guidelines as these advances continue to reshape the reproductive medicine environment.

Modern *in-vitro* fertilization (IVF) clinics increasingly incorporate AI algorithms that predict implantation potential from time-lapse embryo images, achieving predictive scores exceeding the traditional grading methodology. From thousands of digital biomarkers of cleavage through cytoplasmic viscosity, machine learning algorithms are 98.7% reproducible to predict viability *vs.* only 75.4% variability inter-embryologist among human gradings[2]. Aside from raising live birth rates, the new model lowers time-to-pregnancy through earlier embryo transfer of higher-quality embryos. Yet, the "opaque model" nature of most AI implementations precludes investigation into algorithm bias when training databases sub represent ethnic minorities or unexpected genetic profiles[3]. While new FDA-cleared systems now generate outcome transparency reports, the field of reproductive technology remains in immediate need of standards of validation on broad patient cohorts[4].

Integrating pharmacogenomic information with ART protocols is a prime example of how personalized medicine will be a game-changer in reproductive technologies' outcomes. There have recently been 127 identified genetic variants that are associated with ovarian response to gonadotropins, which can be optimized in terms of dose in order to minimize risks from hyperstimulation by 41% with optimal oocyte production[5]. In addition, machine learning models established from multi-omic based data on transcriptomic, proteomic, as well as metabolomic profiling are currently predicting blastocyst euploidy in a single individual with 89% accuracy before

a biopsy. While these are encouraging developments, challenges do remain. A 2025 report cited small sample sizes as a source of concern as much as overfitting in high-dimensional data[6]. Other studies have noted that models of personalized dosing, as innovative as they are, have sometimes failed validation in independent cohorts. The observations are a powerful reminder of the critical need for more extensive longitudinal data that not only incorporate genetic, hormonal, and metabolic variables, but also lifestyle, environmental, and epigenetic variables—dimensions not captured in most registries in IVF[7].

In order for the ART community to be at the crossroads requiring collective, immediate action the following steps must be taken: reconciling technological progress with moral requirements. Three complementary efforts must be the next step in this endeavor: First, developing WHO-endorsed standardization platforms for validating AI in ART—demanding diversity audits of training data and transparency of outcomes—to minimize algorithmic bias and facilitate ethical clinical deployment[8]. Second, convening international tribunals of disciplinary bioethics composed of patient advocacy groups, clinicians, and legal scholars to come to consensus on permissible uses of preimplantation genetic testing, avoiding exploitative "designer embryo" markets while ensuring access to required screenings. Third, putting longitudinal studies

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How to cite this article: Nair N, Mishra V, Badge A, Shendre S. Emerging frontiers in assisted reproductive technology: Balancing innovation and ethics in AI-driven embryo selection and personalized medicine. *Asian Pac J Reprod* 2025; 14(4): 189–190.

Article history: Received: 6 March 2025; Revision: 7 April 2025; Accepted: 10 May 2025; Available online: 31 July 2025

atop the research agenda to measure the psychosocial consequences of AI-based embryo selection, particularly its long-term effect on family structure and societal attitudes toward genetic idealization[9]. Collectively, these steps address the inflection point at which the technological potential of ART risks outstripping governance systems. Only with such disciplinary collaboration—outside the scope of computational science, clinical practice, bioethics, and social sciences—can the field responsibly harness nascent innovations to decrease burdens of infertility while upholding principles of equity, transparency, and human dignity.

Conflict of interest statement

The authors declare no competing interests.

Funding

The study receives no extramural funding.

Authors' contributions

Nancy Nair contributed to the conception or design of the work, drafting of the work, approval of the final version of the manuscript, and agreed on all aspects of the work. Vaishnavi Mishra contributed to the literature review, revision of the manuscript for important intellectual content, approval of the final version of the manuscript, and agreed to all aspects of the work. Ankit Badge contributed to the literature review, revision of the manuscript for important intellectual content, approval of the final version of the manuscript, and agreed to all aspects of the work. Sahil Shendre contributed to the review and revision of the manuscript for important intellectual content.

Publisher's Note

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Edited by Lin LY, Lei Y