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Artificial Intelligence in Human in Vitro Fertilization

Harpreet Kaur[1], Dr. Priyanka Gupta[2], Dr. Kamaljit Kaur[3]
[1, 2, 3] *PG, Department of Biotechnology, Khalsa College Amritsar, Punjab, India.*

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Abstract: *In vitro fertilization is a medical procedure that helps females with trouble getting pregnant. It is a medical procedure where an egg and sperm are joined together outside the body, typically in a lab, and the resulting embryo is then placed into the uterus. It is now one of the most common methods used to treat infertility."This paper represents the latest techniques to develop over time. With the latest advancements in the field, some challenges still exist. It explores improvements such as embryo selection and grading, Time-lapse imaging, sperm selection, personalizing treatment plans, minimizing human error, the success rate, and the artificial womb. However, Artificial intelligence is increasingly being integrated into IVF to enhance the improvement of efficiency to make the process more personalized. Artificial intelligence plays an essential role in IVF treatment. In earlier times it was not an easy task but now with artificial intelligence, the treatment is more easy and efficient for doctors as well as for patients who are struggling to have healthy children. They can also predict the success rate with the help of Artificial Intelligence.*

Key Word: *In vitro fertilization, Artificial Intelligence, Embryo selection and Grading.*

1. INTRODUCTION

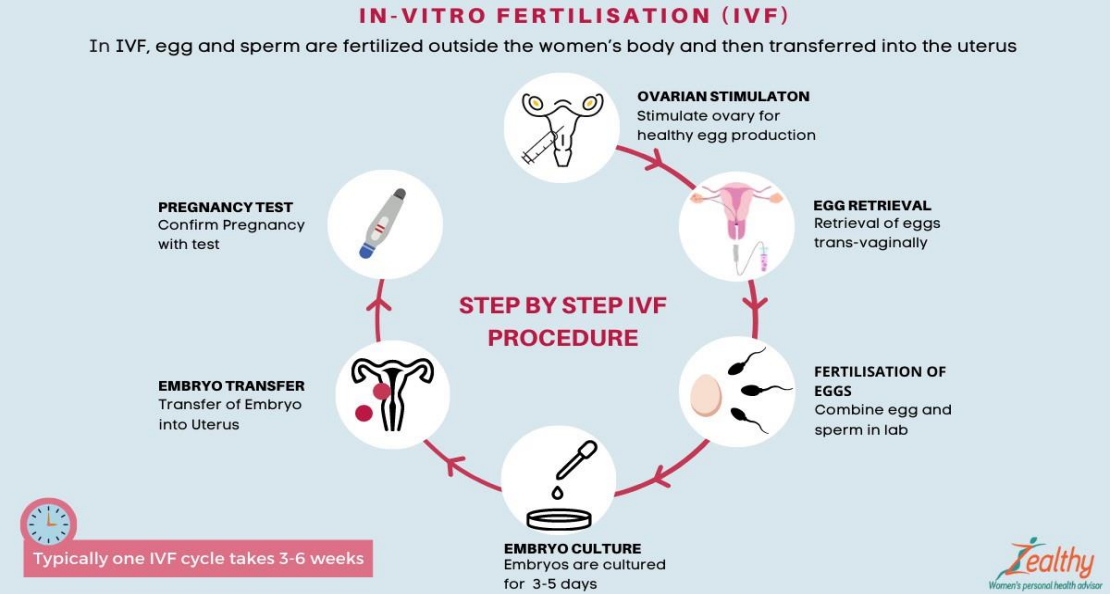
IVF known as in vitro fertilization has a vast scope in the treatment of infertility. In the IVF treatment the egg from the woman's ovary is taken and then fertilized with man's sperm in the proper laboratory setting to develop an embryo, then the embryo is further transferred to the woman's uterus for the growth of a healthy child. This procedure/ treatment works as a magic or hope for the people who are having trouble conceiving pregnancy. (1)

In some cases IVF is also treated as a main treatment for people who are above 40 or for people who are suffering from some health issues like: There is some damage in their fallopian tube, ovulation disorder, any genetic disorder, sperm issue like low count of sperm, uterine fibroids, Endometriosis, previous surgery to prevent pregnancy and the unexplained fertility. In some cases when someone is suffering from cancer treatment such as chemotherapy or radiation they cannot have fertility. Still, with the help of IVF treatment, they can collect the eggs from the ovaries & freeze them for later use .(2)Although IVF is a great technology for people as it helps many people to have a child, also it cannot be denied that it is expensive for the normal people who cannot afford it. Moreover, the success rate also depends on the quality of eggs and the overall sperm health (3). The advancement in technology, which is known as Artificial Intelligence**,** "AI is a major area of research in computer science. Because of its fast development and many uses, it's quickly becoming a part of everyday life. This is mainly because AI can handle problems that are too hard for people or regular computers to solve easily (4).AI tools can quickly handle and study large amounts of data in a short time.(5) It has helped very much in IVF treatment. It is not only helpful for the people or parents but also for the doctors to choose the best embryos. They plan the whole procedure in a way that makes it more accurate, fast, and successful (3)

II.IN VITRO FERTILIZATION

Infertility has become a worldwide concern, which is affecting more than 80 million people around the world. (6). In vitro fertilization (IVF) has transformed infertility treatment in the field of assisted reproductive technology, leading to the birth of over 10 million babies since it was first developed (7,8). In the year 1978 the first baby named Louis Brown was born through a natural IVF cycle which means no fertility drugs were used. Even the scientist who developed this procedure was awarded the Nobel prize (9,10). IVF treatment help many women who were struggling getting pregnant because in some cases their fallopian tubes were damaged or blocked which makes the natural fertilization process hard, and it becomes a complication for both parents .In some of the cases men also suffer from infertility issue cause of low quality sperm in those cases a special type of method ICSI (intracytoplasmic sperm injection) is used, in which only single sperm is directly fertilized with the egg. This process ICSI is helpful sperm directly cannot enter on its own or when there is low quality sperm. On that time ICSI can improve the chances of IVF success.(11) However during an IVF procedure the embryos are created in the lab and then transferred in the uterus on the 3 or 5 day frozen for future use, or discarded, depending on how healthy and developed they look, as they are judged by an embryologist.(12).Embryos are chosen for transfer based on a scoring system that looks at their appearance on day 3 or day 5. Some embryos are selected after genetic testing (PGT-A) to check for chromosomal issues. Traditional methods, which involve visually checking of the embryos, are still used to improve the chances of a successful pregnancy. However, these methods depend on the *experience* of the person doing the evaluation and can vary.(13, 14)Earlier times In IVF, doctors have used microscopes from the beginning to look and score embryos. Experts check things like how thick the outer layer of the embryo is, how many cells it has, if

the cells are even, if there's any damage inside, if the embryo has the right number of chromosomes, and the mother's health. But even with all this, these methods don't always give accurate results, which can make IVF less effective. (15, 16)



These above are the Ivf cycle steps which are performed in the treatment of IVF:

Ovarian Stimulation:

It is the very first step in the IVF treatment which is known as Ovarian hyper stimulation in which medicine is used to produce more eggs by the ovary at a time. Before starting this procedure doctors check a few of the things like the patient's age, the number of small egg cells in their ovaries, and a hormone level called AMH. This helps them to choose the right treatment and the right amount of medicine for their body. To make the ovaries produce more eggs, doctors usually give hormone injections called gonadotropins (often FSH). Doctors check hormone levels and watch the growth of the egg sacs (follicles) using ultrasound. These injections are usually given for about 10 days. (17).

Egg Retrieval:

In this process the eggs are collected using a special method called transvaginal ultrasound aspiration. In this process, a thin needle is gently guided into the ovaries using an ultrasound. A needle is inserted into each follicle to draw out the fluid that holds the eggs this fluid is then given to an embryologist, who looks for the eggs. Usually, 10 to 30 eggs are collected. The whole process takes about 20 to 40 minutes and is done while the patient is either lightly sedated or under general anesthesia, so they don't feel pain. Once the eggs are collected, they're quickly taken to the lab for the next steps in the IVF process. (18).

Fertilization Of Eggs:

In this procedure the egg of the female is fertilized with male sperm, Firstly they are being c h e c k e d if the oocytes are ready to be fertilized. In some of the cases the oocytes are in the (metaphase I) in those situations they are kept for a little longer period of time to get matured enough for the fertilization process. During that time the semen is prepared by removing the non-active sperm and other fluids through a process called sperm washing. (19) After that the egg and sperm are placed together with medium/ or special liquid for the fertilization process. A recent review study has proven that letting egg and sperm stay together for 1 to 4 hours gives better results for pregnancy, as compared to leaving them for a longer period of time such as 16 to 24 hours. (19).

Once fertilized, the egg is placed in a special medium to develop into an embryo with 6 to 8 cells over the course of about two days. In a different method called gamete intrafallopian transfer (GIFT), the egg and sperm are placed in the woman's fallopian tube so that the fertilization process happens naturally inside the body (in vivo). (20, 21)

Embryo Culture:

After the fertilization is completed the Embryos are formed and then they are grown in the lab for further days. They are kept for 2 or 4 days until they start dividing after 5 to 6 days until they reach a stage which is known as blastocyst (22). Letting embryos grow until day 5 or 6 (blastocyst stage) then there are more or better chances of having a baby with that one embryo, but it also means that there would be less embryos left for further use or for freezing. So early transfer of embryos like (on day 2 or 3) may give more chances to get pregnant overall (23).

However the transfer of embryos either on the day 2 or day 3 after the fertilization process makes no difference in the chances of having a baby (23).

Embryo Transfer:

During embryo transfer, a slender catheter is carefully guided through the vaginal canal and cervix to deliver the embryo

into the uterus. The number and selection of embryos transferred depend on several factors, including the embryo's quality, the woman's age, and her overall health condition.(24). The embryo transfer in the uterus is one of the most important parts of the IVF treatment, because most of the time pregnancy rate depends upon the overall handling of the procedure, the person or doctor should have proper handling of embryo transfer (25, 26).

At the very last step in the IVF is a pregnancy test which confirms the pregnancy with a pregnancy test or with ultrasound.

III. ARTIFICIAL INTELLIGENCE IN IVF

The first baby born through IVF was over 40 years ago, since then, the IVF treatment has been improved a lot with the new advances, such as safer embryo transfer, and more personalized care. Although there are many advances in this field, for many people IVF is still a long, emotional, and expensive journey (for the people who cannot afford it) . Actually IVF treatment does not always result in a baby (27). The IVF cycle involves several steps: in this process firstly physicians suppress the woman's natural menstrual cycle; then, they stimulate the ovaries to produce eggs using hormones. The sperm is then used to fertilize the eggs in a laboratory setting. The embryos are then monitored and cultured until they are ready to be transferred into the woman's uterus or frozen for later use (28). A few years ago, using artificial intelligence (AI) in human reproduction seemed like something out of science fiction. (29,). Artificial intelligence is a broad term for computer systems that try to think and act like humans or animals (30).

Artificial intelligence is being used in every field including reproductive medicine to help the physicians and embryologists to make better decisions in the IVF treatment.

It works like a smart assistant, offering advice based on data. However, in the future, Artificial intelligence might take over some of these decisions, reducing the need for human input in these treatments. Many new Artificial Intelligence advanced tools are currently being introduced. These advancements are used to check how many eggs a woman might have (ovarian reserve) and to create more personalized hormone treatments for better results. (31) Artificial Intelligence is very helpful. It is being used to count follicles automatically, predicting the stage of embryo development, and used for choosing the best sperm by checking its quality. It is also helpful to improve the success of procedures like ICSI (intracytoplasmic sperm injection) (31, 32), Predicting whether a baby will be born successfully (33). Predicting the chances of having a successful pregnancy and birth using traditional IVF methods. (34).Personalized treatment plans for each patient, and better matching of egg donors with recipients for example, by using facial resemblance in cases of donor-assisted reproduction and making the embryo selection more better and accurate (35).

IV. ARTIFICIAL INTELLIGENCE IN GAMETE AND EMBRYO SELECTION

The Gamete selection depends upon the health assessments that aim to identify early signs through the visual inspection or through microscopic imaging and videos. The quality of female gametes is typically assessed based on factors such as the size of the follicle, the shape of the egg, and the appearance of the cytoplasm. For sperm, factors such as shape, count, and movement ability of sperm (motility) is an important factor influencing the success of IVF treatment. However, assessments can vary between operators, leading to inconsistencies (36). When it comes to embryo and gamete selection through Artificial Intelligence has become more helpful as it can improve the outcomes or at least make the process more automated. The aim of AI is to make a system that can automatically decide which embryo is best for transfer after the fertilization process, because this technique can help to get a better success rate in the IVF treatment who are having more complications in some cases (37-40). One of the major benefits of this automated system is that it reduces the time needed for evaluation, it is a faster process that can be done automatically (41). The time lapse imaging in embryo selection is ten times faster than doing it manually (42). The Artificial Intelligence is used to predict the blastocyst quality with TLM (time lapse imaging which is 97% accurate and perform better than human visual inspection in the selection of embryos in this way AI is very helpful in the embryo selection for more accuracy and to get the IVF treatment more success (43,44).

V. ARTIFICIAL INTELLIGENCE IN SPERM SELECTION

Infertility is becoming a major global health issue, affecting about 50 million couples worldwide. In roughly 30% of these cases, the problem is due to male-related factors (45,46).Male factor infertility is frequently linked to social stigma, causing it to be overlooked or underestimated, particularly in low- and middle-income countries (47) . The Semen analysis depends on various factors such as Morphology, DNA integrity, and motility. They play an important role for diagnosing and treating male factor infertility (48). Semen qualities like shape, count, and movement are key signs of a sperm's ability to fertilize an egg and lead to pregnancy (49). Artificial Intelligence has shown strong promise in improving the accuracy and efficiency of sperm selection in IVF compared to traditional analysis methods. Moreover with the help of Artificial Intelligence it is easier to identify sperm with best shape, motility, on the movement and small details in the images. Sperm movement (motility) is an important factor in regular semen analysis. Many clinics use computer-assisted sperm analysis to measure motility. But by adding Artificial Intelligence (AI) to video analysis, it's possible to look at sperm movement more accurately and faster. It has totally changed the IVF process as the whole process depends upon the good quality of sperm it has the capability to the best sperm for fertilization (50, 51)

VI.ARTIFICIAL INTELLIGENCE USED ITS SUCCESS RATE IN INVITRO FERTILIZATION

The in vitro fertilization process is very helpful for both women and men, and the advancement in the IVF makes this process more efficient, fast and accurate (52). These treatments are more efficient, as they can reduce the physical and emotional stress on women. This also helps them to predict the chances of success, which supports decision-making about starting a family and planning their future (like career or personal goals) . A big benefit of AI in IVF is that it can help women feel more confident about their pregnancy. This can help them start bonding with their baby earlier (53). Artificial Intelligence gives more accurate

results whether it's in the embryo selection and grading, time-lapse imaging, or sperm selection as compared to embryologist which leads to more success rates in IVF (54)

VII. CONCLUSION

In vitro fertilization (IVF) has significantly transformed the landscape of infertility treatment, offering hope to millions of individuals and couples striving to conceive. As reproductive technologies have advanced, the integration of Artificial Intelligence (AI) has marked a major leap forward in optimizing the IVF process. From egg and sperm selection to embryo grading and transfer, Artificial Intelligence AI contributes to greater precision, consistency, and efficiency. It reduces the reliance on subjective human judgment and enhances the success rate of IVF through data-driven insights. Furthermore, AI supports the development of more personalized treatment plans, which are essential for improving outcomes in complex infertility cases. Despite its cost and emotional challenges, IVF—especially when powered by AI—continues to evolve, making the dream of parenthood more accessible and attainable.

REFERENCES

1. *Louise Brown: World's first IVF babies family archive unveiled.'' 24 July 2018. Retrieved 29 July 2021*
2. *Oktay, K., Harvey, B. E., & Partridge, A. H. (2018). Fertility preservation in patients with cancer: ASCO clinical practice guideline update. Journal of Clinical Oncology, 36(19), 1994–2001*
3. *Van der Gaast, M., et al. (2018). Factors influencing the success of IVF treatment: A meta-analysis. Human Reproduction Update, 24(1), 31-45*
4. *Rich E, Knight K, Nair S. Artificial intelligence. 3rd ed. McGrawHill. 2008.*
5. *Penixoto MS, Barros LC, Bassanezi RC, Fernandes OA. An approach via fuzzy systems for dynamics and control of the soybean aphid. Proceedings of the 2015 Conference of the International Fuzzy Systems Association and the European Society for Fuzzy Logic and Technology. Atlantic Press. Adv Intel Syst Res. 2015;89:1295–301.*
6. *Ombelet, W., and Campo, R. (2007). Affordable IVF for developing countries. Reprod. Biomed. Online 15, 257–265.1472-6483(10)60337-9.*
7. *ESHRE (2023). ART.Factsheet. https://www.eshre.eu/Europe/ Factsheets-and-infographics*
8. *Pinborg, A., Henningsen, A.-K.A., Malchau, S.S., and Loft, A. (2013). Congenital anomalies after assisted reproductive technology. Fertil. Steril. 99, 327–332*
9. *Gosden R (June 2018). "Jean Marian Purdy remembered – the hidden life of an IVF pioneer". Human Fertility. **21** (2): 86–89. doi: 10.1080/14647273.1351042. PMID 28881151. S2CID 5045457*
10. *Reuters. 3 May 2012. Retrieved 5 November 2015.2008;38:1177–86.*
11. *" Fertility: assessment and treatment for people with fertility problems'' . NICE clinical guideline. February 2013*
12. *Wang, J., and Sauer, M.V. (2006). In vitro fertilization (IVF): a review of 3 decades of clinical innovation and technological advancement. Therapeut. Clin. Risk Manag. 2, 355–364*
13. *Baxter Bendus, A.E., Mayer, J.F., Shipley, S.K., and Catherino, W.H. (2006). Interobserver and intraobserver variation in day 3 embryo grading. Fertil. Steril. 86, 1608–1615.*
14. *Storr, A., Venetis, C.A., Cooke, S., Kilani, S., and Ledger, W. (2017). Interobserver and intra-observer agreement between embryologists during selection of a single Day 5 embryo for transfer: a multicenter study. Hum. Reprod. 32, 307–314.*
15. *Wahl, B., Cossy-Gantner, A., Germann, S., and Schwalbe, N.R. (2018). Artificial intelligence (AI) and global health: how can AI contribute to health in resource-poor settings? BMJ Glob. Health 3, e000798.*
16. *Hosny, A., and Aerts, H.J.W.L. (2019). Artificial intelligence for global health. Science 366, 955–956.*
17. *La Marca A, Sunkara SK (2014). Individualization of controlled ovarian stimulation in IVF using ovarian reserve markers: from theory to practice." Human Reproduction Update. **20** (1): 124–140.*
18. *Humaidan P, Kol S, Papanikolaou EG, et al. (Copenhagen GnRH Agonist Triggering Workshop Group) (2011). " GnRH agonist for triggering of final oocyte maturation: time for a change of practice?" .Human Reproduction Update. **17** (4): 510–524*
19. *Zhang XD, Liu JX, Liu WW, Gao Y, Han W, Xiong S, et al. (2013). "Time of insemination culture and outcomes of in vitro fertilization : a systematic review and meta analysis" . Human Reproduction Update. **19** (6): 685–695.*
20. *Abyholm T, Tanbo T, Dale PO , Mangus O (February 1992). "In vivo fertilization procedures in infertile women with patent fallopian tubes: a comparison of gamete intrafallopian transfer, combined intrauterine and intraperitoneal insemination, and controlled ovarian hyperstimulation alone" . Journal of assisted Reproduction and Genetics. 9 (1): 19–23.*
21. *Wetscher F, Havlicek V, Huber T, Gilles M, Tesfaye D, Griese J, et al.(July 2005). " Intrafallopian transfer of gametes and early stage embryos for in vivo culture in cattle" . Theriogenology. 64 (1): 30–40.*
22. *Dar S, Lazer T, Shah PS, Librach CL (2014). "Neonatal outcomes among singleton births after blastocyst versus cleavage stage embryo transfer: a systematic review and meta-analysis" . Human Reproduction Update. 20 (3): 439–448.*
23. *Farquhar C, Marjoribanks J (August 2018). " Assisted reproduction technology: an overview of Cochrane Reviews". The Cochrane Database of Systematic Reviews. 2018 (8): CD010537*
24. *Timeva T, Shterev A, Kyurkchiev S (october 2014). "Recurrent implantation failure: the role of the endometrium" . Journal of Reproduction & Infertility. 15 (4): 173–183.*
25. *Hearns-Stokes, R.M. Miller, B.T. Scott, L. ... Pregnancy rates after embryo transfer depend on the provider at embryo transfer Fertil Steril. 2000; 74: 80-86 Level II-2*
26. *Angelini, A. Brusco, G.F. Barnocchi, N. ... Impact of physician performing embryo transfer on pregnancy rates in an assisted reproductive program. J Assist Reprod Genet. 2006; 23:329-332 Level II-2*
27. *De Geyter C, Wyns C, Calhaz-Jorge C, de Mouzon J, Ferraretti AP, Kupka M, Nyboe Andersen A, Nygren KG & Goossens V 2020 20 years of the European IVF- monitoring consortium registry: what have we learned? A comparison with registries from two other regions. Human Reproduction 35 2832–2849.*
28. *Go, K.J.. "By the work, one knows the workman'': the practice and profession of the embryologist and its translation to quality in the embryology laboratory. Reprod. Biomed. Online. 31(4), 449–458(2015).*

29. *Zaninovic, N., Elemento, O., Rosenwaks, Z.: Artificial intelligence: its application in reproductive medicine and the assisted reproductive technologies. Fertil. Steril. 112(1), 28–30(2019).*
30. *Fernandez, E.I., Ferreira, A.S., Cecilio, M.H.M., et al.: Artificial intelligence in the IVF laboratory: overview through the application of different types of algorithms for the classification of reproductive data. J. Assist. Reprod. Genet. 37, 2359–2376.*
31. *Hajirasouliha, I., Elemento, O.: Precision medicine and artificial intelligence : overview and relevance to reproductive medicine. Fertil. Steril. 114(5), 908–913(2020).*
32. *Chow, D.J.X., Wijesinghe, P., Dholakia, K., Dunning, K.R.: Does artificial intelligence have a role in the IVF clinic? Reprod. Fertil. 2(3), C29–C34 (2021).*
33. *Goyal, A., Kuchana, M., Ayyagari, K.P.R.: Machine learning predicts live birth occurrence before in-vitro fertilization treatment. Sci. Rep. 10, 20925(2020).*
34. *Gunderson, S.J., Puga Molina, L.S., Spies, N., Balestrini, P.A., et al.: Machine- learning algorithm incorporating capacitated sperm intracellular pH predicts conventional in vitro fertilization success in normospermic patients. Fertil. Steril. 115(4), 930–938(2021)*
35. *Jatin, K.: Artificial intelligence in assisted reproductive technology– current scenario and future implications . Fertil. Sci. Res. 6(2), 57–60 (2019).*
36. *Manna C, Nanni L, Lumini A& Pappalardo S 2013 Artificial intelligence technique for embryo and oocyte classification. Reproductive Biomedicine Online 26 42–49.*
37. *Gianaroli L, Magli MC, Gambardella L, Giusti A, Grugnetti C, Corani G. Objective way to support embryo transfer: a probabilistic decision. Hum Reprod. 2013; 28:1210–20.*
38. *Hernandez-Gonzalez J, Inza I, Crisol-Ortiz L, Guembe MA, Inarra MJ, Lozano JA. Fitting the data from embryo implantation prediction: learning from label proportions. Stat methods Med Res. 2018;27:1056–66.*
39. *Morales DA, Bengoetxea E, Larranaga P. Selection of human embryos for transfer by Bayesian classifiers. Com Biol Med. 2008;38:1177–86.*
40. *Corani G, Magli C, Giusti A, Gianaroli L, Gambardella LM. A Bayesian network model for predicting pregnancy after in vitro fertilization. Comput Biol Med.2013*
41. *Morales DA, Bengoetxea E, Larranaga P, Garcia M, Franco Y, Fresnada M, et al. Bayesian classification for the selection of in vitro human embryos using morphological and clinical data. Comput methods prog Biomed. 2008;90:104–16.*
42. *Raudonis, V., Paulauskaite-Taraseviciene, A., Sutiene, K., etal.:Towards the automation of early-stage human embryo development detection. BioMed. Eng. OnLine 18,120 (2019)*
43. *Khosravi, P., Kazemi, E., Zhan, Q., et al.: Deep learning enables robust assessment and selection of human blastocysts after in vitro fertilization. Digit. Med. 2,21 (2019)*
44. *Ducharme, J.: how artificial intelligence could change the fertility world. Time (29 January 2019). Accessed 9 March 2022.*
45. *Inhorn, M. C. & Patrizio, P. infertility around the globe: new thinking on gender, reproductive technologies and global movements in the 21st century. Hum. Reprod. Update 21, 411–426 (2015).*
46. *Agarwal, A., Mulgund, A., Hamada, A. & Chyatte, M. R. A unique view on male infertility around the globe. Reprod . Biol. Endocrinol. 13, 37 (2015).*
47. *Ombelet W, Global access to infertility care in developing countries: a case of human rights, equity and social justice. Facts Views Vis Obgyn 2011;3: 257–66.*
48. *Bjorndahl L, Kirkman Brown J. Other Editorial Board Members of the WHO Laboratory Manual for the Examination and Processing of Human Semen. The sixth edition of the WHO laboratory Manual for the examination and processing of Human semen: ensuring quality and standardization in basic examination of human ejaculates . Fertil Steril 2022; 117: 246–51.*
49. *Donnelly ET, Lewis SE, McNally JA, Thompson W. In vitro fertilization and pregnancy rates: the influence of sperm motility and morphology on IVF outcome. Fertil Steril 1998;70:305–14.*
50. *Tsai, V.F. Zhuang, B. Pong, Y.H. … Web- and artificial intelligence- based recognition for sperm motility analysis: verification study JMIR Med Inform. 2020; 8. e20031*
51. *Ottl, S. Amiriparian, S. Gerczuk, M. … motilityAI: a machine learning framework for automatic prediction of human sperm motility iscience. 2022; 25, 104644.*
52. *Chow, D.J.X., Wijesinghe, P., Dholakia, K., Dunning, K.R.: Does artificial intelligence have a role in the IVF clinic? Reprod. Fertil. 2(3), C29–C34 (2021)*
53. *Heitman, E.: Social and ethical aspects of in vitro fertilization. Int. J. Technol. Assess. Health. Care. 15(1), 22–35 (1999)*
54. *Khosravi P, Kazemi E, Zhan Q, Malmsten JE, Toschi M, Zisimopoulos P, Sigaras A, Lavery S, Cooper LAD, Hickman C et al. Deep learning enables robust assessment and selection of human blastocysts after in vitro fertilization. NPJ Digit Med 2019;2:21*