

A Systematic Review on the Role of Artificial Intelligence in Assisted Reproductive Technology

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Abstract

Artificial Intelligence (AI) has significantly transformed Assisted Reproductive Technology (ART) over the past five years, enhancing diagnostic accuracy, treatment personalization, and overall success rates. AI-driven algorithms and machine learning models have been integrated into various aspects of ART, including sperm selection, embryo grading, and predicting implantation success. Deep learning techniques have improved image-based embryo assessment, reduced human subjectivity and increased efficiency. Additionally, AI-powered predictive analytics have helped optimize ovarian stimulation protocols and identify potential causes of infertility. AI has proved its worth in all most all sectors, it has the potential to bring a boom in Reproductive field as well as AI can help to analyze the data and can predict results which may help the women who wish to conceive through ART techniques. This will improve overall health, mental condition and create an understanding between patient and doctor, which will result increase in success rate of pregnancy achieved through ART methods. This review highlights the role of Artificial Intelligence in ART like IUI, IVF and ICSI, discusses its impact on clinical outcomes, and explores future possibilities in the field. Paper aims to focus on role of AI in ART techniques, AI in ART in low- and middle-class families, embryo selection using AI, sperm selection using AI. Paper also gives a review of factors for the success of ART through AI with focus on providing personalized experience through AI to the women patients. Along with this role of AI in ICSI and IUI is also reviewed. While AI has shown great promise in improving reproductive success, ethical considerations and regulatory frameworks remain crucial to ensure safe and effective implementation in clinical practice.

Keywords: ART, IVF, AI, Embryos, Robotics, ML, IUI, ICSI, FET

INTRODUCTION

ART (Assisted Reproductive Technology) is the reproductive methods to achieve pregnancy by enhancing the quality of embryos and sperms in the IVF (In vitro Fertilization) lab. Artificial Intelligence has proved its worth in different segments and now this technology is all set to help couples to achieve pregnancy and treat infertility. The biggest revolution in infertility is IVF in which every step is performed with precision and care to deliver best results in each cycle. Complete ART cycle involves [1].

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Received Date: May 29, 2025

Accepted Date: January 06, 2026

Published Date: January 06, 2026

Citation: Latika, Renuka Arora. A Systematic Review on the Role of Artificial Intelligence in Assisted Reproductive Technology. International Journal of Bioinformatics and Computational Biology. 2026; 4(1): 21–29p.

- Providing Fertility drugs to women to improve the quality of eggs.
- Retrieval of eggs.
- Mixing eggs with best sperm sample.
- Development of embryos in laboratory.
- Transfer of one or more embryo in uterus of women.

This systematic review aims to provide the research done in this field for past five years. The

paper aims to review each method used in each research papers by specifying the technology used and features on which results are concluded. Paper provides the role of AI in ART Technologies on the scale of usage, precision, accessibility. IUI (Intrauterine Insemination) is briefly explained and the complete process of IVF is also studied. The usage of ML algorithms at each step is also studied. Artificial Intelligence along with Machine Learning algorithms can make decision making at every step easier by training the machine on different parameters like BMI, patient medical history, embryo images, etc.

METHODOLOGY

In this review, we are bound to provide review of role of AI in the field of ART, IVF. The literature search is conducted through Google Scholar, Springer Nature, taking combination of keywords like IVF, Machine learning, AI, ART & IUI. The paper aims to provide review of papers from past 5 years, i.e., from 2020 to 2024. Total of 24 Articles are discussed in the entire paper.

AI in Assisted Reproductive Technology

Artificial Intelligence is a technology that make computers learn and perform in ways that require human intelligence. AI can enhance the process of decision making, it can predict much better and can create new content. Machine Learning is a type of Artificial Intelligence that learn from patterns, depending on data on which it is trained. ML make predictions on data on which it is trained through different ML algorithms like Linear Regression, Logistic regression, Naïve Byes, Random Forest, KNN and much more. Deep learning is a type of Machine Learning that learns from artificial neural networks. NLP is Natural Language Processing that is used in Chatbots, Sentiment analysis, etc. Assisted Reproductive Technology on another hand is a term that uses selection of best embryos and sperm to achieve successful pregnancy. Since Artificial Intelligence has its role in almost all genres, it is expanding its dimension in the field of ART. ART involves processes like IUI, IVF, ICSI, FET is using frozen embryos in IVF to achieve successful pregnancy. IUI where sperm is injected directly into uterus to achieve successful pregnancy. In IVF, women are provided with fertility supplements to improve the quality of eggs. At maturation eggs are taken from women body. These collected eggs are analyzed and best eggs are taken to mix with sperm sample of men. In laboratory, fertilization is done. This fertilized sample is termed as embryo. The best embryo is transferred into uterus to achieve pregnancy. ICSI is Intracytoplasmic sperm injection that involves injecting sperm into egg. This is usually referred when sperm count is very less. In ART methods, traditionally, all decisions are made by embryologists like selection of best embryos, best sperm, making decisions based on various factors like age, intercourse frequency but these traditional method does not offer personalized experience to patients, no description of side effects, probable health risks to human body. As these processes involves a lot of financial and mental involvements which can surlily affects one mental health and finances, there is a dire need for automation, AI, ML models that can suggest best embryos, best sperm, best time to perform ART, chances of conception, and much more. AI can improve the efficiency and accuracy of ART methods [1]. The AI ART Software keeps track of all the steps that are performed in IVF that majorly involves AMH based ovarian stimulation, measurements of follicular diameter, sperm test, embryo selection and much more. According to the authors, Deep learning provides better approach as compared to ML in terms of mapping labels with the input features. The complete IVF cycle of patients is recorded in this software starting from first appointment to the final IVF process then discharge. The complete IVF process is automated. To maximize the chance of successful conception machine is provided with ultrasound images. Paper is concluded with the fact that this software can be used as a facilitator, as an instrument of clinical findings to make a better decision at every step of IVF [2]. Author provides the role of AI in present and future. At present, AI finds its role in embryo selection. The most important aspect of Process is oocyte quality. Author also discussed robotics procedures in the field of ART through reproductive medicines. In terms of future of AI in this field, reproductive surgeries, hormonal analysis, ovarian stimulation protocol, evaluation of oocytes, sperm selection, ICSI, Embryo culture and tracking, Embryo freezing may be automating through AI algorithms for better clinical decision making [3]. AI has a potential to improve the outcomes at each step of IVF if automated with it. Using ML and Deep Learning models we can achieve much precision. Using AI, customized IVF plan can be built on Basis of patient characteristics. AI can be used in gamete selection, good embryo grading and

selection. It can be used in treatment regimen which involves patient age, medical history, embryo selection. Paper also explains hurdles towards adoption like limited computing and data storage, discrepancy in data recorded and actual reported data of patient. AI can only be adopted when there is some standardization of data, sharing of data among clinics, etc. Author concludes with the fact that incorporating AI in to ART technology will enhance patient personal experience towards successful pregnancy or conception [4]. To personalize ART outcomes, ML can be used. AI chatbots can enhance the process of initial assessment of infertility. Random Forest Model is used to optimize the trigger day. To achieve healthy live birth AI capabilities can be used where it can analyze large amount of data. AI can enhance the experience by providing customized experience at every decision point in process of IVF.

AI for ART Especially for Low-or Middle-Income People

The process of ART technologies like IVF is very costly in terms of finances, expenses and on one's health as it involves a lot of change in women body due to involvement of reproductive medicines [5]. Infertility affects 48.5 million couples worldwide. ART is unaffordable for low income or middle-income groups. The review states that WHO needs to look in to this landscape especially for Lower income groups as the complete process of IVF is costly. Regions on which studies are done are Middle East and North Africa, Europe and central Asia, Sub-Saharan Africa, Latin America. The main focus is to provide ART methods in low-income groups by providing focus on easy accessibility, feasibility and acceptability [6]. IVF is known to give birth to 9 million babies worldwide. The process of IVF needs experienced and skilled people as it needs utmost care, precision at every step, so innovation is needed in this field. The focus should be on providing patients an easy pathway to process of IVF plus making these methods affordable. A deadly combination of ML and NLP act as a savior to the massive clinical data that will be collected through patients: automation is must. There is dire need to automate the process that should be patient specific that is analyzing patients' demographics and then predicting the medical dose on reports of patient. Oocyte retrieval and selection the most important step in IVF needs better system for selection. Sperm selection and injection the final step to complete the IVF process. The automation of ART will reduce the task of embryologist and would help them in better decision making. Automation is meant to make better decisions rather than replacing the skilled people.

Embryo Selection Using AI

Embryo selection is the most important step of IVF process to predict successful conception [7]. Embryo selection refers to the process of evaluating the quality of fertilized eggs and selecting the best from them for transfer. On retrospective data, AI models are best as compared to the human selection. Images and videos are taken as parameters. AI model is built and classification metrics is used for evaluation like binary classification and confusion metrics [8]. Nowadays, one embryo is transferred in most assisted reproductive technique. So, Embryo selection plays an important role. As the prime goal of ART is to get a single, healthy baby that requires single best embryo. To choose from fertilized embryos, the challenge for embryologist is to select the best embryo for transfer which will implant itself to uterine lining in women. Morphological Embryo assessment is discussed like all stages of embryo development including blastocyst stage. The challenge at this stage is the precision which is difficult to achieve due to change in observation at day 2 and day 3. Blastocyst transfer, timelapse imaging is explained then the AI role is discussed in embryo selection where the best combination of ML and Deep learning may predict the best embryos. Overall Artificial intelligence has the potential which may help embryologists to select best embryos as the goal is to get healthy pregnancies. Embryo selection at blastocysts stage has high potential that can give more healthy pregnancies [9]. The advantage of using AI in ART is Machine learning can handle lots of data and can predict, computer vision allows large image data to be analyzed using algorithms. Black box models of AI are discussed that force the embryologists to take decisions without understanding the algorithms in to it. Black box models are difficult to explain and troubleshoot too. Overall, Interpretable AI may give better results than black box as decision making lies with the embryologist or clinicians [10]. AI models give better prediction as compared to the Embryologist by giving 4% higher prediction accuracy. Parameters like Images, time lapse, clinical records, patient history is taken.

Factors to Success of IVF Through AI

ART methods involve two modules one is the process of ART technique second is factors that can lead to successful pregnancy. Just by selecting best embryos does not ensure successful conception but factors like stress, obesity, affects the live birth rate. To understand these factors, one must understand what a women body had to undergo during ART procedures like IVF, IUI or ICSI [11]. Impact of chronic or acute stress on each step of IVF is studied. Infertility affects millions of people at their age of conceiving. Infertility causes stress and there are various studies that ART techniques also cause stress. Stress can affect on the quality of oocytes retrieved; chronic stress is found during phases of IVF. Live birth or hope for successful conception causes both kind of stress in couples [12]. Focus is on the patients undergoing IVF should know the chances of successful IVF while going through the process. The author conducted a survey, filled questionnaires from patients who wish they might know what changes the ART methods will make to their body and life. Some said IVF does not guarantee successful conception and healthy baby. Paper concluded with the fact that the fertility clinics should give them real picture on ART techniques [13]. Obesity is another factor on which pregnancy depends. Obesity has negative effect on reproduction, may cause infertility. It has negative effect on response of ART treatments as well. It may lead to endometriosis, ovulation disorders, ovarian reserve. Parameters like FSH, HCG are also explained in the paper.

Automation in ART with AI

Infertility affects many women in the age group of (20–44) [14]. Automation in ART can be done at every step to facilitate easy decision making. First is Data Management where combination of ML and NLP can ensure better data Management. Second is Patient Treatment Pathway, where AI can ensure personalized care to patients like how much dose to be given depending upon their characteristics. Third is Trans- Vaginal Oocyte Retrieval where AI can be used to train machine with ultrasound images. Fourth step is oocytes selection where AI can help in taking decisions related to freezing, oocytes allocation strategies can be defined. Fifth step is Semen Analysis and Preparation by utilizing microfluids, CNN based AI algorithms can be used. Overall, the goal of Automation will only be to help the embryologist and clinicians in making better decision to achieve healthy pregnancy [15]. Influence of endometriosis is studied where early and late treatment groups showed higher live birth rate than the ones that are not treated medically. The study states that endometriosis has a negative influence on IVF treatments but its controlled activity may result in higher chances of live birth rate [16]. Author discusses Deeptech revolution powered by Femtech where Femtech is a technology that relates to electronic devices or software's related to women health. Deeptech may help ART techniques to Masses [17]. AI predicts better prediction compared to conventional systems. Parameters like BMI, COCs, PCOS are taken to predict the results on patients [18]. Two ART methods are discussed, i.e., IVF and IUI. IUI is usually the first step which is taken in cases of infertility or in couples hoping for pregnancies. If IUI is unsuccessful, it is usually followed by IVF, which has a much higher success rate compared to IUI. IVF involves transferring of best fertilized embryos where embryologist have a chance to transfer best embryos to achieve successful conception and better live birth.

Role of AI in Sperm Selection and Analysis

Assisted Reproductive Technology (ART) like IVF, IUI, ICSI, involves study of both men and Women features to achieve successful conception. In this section, the role of AI is reviewed in sperm selection and Analysis [19]. A systematic Literature review is performed in the PubMed database. Male infertility in laboratory is analyzed by taking sperm samples. Various automated computer assisted semen analysis (CASA) are used to analyze the sperm quality. ML models are trained on factors like cigarette smoking, age, alcohol consumption, etc. AI can be used in evaluation of sperm concentration via CASA systems, evaluation of sperm motility is also given by CASA systems. ML models are trained using morphology characteristics to predict the sperm morphology. Use of AI in sperm DNA and damage is also studied. All-important sperm parameters like sperm concentration, count, motility, and morphology are studied using AI/ML Models [20]. Role of AI in Reproductive medicines, its applications and impact is studied. Various branches of AI like Machine Learning, Deep Learning and NLP (Natural Language Processing) are explained. Various risk factors are studied using ML models

and algorithms. ML models like ANN and DL are used to predict Seminal Quality. Paper concluded with the use of AI as a revolution in the field of reproductive medicines as AI is revolutionizing the treatment and evaluation of male infertility.

Role of AI in IUI & ICSI

IUI is one of the ART methods that involves collecting sperm sample and transferring it in to uterus of women to increase chance of conception. This is the simplest ART method. ICSI is Intracytoplasmic Sperm Injection, is an advanced IVF technique that involves transfer/injection of single sperm cell in to the cytoplasm of egg. This is usually referred in case of male infertility or low sperm count [21]. ICSI offers high success rates as compared to IVF and IUI as it increases the chances of successful conception. AI can best play role in ICSI in oocyte retrieval and cases where it is unexplained male and female infertility. Failure of IUI is due to sperm morphology and motility and if AI is included in IUI cycle it can provide patient specific treatments [22]. A computer Assisted Program SiD is developed to address the selection of sperm and its assessment. AI has the potential to minimize interoperator variability, thereby reducing the chances of errors. Factors like patient recurrent failures, miscarriages and age are considered to derive the results. Effective utilization of AI is demonstrated in context of ICSI.

AI: A Path Towards Personalized Experience

Conventional Methods lack in terms of objectivity, limited functionality, inter and intra observer variability and inability to integrate the data [23]. Whereas AI can ensure predicting ovarian response, embryo selection, sperm assessment and quality. It can guide through the process of embryos grading. AI can make predictions in terms of best sperm selection which has higher chances of conception. AI can increase the chances of successful conception, thereby reducing stress in expecting couples, bring a sense of satisfaction and personalized experience to the patients undergoing treatment through ART techniques. AI plays its major role in handling large amount of data and its ability to predict or near to perfect prediction which reduces much pressure on clinical decisions. It can surely provide patients a personalized experience as patient would get a process to understand and its chances of achieving successful pregnancy through various ML algorithms and models. AI models allow integration of omics data, intelligent sperm selection and final prediction of success rates. It can ensure personalized dose stimulation, personalized treatment plans and much more. AI is a revolution in the field of reproductive medicines [24]. Challenges faced by traditional ARFT methods are: high cost, invasive procedures, ethical concerns, limited success rates and lack of personalized treatments. Robotics assisted laparoscopy is discussed along with AI models. With the involvement of AI, it has its roots in gamete and embryo selection, in taking decisions in terms of selecting embryos, in terms of causes that cause an IVF or IUI failure. Automated Reproductive Procedures can offer better insights as compared to the conventional methods (Table 1).

Table1. Role of AI in ART methods like IVF/IUI/ICSI/Embryo Selection/Sperm Analysis.

S.N.	Approaches/ technologies	Key findings	References
1	AI at ART	Complete IVF process is automated starting from one phase to end phase, i.e., conception. Author proposed a fertility treatment software that covers the entire workflow of IVF treatments.	[1]
2	AI in ART Present and Future	AI at present has role in embryo selection, in future it finds its reach in hormonal assessment, embryo freezing, blastocyst transfer. AI has its future in Reproductive Surgeries, Hormone Analysis, Ovarian Stimulation Protocol, Oocytes evaluation and sperm selection.	[2]

3	Role of AI in IVF clinic	Use of AI in gamete selection and providing personal assistance, patient centric approach, data driven precision in embryo selection. AI can revolutionize the process of IVF with enhancement in precision and outcomes.	[3]
4	Prospect of AI to personalize ART	AI chatbots can assess ones causes of infertility. AI is suitable for handling and managing large datasets which usually occur in each phase of ART Cycles.	[4]
5	IVF and ART in low- and medium- income countries	Easy accessibility, feasibility and acceptability in low- and medium- income countries. Due to high cost of IVF treatments, low income people can not afford these treatments. Role of IVF is discussed in low and medium countries.	[5]
6	Automation in ART	Combination of NLP and ML is best for automating ART process, can make decision making easy. IVF is limited to affordability, accessibility and involves technically challenging processes, there comes the need of innovation. There comes the need of Automation in ART.	[6]
7	Embryo selection with AI	Usage of videos and images and selection of embryos with AI rather by embryologists. Various AI models are compared on the basis of evaluation metrics of different models.	[7]
8	Making and selecting best embryos	Blastocysts or best embryo selection as primary goal is to have one single best sample for successful Conception. Paper discusses various methods of embryo selection, their strengths and weakness.	[8]
9	AI for best Embryo Selection Black box or interpretable	Interpretable give better flexibility than black box AI as black box algorithms force the embryologist to take the decision. AI models in the field of IVF should be evaluated with Randomized Controlled trials before they are used to decide good and poor quality of embryos.	[9]
10	Embryo selection by AI versus embryologist	AI models give 4% better Accuracy than embryologist. AI models predicted better efficiency than the clinical embryologist. AI has completely outraged the Clinical embryologist.	[10]
11	Effect of stress on IVF	Stress can reduce the success rate of conception. It can affect both men and women. Chronic and acute stress decreases the quality of egg at the time of retrieval.	[11]

		Paper emphasis on the role of stress in successful conception.	
12	Women undergoing IVF understand about IVF	Fertility clinics should give clear picture to women undergoing IVF as IVF does not guarantee successful conception and happy Baby. Patient data is collected where they share their fertilization cycle, experience when they go through first IVF cycles. Responses from participant are analyzed based on questions like what made them ready to go for ART methods.	[12]
13	Obesity associated with lower AFC and adverse effect on IVF	Obesity leads to endometriosis, ovulation disorders. BMI and Obesity pose a risk to the chances of successful conception. Overall Obesity is associated with low ovarian reserve, smaller oocyte size and suboptimal pregnancy outcomes.	[13]
14	Automation in ART: Future of Infertility Treatments	Data Management through ML and NLP and using AI at each step of IVF like embryo selection to transfer of fertilized embryo. Author summarizes the innovations in automation with or without AI Integration.	[14]
15	IVF outcomes in endometriosis patients and recurrent implantation failure	Endometriosis has negative effect on conception and it can affect live birth rates. It is necessary for patients with endometriosis to seek medical help before trying for conception through ART techniques.	[15]
16	Power of Deeptech to bring ART to masses	Multiple software to predict women health. Reproduction is rapidly changing so is the need that Deeptech techniques should be used to give patients personalized experience.	[16]
17	Conventional versus ART methods	Parameters like BMI, PCOS are Used to predict conception. Parameters like patients with higher BMI/ patients with PCOS are analyzed. AMH parameter is also studied and analyzed.	[17]
18	IVF versus IUI for unexplained Infertility	IVF has better success rates than IUI. With IVF the chances of successful conception are high compared to IUI.	[18]
19	Role of AI and ML in semen Analysis	Models are trained on basis of cigarette smoking, alcohol, etc. evaluation of sperm is done using CASA Algorithms work better when there is large data sets. AI and Machine learning is creating revolution in bio medical applications.	[19]
20	Role of AI in male fertility	ANN and DI are used to predict semen quality. AI models can accurately estimate the sperm quality, diagnose with any issues with sperm and may help in improving semen quality.	[20]
21	Role of AI in ICSI and IUI	ICSI gives best results compared to IVF and IUI. IUI can be best explained with AI giving patient specific treatments. AI can be used to select the high quality oocytes and sperm which could further increase the chances of successful pregnancy.	[21]
22	Automated SID in ICSI	Computer developed software SiD is used for sperm evaluation and assessment. ICSI-SiD produces better results then ICSI itself.	[22]

23	Sperm Analysis using AI	AI can ensure personalized dose stimulation, Personalized treatment plans and ensure better sperm selection for successful conception. AI integrated with IVF would help in handling large volume of data, could improve precision which would further strengthen the process of best embryo selection and AI can produce better reproducible diagnostic.	[23]
24	Impact of Robotics and Ai in ART	Robotics Laparoscopy and AI in gamete selection and selecting best embryos can be a game changer. Collaboration of AI with robotics in fertility treatments would lead to revolution in filed of reproductive technology.	[24]

CONCLUSIONS

AI has a potential in taking ART Techniques to boom. ML with Deep Learning and NLP will make data management in ART techniques easier. Automating ART techniques not only help embryologist a chance to make better decision making but can help patients to understand the complete process of ART techniques like IVF and IUI. AI can help fertility clinics to give personalized experience to the couples with infertility to understand their chances for live birth, for healthy baby. With technology there is a need to understand that during these procedures women body goes through number of transformations in terms of hormonal changes, weight gain, obesity, mood swings. To improve chances of successful conception both mentally and physically one needs to be ready. AI has a lot of scope in reproductive medicine and may help this field a lot which ultimately help couples to have babies and thus improving live birth rate achieved through ART Techniques. Semen Analysis is one of the important parts that needs to be taken care of while predicting successful conception. Paper discusses about role of AI in women fertility concerns like embryo selection, grading, etc. as well as male fertility concerns like sperm count, sperm motility, etc. Role of AI in giving personalized patient experience is also discussed. Different ART techniques like IVF, IUI, ICSI are also discussed. Although AI is a boom to the field of reproductive medicines but ethical considerations and regulatory framework remain crucial to ensure its effective implementation.

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