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Review of Recent Developments in AI Applications in IVF Laboratories

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Abstract: *Over the past ten years, progress has been concentrated on the integration of deep learning algorithms and artificial intelligence into medical care, especially in the areas of in vitro fertilization and assisted reproductive technologies. The area of IVF is heavily dependent on visual judgments, which can be vulnerable to subjectivity and inaccuracy and depend on the amount of training and skill of the observing embryologist. This is because embryo morphology is the cornerstone of clinical decision making for IVF. AI algorithms can be used in the IVF lab to provide fast, unbiased, and accurate evaluations of microscope pictures and clinical data. This paper aims to explore the numerous advancements in various elements of the IVF process by discussing the ever-expanding uses of AI algorithms within the IVF embryology laboratory. We will go over how AI will enhance a number of processes and procedures, including cell tracking, embryo witnessing, micromanipulation, ploidy prediction, fertilization evaluation, embryo assessment, oocyte quality assessment, sperm selection, and quality management. All things considered, AI has much promise for enhancing not just clinical results but also laboratory efficiency—a crucial area of study given the rising number of IVF clinics across the country.*

Keywords: Artificial intelligence, machine learning, predictive modeling, IVF, embryology, time-lapse imaging, assisted reproduction, ART

I. INTRODUCTION

Over the past 40 years, in vitro fertilization has transformed reproductive medicine by offering a way to cure infertility and overcome several diagnoses with increased effectiveness and better results. In order to get the best results, the IVF laboratory is a complicated setting that demands accuracy, consistency, and precision. Artificial intelligence is becoming more and more popular in IVF labs as a potential technique to enhance the effectiveness and caliber of IVF treatments. The goal of this systematic review was to examine how artificial intelligence is developing currently, how it will be used in the future, and how it will affect different IVF processes.

II. METHODOLOGY

Our review's objective was to look at the ways artificial intelligence is currently being used in IVF facilities. Using a mix of pertinent keywords, we carried out an extensive literature search across many databases, including Web of Science, ProQuest Central, PubMed Central, and MEDLINE-Academic. Intracytoplasmic sperm injection infertility, IVF, oocyte, sperm, embryos, assisted reproductive technology deep learning, artificial intelligence, neural networks, and machine learning were the search terms utilized. Our search was restricted to peer-reviewed English-language publications released between 2010 and 2023 in order to concentrate on the most current developments in the field of artificial intelligence in IVF laboratories. There were 115 results for the search. In order to assess each reference, we first looked through the abstracts and titles to make sure they were pertinent to our research issue. The full-text publications of the chosen references were then examined to make sure the research were peer-reviewed and concentrated on the application of AI to human IVF. We eliminated 89 articles that didn't fit our inclusion criteria after the first screening. Ultimately, in order to gather pertinent data for our study, we thoroughly examined the 26 publications that remained.

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Oocyte quality

For effective embryo growth and implantation, oocyte quality is essential. It has been demonstrated that several morphological traits of metaphase II oocytes are clinically significant. Therefore, a deeper comprehension of oocyte morphology may result in better treatment recommendations and patient outcomes. At the moment, skilled embryologists manually evaluate the quality of oocytes; however, this procedure is laborious and subjective, which might result in variations throughout labs. By using objective evaluations and outcomes-based predictive modeling, the application of artificial intelligence and deep learning technologies to evaluate oocyte quality has the potential to increase the process's accuracy and efficiency. There are currently just a few publications that detail the use of support vector machines and convolutional neural networks to scan oocyte pictures and estimate their potential for development. These technologies are mostly used to analyze oocyte pictures and detect morphological traits in order to identify oocytes with higher developmental potential. Based on static pictures of oocytes, Kanakasabapathy et al. trained a CNN to estimate the probability of fertilization. Similar to this, oocytes have been categorized using SVMs according to their morphological characteristics. AI can help IVF clinics better understand the factors that impact oocyte quality, which will lead to enhanced protocols and treatments down the road. AI can provide more accurate and trustworthy assessments of oocyte quality.

Sperm selection

There is a lot of potential in using AI and DL technologies to pick sperm for IVF using ICSI. Because sperm evaluation has a substantial degree of interobserver variability, traditional sperm morphology analysis has limitations. An ML-based analysis provides a special remedy by identifying sperm with ideal morphology through expert-trained computer processing. Using manually annotated sperm data sets, which include details on common classes of sperm head morphologies as described in the WHO guideline many algorithms have been trained. The accuracy and effectiveness of conventional semen analysis might be greatly increased by using AI and DL technologies to choose sperm for IVF and ICSI. Artificial intelligence techniques are able to detect sperm with the best morphology, categorize sperm according to motility, and detect minute details in brightfield pictures that indicate the existence of characteristics harmful to the health and development of the fetus. Even if there are still some issues to be resolved, clinical embryologists may find that the development of AI-based systems eventually gives them helpful tools to increase ICSI success rates. For example, in a traditional semen analysis, sperm motility is a crucial characteristic that is assessed. In many clinics throughout the world, computer-assisted sperm analysis has become the standard method for determining sperm motility. By combining AI with video analysis, distinctions based on linear movement may be examined more quickly and correctly. According to recent research, artificial intelligence (AI) can perform as well as or better than conventional methods in the motility classification, offering a quick and affordable substitute for traditional semen analysis. Furthermore, the objective evaluation of minute variations in sperm motility patterns is made possible by AI-based computer vision, which may also be used to find previously undetected motility abnormalities for more accurate sperm grade categorization. The most intriguing aspect of AI in sperm selection is that it can recognize subtle variations across photos, which might help uncover sperm differences that a human observer alone could miss. Fluorescence microscopy assays for sperm function can be carried out while concurrently obtaining brightfield microscopic images of sperm morphology. From these images, subtle features that could potentially negatively impact embryonic development and health can be identified. This reasoning was applied in a recent study that looked at sperm DNA fragmentation, a sperm characteristic linked to repeated miscarriages. In order to estimate the acridine orange level based just on a brightfield picture, McCallum et al. developed an algorithm utilizing sperm stained with acridine orange to identify excessive DNA fragmentation. The capacity of this method to distinguish sperm with varying degrees of DNA fragmentation was shown to be modest. These first algorithms demonstrate the potential for enhancing sperm selection to maximize fertilization rates and embryo development by leveraging the objective predictive capabilities of AI models.

Fertilization assessment

A crucial stage in the IVF procedure is called fertilization evaluation, which entails counting and analyzing the quantity and quality of properly fertilized eggs 14–18 hours after insemination. An embryologist should be able to see two

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pronuclei in the fertilized egg's cytoplasm in a properly fertilized oocyte. The genetic material from the paternal and maternal nuclei is represented by these two pronuclei, which are indicative of a healthy fertilization process. Furthermore, uncommon or aberrant combinations of genetic material can result in improperly fertilized embryos, such as 0PN, 1PN, or 3PN embryos. A higher chance of genetic defects, developmental problems, and miscarriage makes improperly fertilized oocytes unsuitable for transfer or cryopreservation, while recent research indicates these embryos may still be viable. The fertilization report is frequently used to influence choices, which highlights how important it is for embryologists to classify embryos accurately. Dimitriadis et al. constructed a CNN to discriminate between regularly and abnormally fertilized oocytes, which helped determine PN status. The CNN performed at a 93.1% accuracy, proving the usefulness of AI in assessing fertilization. By serving as an additional set of "eyes" to verify manual fertilization determinations, this technique may be useful for embryologists. Although still in its early stages, the application of AI and DL technologies for fertilization evaluation has promise for bettering both the process of selecting embryos and the success of pregnancies. Research have demonstrated that using morphokinetic characteristics, AI systems can reliably forecast an embryo's capacity for development. For instance, a recent work by Coticchio et al. shown that blastocyst development may be predicted by employing AI to analyze cytoplasmic motions. Otsuki et al. created a model in a different research that combined male and female PN size to predict live birth. The application of AI to evaluate fertilization has the potential to yield important insights into the intricate processes of fertilization and early embryonic development, even if there is still more study to be done. From a laboratory standpoint, this might result in increased pregnancy rates, more effective and efficient embryo selection, and ultimately better outcomes for IVF patients.

Embryo assessment

Usually, IVF requires cultivating embryos in the embryology laboratory under carefully monitored and regulated settings for several days. In order to verify their quality and decide their future, these embryos are evaluated by highly qualified embryologists using visual morphological grading at various stages of embryo development. Nonetheless, traditional visual assessments of embryo morphology remain extremely subjective, with significant levels of intra- and intervariability. This can result in inconsistent decision-making that jeopardizes patient care as well as the development of the field as a whole.

Computer-assisted assessments may reduce the variation in embryo rating among embryologists in order to solve this problem. Due in part to the intricacy of embryo morphologies, fully automated assessments of embryos—where quality scores are provided without user interventions—are difficult. But without requiring manual feature engineering, machine learning advancements have made objective and accurate picture categorization possible in both medical and non-medical domains. As a subset of machine learning, deep learning uses representation learning to identify features in a novel way. Specifically, the system does not rely on manually created or annotated features, but rather directly detects features. CNNs are among the most widely used deep learning models and have been widely applied in assisted reproduction. Large data sets of static embryo pictures are used to train these algorithms, and over time, they acquire the necessary parameters linked to certain attributes (21).

In terms of consistency in embryo scoring and decision-making, these networks far outperform human performance. This reduces variability in decision-making among embryologists and enhances the general standard of patient care in the field of assisted reproduction. Bormann et al. conducted a study evaluating the consistency of 10 embryologists in carrying out routine clinical tasks, such as choosing embryos for biopsy, cryopreservation, or discard. In terms of consistency in embryo grading and decision making, they directly compared the performance of the embryologists with the CNN-based framework and showed that the CNN-based framework considerably outperformed human performance. This work demonstrated how CNN-based frameworks for embryo analysis may be used to enhance the general standard of patient care in the field of assisted reproduction. The IVF laboratory may profit in a number of ways from the assessment and prediction of embryo quality using AI and DL. The first benefit is that AI and DL algorithms have the potential to identify minute variations in morphological characteristics that may be invisible to the human eye, which might increase the accuracy and consistency of the evaluation of embryo quality.

This could result in more uniform and objective embryo grading, which would raise IVF success rates. Secondly, embryologists might be able to free up more time for other important activities by utilizing AI and DL to save time.

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Predicting and evaluating embryo quality takes a lot of time and demands a great deal of training. Moreover, AI and DL could shorten the time required for these jobs, freeing up embryologists to concentrate on other crucial IVF laboratory duties. The workload of embryologists may also be lessened by AI and DL, enabling task leveling as the need for IVF services grows across the country. Furthermore, simple operations like evaluating the quality of an embryo might be automated by AI and DL, freeing up embryologists to work on more difficult projects that demand for more specialized knowledge or physical dexterity.

Ploidy prediction

The term "ploidy" describes how many sets of chromosomes an organism has. Preimplantation genetic testing for aneuploidy a screening technique that requires genetic sequencing of a trophectoderm biopsy to identify whether the embryo is euploid or aneuploid, is routinely used in IVF to evaluate ploidy status. While euploid status can help in the selection of embryos for transfer, PGT-A is an expensive and intrusive procedure that requires biopsy, which may reduce the likelihood of a successful implantation.

Through the analysis of photos taken during the IVF procedure, artificial intelligence systems have demonstrated a promising ability to noninvasively forecast the ploidy status of an embryo. With the use of these technologies, predictions may be made by recognizing patterns and characteristics linked to euploid and aneuploid embryos. Several teams have made an effort to create an AI model that can identify euploidy. According to Kato et al. there was a strong correlation between euploidy and the Gardner grade and KIDScore of D5 blastocysts; euploidy was indicated by a higher Gardner grade and KIDScore. Furthermore, the study discovered a negative correlation between euploidy and the age of the female, the number of embryonic frozen days, and morphokinetic traits, suggesting that euploidy declined as these parameters increased. This study supported the notion that AI can effectively and noninvasively predict euploidy by integrating clinical parameters and morphokinetic imaging data.

Jiang et al. reported the application of an AI system that combines patient characteristics with blastocyst images to enhance the accuracy of predicting embryo ploidy status. In order to predict embryo ploidy status, the AI system combined patient characteristics, including maternal age, AMH level, paternal sperm quality, total number of normally fertilized embryos, and static blastocyst images. It did this by using a soft voting ensemble made up of a CNN, an SVM, and a multilayer neural network. This study discovered that the accuracy of classifying euploid or aneuploid embryos was greatly increased by integrating patient features with image-based algorithms.

Similar to this, two further research showed that adding patient and clinical data to algorithms increased the capacity to predict the ploidy status of embryo pictures. The creation of such instruments would offer an economical, standardized, and non-invasive method of selecting embryos, which might lower medical expenses and lessen the psychological, physical, and emotional toll that patients must take. These studies do have certain limitations, though, including the bias resulting from the choice of data sets, the use of only time-lapse microscopy images, and the use of a binary classification scheme that may misclassify mosaic embryos with high implantation potential. To guarantee the precision and dependability of these noninvasive methods for determining the ploidy status of embryos, more investigation and validation are required. Notwithstanding these drawbacks, this method can offer noninvasive, economical, and time-efficient standardized embryo selection and prioritizing.

Embryo selection for transfer

Artificial intelligence systems are now being developed to assess and categorize embryo photos based on morphology, kinetics, and genetic information, among other criteria. Better clinical results can be achieved by using these algorithms to identify prospective embryos with greater implantation and pregnancy rates. As of right now, a number of retrospective studies have shown the viability and value of AI models in forecasting IVF success rates, despite the fact that no peer-reviewed, prospective, interventional clinical trials have been published to yet.

The use of AI to embryo selection and grading has been the subject of several studies in recent years, with the goal of enhancing the procedure's repeatability, impartiality, and accuracy. "STORK," a deep neural network platform trained to predict blastocyst quality using embryologist-annotated photos of excellent and low grade blastocysts, was created by Khosravi et al.. When compared to the majority view of the embryology team, the STORK system demonstrated a remarkable AUC of 0.987 and an accuracy score of 96% in blind testing.

This model's entirely automated approach, which eliminated the need for human image processing or annotation and reduced the burden of laboratory personnel, was one of its main advantages. An AI platform named "Life Whisperer" was created in a different research by an Australian-US partnership. It was taught using deep learning to forecast pregnancy outcome based on data from real-world clinical pregnancy outcomes. The model outperformed the predictions of embryologists alone by 42% and had an accuracy rating of 64.3%. Significantly, this model performed better than earlier models since it was created, trained, and evaluated using fetal heartbeat outcomes that were known to be good, highlighting the significance of forecasting live births as opposed to implantation potential. Furthermore, all blastocyst phases in an extended culture system might be evaluated by this approach.

The application of AI to forecast pregnancy outcomes based on embryo morphology has also been investigated in a number of research. Two AI models, AIR E and ERICA, were created by Chavez-Badiola et al. and trained to predict positive pregnancy tests based on embryo morphology. The models achieved accuracy rates ranging from 0.70 to 0.77 by extracting and describing a multitude of characteristics from blastocyst photos with the use of DNN and computer vision. These models' capacity to extract characteristics from embryonic photos was one of their advantages; it offered a versatile method that could be applied in many labs with various microscopes and environments. An further benefit was the models' capacity to prioritize embryos within a group, sometimes surpassing the expertise of experienced embryologists. While many of these algorithms were designed to function independently, requiring simply the input of clinical data, the use of AI in IVF requires the support of embryologists and laboratory integration. Fitz et al. evaluated the ability of highly skilled embryologists to choose superior day 5 euploid blastocysts both with and without the use of a DL algorithm in an effort to address the usefulness of paired utilization. This study showed that adding AI assistance to standard embryologist evaluation of euploid day 5 blastocysts resulted in improved selection rates of successfully implanted embryos compared with those of embryologist evaluation alone. This was achieved by using previously graded and transferred day 5 euploid blastocysts with known implantation outcomes. Whereas embryologists chose the successfully implanted embryo in an average of 65.5% of embryo pairs, the AI system chose the embryo in 78.5% of the embryo pairings. After giving embryologists access to the AI-selected predictions, the selection rate of successfully implanted embryos rose to 73.6%. With the inclusion of AI, the ability of all 14 embryologists to pick embryos most likely to implant increased, with a mean improvement of 11.1%. When the rate of progress was broken down by the expertise level of the embryologist, there was a discernible tendency toward higher improvement in those with less experience. However, there was no statistical difference in the rate of improvement. Furthermore, both before and after they were told of the algorithm's conclusions, the AI algorithm fared better on the evaluations than the embryologists. According to the study, using AI might help embryologists with less experience more and enhance the process of selecting high-quality blastocysts for transfer in general. When taken as a whole, these findings demonstrate how AI has a great deal of promise to enhance the impartiality and accuracy of embryo selection and grading, which will eventually benefit IVF patients. The results thus far are encouraging and suggest that artificial intelligence in reproductive health has a bright future, even if further study is required to validate these models and incorporate them into clinical practice.

Cell tracking and embryo witnessing

To guarantee the precision and security of the IVF procedure, cell tracking and witnessing are essential in the IVF lab. Human mistake can result in mismatched gametes being implanted incorrectly, gametes being lost, and patients suffering grave financial, social, and legal repercussions. Error is common in IVF due to its complicated processes, which include oocyte retrieval, sperm collection, gamete processing, insemination, embryo culture, aided hatching, embryo biopsy, vitrification and warming, and embryo transfer.

This is especially true when there are more patients participating in the process. Gametes and embryos may be misidentified even with the finest methods, which stress supervision or "double witnessing" with initial labeling using manual or electronic witnessing systems. This is because gametes and embryos are transferred from one container to another several times during an ART cycle. It has been suggested that oocytes and embryos be manually tagged with polysilicon barcodes which is an intrusive and time-consuming process that complicates the IVF workflow, in order to track dish contents rather than individual dishes.

AI technology, like CNNs, offers a great deal of promise to help with IVF at every stage of the procedure. CNNs analyze visual images by processing each picture as millions of data points in a multilayer perceptron. Their ability to discern minute morphologic markers associated with embryonic development has been successfully taught, verified, and evaluated on pictures of gametes and embryos. A new work offers an AI-based witnessing program that uses predeveloped deep CNN models to forecast blastocyst development at the cleavage stage and identify blastocysts based on their developmental quality.

This is a unique use of CNN modeling. To ascertain if the embryos in a cohort came from the same patient at a later stage, this technique assigns each embryo in the cohort a unique identification score. The study reported 100% accuracy in sample recall at different timepoints and assessed the efficacy of this AI-based witnessing software on a retrospective cohort of 4,889 time-lapse imaging videos of embryos collected from 400 patients undergoing a new IVF cycle with time-lapse imaging. The study's findings show that properly tracking and identifying embryos within a cohort may be accomplished via AI-based witnessing software that uses CNNs.

All things considered, the study demonstrated how AI may facilitate the observation of gametes and embryos in the IVF lab by offering a simple, non-invasive patient identification system that would allow embryos to be safely tracked at various stages of the process. The consistency and quality of AI algorithms in identifying cells point to the potential of AI and DL technologies as potent tools for embryo witnessing, offering remarkably accurate, systematic, and objective evaluations of embryo pictures. To assure the broad deployment of AI-based witnessing software in the IVF laboratory and to prove its effectiveness in clinical practice, more study is essential.

Automation of micromanipulation procedures

In order to fertilize an egg, a single sperm is injected directly into it using a specialized procedure called intracytoplasmic sperm injection, or ICSI. ICSI is a difficult process that takes a great deal of expertise to perform. Because ICSI requires manipulating extremely small and fragile structures, it is incredibly sophisticated. A small needle is used to precisely pierce the egg to inject a single sperm into the cytoplasm.

The oocyte must be appropriately positioned and maintained during this process. In order to prevent harm to the meiotic spindle and guarantee that the sperm are positioned correctly for fertilization, the needle must be placed at the appropriate angle and depth. The oocyte may sustain damage if appropriate alignment is not achieved, which lowers the likelihood of successful fertilization. Growing interest has been seen in automating the ICSI method due to its complexity and requirement for substantial training.

Automation may increase procedure efficiency and injection accuracy by lowering the possibility of human error and unpredictability. To assure safety and effectiveness, however, creating an automated system to perform ICSI necessitates substantial technological developments in robotics and image processing as well as rigorous testing and validation. Research has demonstrated that the ideal orientation of human oocytes for ICSI may be precisely determined by using DL frameworks. To accurately locate the extruded polar bodies in mature oocytes, researchers developed and tested CNN algorithms to analyze and categorize pictures into 12 groups, spaced 30 apart. The study's findings demonstrated that the CNN-ICSI model could accurately predict, with 99% accuracy, the location of the polar bodies and the appropriate site for sperm injection. By using computer vision to identify the location of oocytes, software modeling may be used with current robotic and microfluidic technologies to advance automation.

Another micromanipulation method that needs careful alignment and substantial training to be used properly is laser-assisted hatching. It is used in IVF to help patients with low embryo quality and advanced maternal age have easier implantation and embryo escape from the zona pellucida. Furthermore, AH is frequently applied to embryos in order to access the ZP for PGT biopsy. Typically, embryologists locate the greatest perivitelline gap to execute AH during the cleavage stage. The embryologist gives priority to the point of AH close to fractured or asymmetric blastomeres if there is not a lot of perivitelline space. To execute AH and reduce the risk of damaging nearby blastomeres while applying the laser to breach the ZP, embryologists must precisely pinpoint these regions.

CNN models were reportedly used by Jiang et al. to train pictures of embryos at the cleavage stage. To offer an appropriate position on the ZP to execute AH, the CNN models were trained and tested to analyze and categorize pictures into 12 categories, spaced 30 apart. The study's findings demonstrated that, with 99.41% accuracy, the CNN-AH model could accurately determine the location on the ZP where laser AH should be applied.

These results show that DL frameworks are capable of precisely determining the best orientation for human cleavage stage embryos in order to carry out intricate micromanipulation procedures like AH. The advancement of deep learning technologies to accurately and precisely handle difficult decision-making tasks is a first step toward automating micromanipulation processes in ART labs. AI's use in determining the best places to use micromanipulation methods can enhance current methods and pave the way for future automation, both of which might lead to better IVF results.

Quality management

Treatment for infertility has been transformed by ART treatments like in vitro fertilization however the effectiveness of IVF is largely dependent on the caliber of laboratory operations and the expertise of doctors and embryologists. The performance of doctors and embryologists has a major impact on the success rates of in vitro fertilization and is essential to ensuring a healthy live singleton delivery in ART. However, because the performance of ART staff members varies greatly amongst themselves due to inherent human variability, quality assurance or quality control among ART staff members is crucial.

The dependence on alternative markers, which take longer to discover, including clinical pregnancy or no blastocyst survival after cryopreservation, has arisen from the absence of objectivity and consistency in embryo grading. A state-of-the-art solution to this problem with quality assurance is artificial intelligence. Furthermore, AI-based image analysis networks, like CNNs, have demonstrated potential in the field of assisted reproductive technology eliminating human subjectivity from the grading of embryos while also forecasting the developmental and implantation outcomes of an embryo. Among all the cleavage stage KPIs published in the literature, the study found that an AI-generated key performance indicator for predicting high-quality blastocyst development from day 3 cleavage stage embryos had the strongest correlation with continuing pregnancy rates.

The study showed how KPIs could be monitored in the IVF lab using an alternative AI-driven approach that eliminated the need for laborious, time-consuming analysis, manual recording, and subjective grading. The research adds to the body of evidence supporting statistical process controls' usefulness in identifying clinically significant changes in culture conditions. In a recent research, Cherouveim et al. sought to evaluate the performance of attending physicians and embryologists in a number of operations, including trophectoderm biopsy, embryo transfer, embryo vitrification, and warming, using AI-based tools as quality assurance metrics. Utilizing embryo photos taken 113 hours after insemination, a CNN trained as a supervised binary classifier was the AI technique employed in the study to forecast the outcome of implantation.

Every embryo's real and AI-predicted implantation results were recorded, and each embryo was categorized based on the provider who carried out the surgery. The AI system's ability to recognize performance anomalies suggests that it can differentiate between different providers and combine anticipated performance outcomes with projected implantation potential, enabling dynamic and effective outcome analysis. The AI system may be used as a performance benchmark; notable differences from this benchmark may indicate that the technique needs to be improved, acting as a warning indication for future poor quality performance occurrences.

III. CONCLUSION

A number of aspects of IVF procedures, including oocyte quality, sperm selection, fertilization assessment, embryo assessment, ploidy prediction, embryo selection for transfer, cell tracking, embryo witnessing, micromanipulation techniques, and quality management, may be enhanced by the application of AI in the IVF laboratory. By precisely predicting an embryo's developmental potential based on morphokinetic factors and pinpointing the best sites for micromanipulation procedures, AI and DL technologies might enhance IVF results and pave the way for future automation. AI-based image analysis networks, or CNNs, may be used to monitor key performance indicators in the IVF lab in a different way, eliminate human subjectivity from embryo grading, and forecast an embryo's progress and implantation results. Thus, incorporating AI into the IVF lab has the potential to transform reproductive medicine and enhance the effectiveness and caliber of IVF treatments.

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