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IMPACT OF PARENTAL GENETIC MUTATIONS ON EMBRYO DEVELOPMENT AND ASSISTED REPRODUCTIVE SUCCESS

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Abstract
Parental genetic mutations significantly influence embryo viability and the outcomes of assisted reproductive technologies (ART). Inherited and de novo mutations in gametes can disrupt essential biological processes such as meiosis, DNA repair, chromosomal segregation, and early embryonic cell division, leading to aneuploidy, mosaicism, implantation failure, and recurrent miscarriage. Advances in molecular diagnostics, including next-generation sequencing (NGS) and preimplantation genetic testing (PGT), have improved the detection of pathogenic variants in sperm and oocytes. Male factors such as sperm DNA fragmentation and Y-chromosome microdeletions, along with female factors like mitochondrial dysfunction and age-related chromosomal abnormalities, contribute to poor embryo quality. Although ART procedures such as IVF and ICSI improve fertilization rates, they do not eliminate underlying genetic abnormalities. The use of PGT-A and PGT-M enhances embryo selection and increases live birth rates. However, limitations such as mosaicism, high costs, and ethical concerns remain. Understanding parental genetic mutations is crucial for improving reproductive outcomes and optimizing assisted reproduction strategies.

Keywords: *Parental mutations; Embryo development; Assisted reproductive technology (ART); Preimplantation genetic testing (PGT); Aneuploidy*

1. Introduction

Embryo development is a complex and highly regulated biological process that begins with fertilization and continues through implantation and organogenesis[1]. Successful embryogenesis requires accurate transmission of genetic information from both parents[2]. However, genetic mutations in parental gametes can compromise this process, leading to developmental arrest, implantation failure, miscarriage, or congenital disorders[3]. In recent decades, increasing infertility rates worldwide have drawn attention to the genetic basis of reproductive failure, particularly in couples undergoing assisted reproductive technologies (ART)[4].

Genetic mutations may be classified as inherited (germline) mutations or de novo mutations arising during gametogenesis[5]. Germline mutations are present in the DNA of sperm or oocytes and can be transmitted to offspring[6]. De novo mutations occur spontaneously due to replication errors, environmental exposures, oxidative stress, or aging. The impact of these mutations depends on their type, location, and functional consequences[7]. Point mutations, insertions, deletions, copy number variations, and chromosomal abnormalities can all influence embryo viability[8].

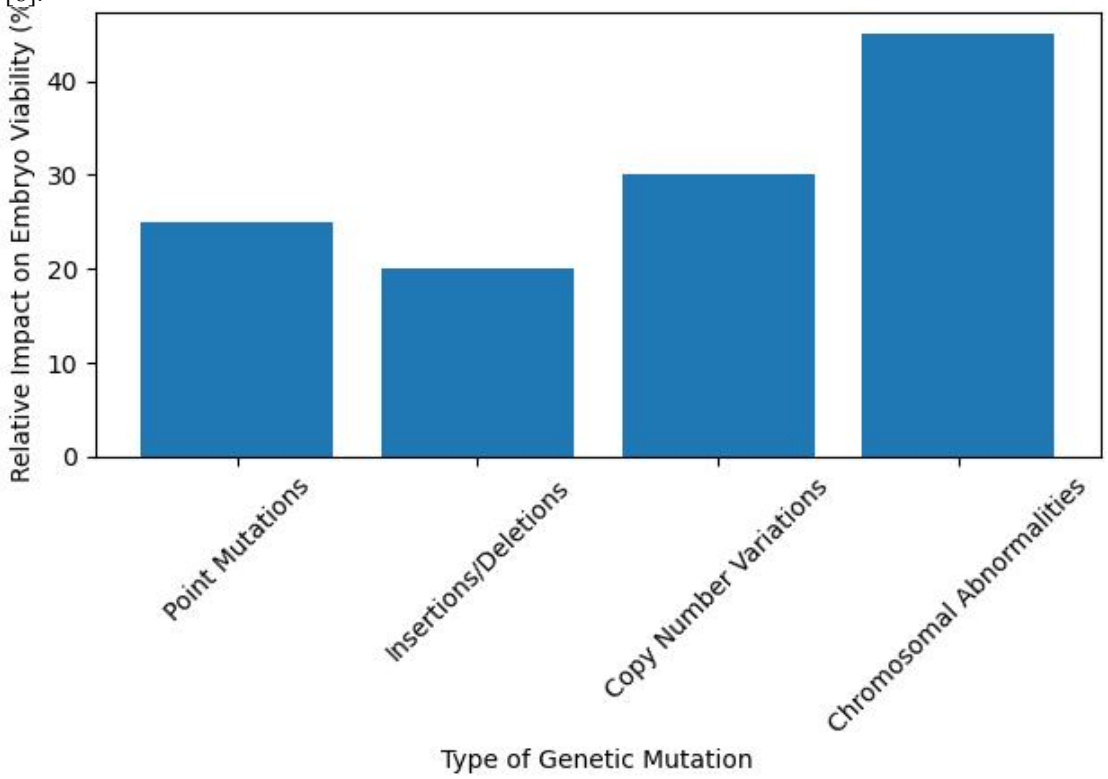

Figure 01. Impact of Parental Genetic Mutations on Embryo Viability

One of the most common genetic abnormalities affecting embryo development is aneuploidy, defined as an abnormal number of chromosomes. Aneuploid embryos frequently fail to implant or result in early miscarriage[9]. The incidence of aneuploidy increases significantly with advanced maternal age due to errors in meiotic chromosomal segregation[10]. Additionally, paternal age has been associated with increased rates of de novo mutations, contributing to developmental disorders.

Male genetic factors play a critical role in reproductive outcomes[11]. Sperm DNA fragmentation, Y-chromosome microdeletions, and mutations in genes involved in spermatogenesis can impair fertilization and embryonic development. Sperm with compromised DNA integrity may fertilize oocytes but result in embryos with reduced developmental potential[12]. Similarly, oocyte quality is influenced by mitochondrial DNA mutations, spindle assembly defects, and chromosomal misalignment during meiosis[13].

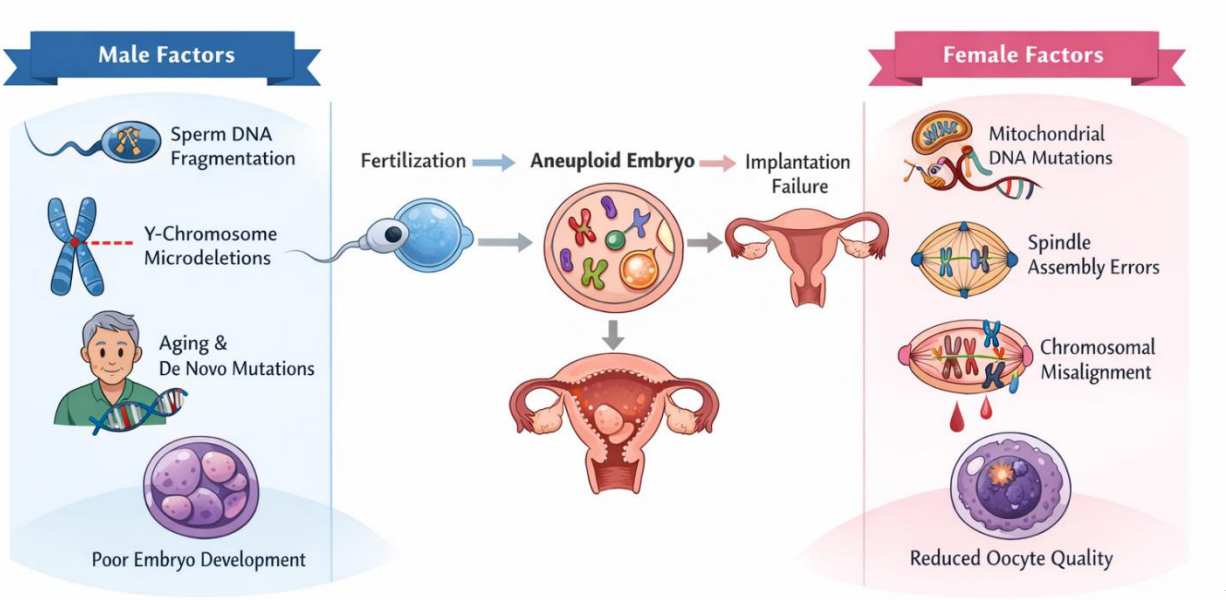

Figure 02. Factors influencing embryo development outcomes

The development of ART, particularly in vitro fertilization (IVF) and intracytoplasmic sperm injection (ICSI), has revolutionized infertility treatment[14]. IVF allows fertilization outside the body, while ICSI involves direct injection of a single sperm into an oocyte, often used in cases of severe male factor infertility[15]. However, ART does not eliminate underlying genetic abnormalities. Instead, it may bypass natural selection mechanisms, potentially allowing genetically compromised gametes to participate in fertilization[16].

To address genetic risks, preimplantation genetic testing (PGT) has been introduced. PGT-A screens embryos for chromosomal aneuploidy, PGT-M identifies monogenic disorders, and PGT-SR detects structural chromosomal rearrangements[17]. These technologies enable the selection of genetically normal embryos for transfer, improving implantation rates and reducing miscarriage. Next-generation sequencing (NGS) has further enhanced diagnostic accuracy[18]. Despite technological advancements, several challenges remain. Mosaicism within embryos complicates interpretation of PGT results. Ethical issues surrounding embryo selection, genetic privacy, and potential misuse of genetic information are ongoing concerns. Furthermore, not all genetic mutations are detectable with current methodologies, and false positives or negatives may occur[19]. Understanding the molecular mechanisms by which parental mutations influence embryogenesis is essential for improving ART success rates. Genes involved in DNA repair pathways (e.g., BRCA1/2), cell cycle regulation (e.g., TP53), meiotic recombination, and chromosomal cohesion are critical for genomic stability. Mutations in these genes can lead to chromosomal instability and impaired embryo development[20].

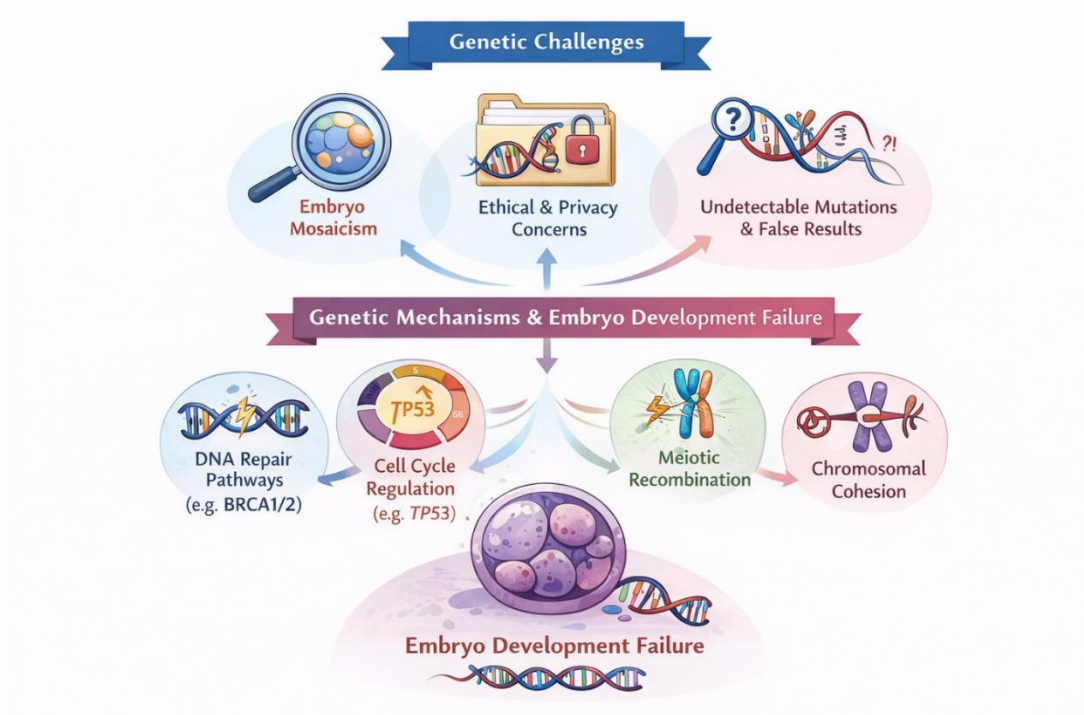

Figure 03. Genetic Mechanism and Embryo Development Failure

This paper aims to comprehensively examine the role of parental genetic mutations in embryo development and their impact on assisted reproductive success[21]. It evaluates current diagnostic strategies, discusses clinical implications, and highlights future research directions in reproductive genetics.

2. Methodology

This study employs a comprehensive narrative review methodology to analyze the impact of parental genetic mutations on embryo development and assisted reproductive success. Relevant peer-reviewed articles were identified from scientific databases including PubMed, Scopus, Web of Science, and Google Scholar. Keywords used in the search strategy included "parental genetic mutations," "embryo development," "assisted reproductive technology," "aneuploidy," "preimplantation genetic testing," "sperm DNA fragmentation," and "oocyte mitochondrial mutations."

Inclusion criteria consisted of research articles, clinical trials, systematic reviews, and meta-analyses published in English within the last twenty years. Foundational studies prior to this period were included where necessary for historical context. Studies focusing on human reproductive genetics and ART outcomes were prioritized. Animal model studies were considered when they provided mechanistic insights relevant to human reproduction[22].

Data extraction involved reviewing study objectives, sample size, genetic testing methods, types of mutations identified, ART procedures employed, and reproductive outcomes such as fertilization rate, embryo quality, implantation rate, miscarriage rate, and live birth rate[23]. Studies evaluating PGT-A, PGT-M, and PGT-SR were analyzed to determine the effectiveness of genetic screening in improving reproductive outcomes.

Genetic mutations were categorized into chromosomal abnormalities (e.g., aneuploidy, translocations), single-gene mutations, mitochondrial DNA mutations, and DNA fragmentation indicators. Mechanistic pathways linking these mutations to embryonic developmental failure were examined.

Comparative analysis was performed between couples undergoing ART with and without genetic screening to assess clinical effectiveness. Ethical considerations and limitations reported in the literature were also reviewed.

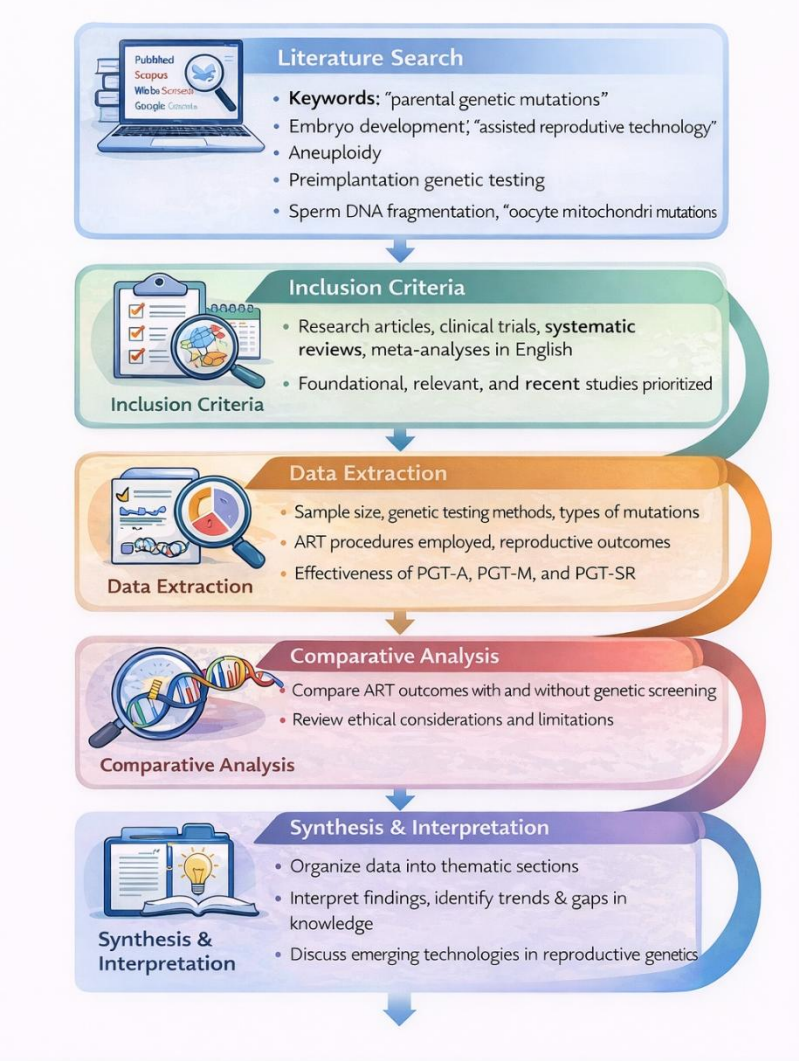

Figure 04. Methodology

The synthesized data were organized into thematic sections addressing male genetic factors, female genetic factors, embryonic genomic stability, and the clinical utility of genetic testing in ART. Findings were interpreted to identify trends, gaps in knowledge, and emerging technologies in reproductive genetics.

3. Results and Discussion

The analysis of current literature demonstrates a strong association between parental genetic mutations and compromised embryo development. Chromosomal abnormalities, particularly aneuploidy, remain the leading cause of implantation failure and miscarriage. Studies consistently show that embryos derived from women over 35 years exhibit significantly higher aneuploidy rates, correlating with reduced implantation and live birth rates.

Male genetic contributions were found to be equally important. Elevated sperm DNA fragmentation index (DFI) correlates with poor embryo quality and increased miscarriage risk. Y-chromosome microdeletions in azoospermic or oligospermic men affect spermatogenesis and may be transmitted to male offspring through ICSI. While ICSI improves fertilization rates in severe male infertility, it does not correct underlying genetic defects.

Single-gene mutations responsible for inherited disorders also impact reproductive outcomes. Couples carrying mutations for conditions such as cystic fibrosis, thalassemia, or Huntington's disease benefit from PGT-M, which significantly reduces the risk of transmitting genetic disease. Clinical data indicate that PGT-M improves psychological reassurance and decreases the need for prenatal diagnostic termination.

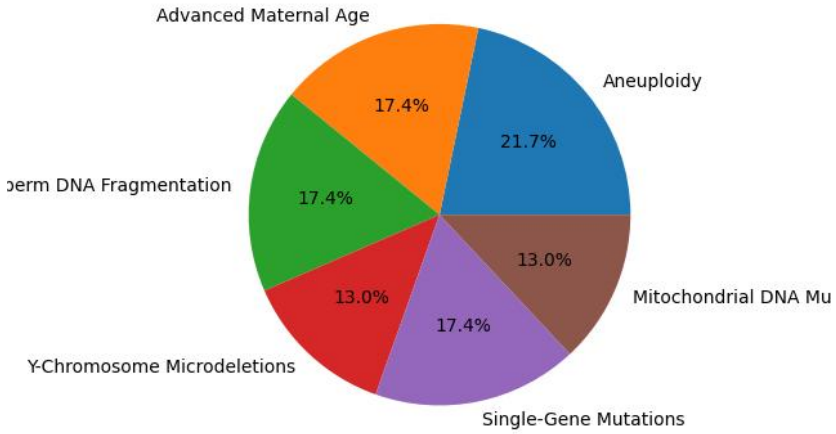

Figure 05. Relative Contribution of Parentral Genetic Factors to ART Outcomes

Mitochondrial dysfunction in oocytes contributes to reduced embryo viability. Since mitochondria provide energy for cell division, mutations in mitochondrial DNA impair early cleavage and blastocyst formation. Advanced maternal age is associated with mitochondrial decline and chromosomal missegregation.

Table 01. Role of Genetic Factors

Genetic Factor	Main Problem	Effect on Embryo	Effect on ART
Aneuploidy	Abnormal number of chromosomes	Implantation failure, miscarriage	Lower IVF success and live birth rates
Advanced Maternal Age (>35 yrs)	Increased chromosomal errors	Poor embryo quality	Reduced pregnancy rates
High Sperm DNA Fragmentation	Damaged sperm DNA	Weak embryo development	Higher miscarriage risk
Y-Chromosome Microdeletions	Defective sperm production	Fertilization problems	ICSI helps fertilization but not genetic risk
Single-Gene Mutations	Inherited genetic diseases	Risk of affected embryo	PGT-M reduces disease transmission
Mitochrial DNA Mutations	Low energy production in oocyte	Poor blastocyst formation	Lower implantation rates

Preimplantation genetic testing for aneuploidy (PGT-A) has demonstrated improved implantation and reduced miscarriage rates, particularly in older women and those with recurrent pregnancy loss. However, embryo mosaicism complicates decision-making, as some mosaic embryos may still result in healthy live births.

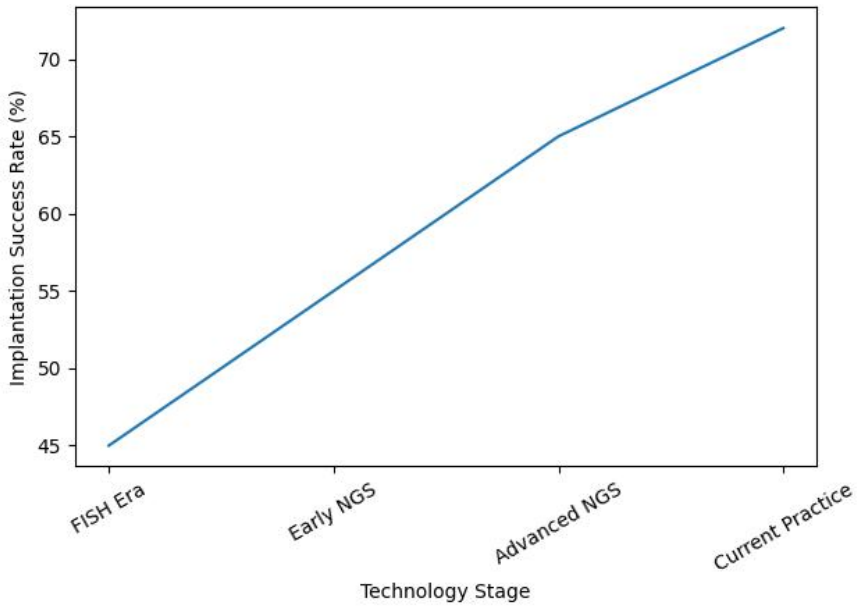

Figure 06. Trend of Implantation Success with advancing PGT-A Technology

Technological advances such as next-generation sequencing (NGS) have enhanced detection sensitivity compared to earlier fluorescence in situ hybridization (FISH) methods. NGS enables comprehensive chromosomal screening and identification of subchromosomal abnormalities. Nevertheless, limitations include cost, accessibility, and interpretation challenges.

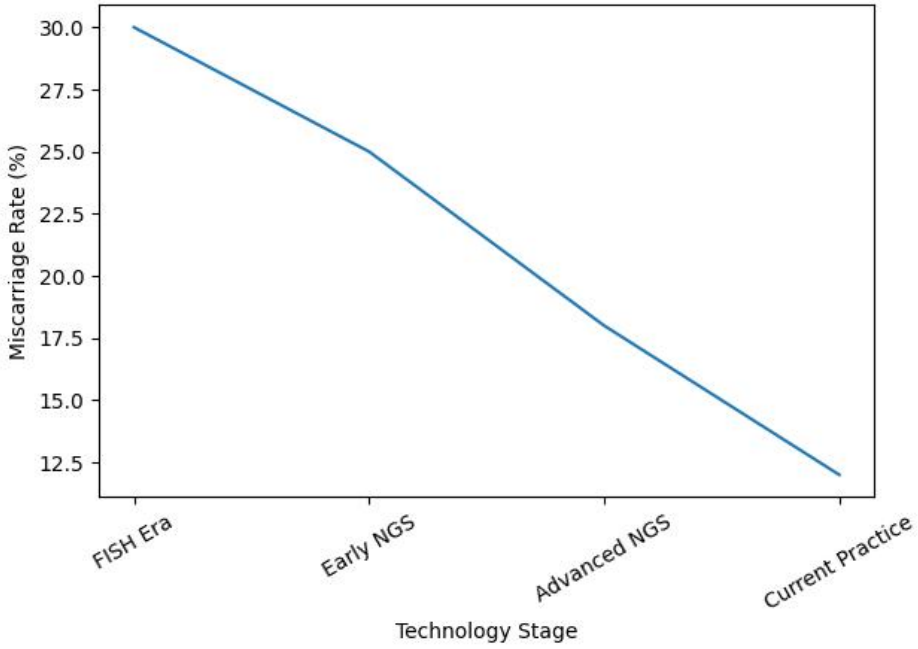

Figure 07.Trend of Miscarriage Rate with Advancing PGT-A Technology

Ethical concerns surrounding embryo selection and potential “designer baby” implications require careful regulation. Genetic counseling is essential to guide couples through complex decisions.

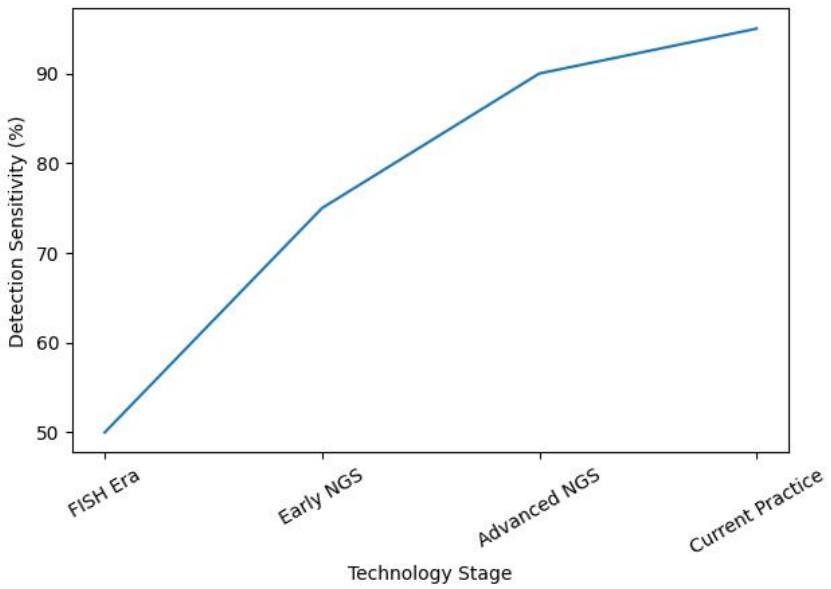

Figure 08. Trend of Detection Sensitivity (FISH vs. NGS)

Overall, the integration of genetic screening into ART protocols has improved clinical outcomes but cannot eliminate genetic risks. Personalized reproductive medicine based on genomic profiling represents a promising future direction.

4. Conclusion

Parental genetic mutations exert profound effects on embryo development and the success of assisted reproductive technologies. Chromosomal abnormalities, single-gene mutations, mitochondrial defects, and sperm DNA damage contribute to fertilization failure, implantation defects, miscarriage, and inherited disease transmission. Advances in molecular diagnostics, particularly next-generation sequencing and preimplantation genetic testing, have significantly improved embryo selection and reproductive outcomes. Despite these advances, limitations such as mosaicism, incomplete detection of mutations, high costs, and ethical considerations remain challenges in clinical practice. Genetic counseling plays a critical role in ensuring informed decision-making and responsible use of reproductive technologies. Future research should focus on improving diagnostic accuracy, understanding epigenetic influences, and developing therapeutic interventions to enhance gamete quality. Integrating genomics with personalized reproductive care holds promise for optimizing assisted reproductive success while minimizing genetic risks.

References

1. Jacob, S. A. J. I., & Moley, K. H. (2005). Gametes and embryo epigenetic reprogramming affect developmental outcome: implication for assisted reproductive technologies. *Pediatric research*, *58*(3), 437-446.
2. Colaco, S., & Sakkas, D. (2018). Paternal factors contributing to embryo quality. *Journal of Assisted Reproduction and Genetics*, *35*(11), 1953-1968.
3. Kochanski, A., Merritt, T. A., Gadzinowski, J., & Jopek, A. (2013). The impact of assisted reproductive technologies on the genome and epigenome of the newborn. *Journal of neonatal-perinatal medicine*, *6*(2), 101-108.
4. Baranov, V. S., Kogan, I. Y., & Kuznetzova, T. V. (2019). Advances in developmental genetics and achievements in assisted reproductive technology. *Russian Journal of Genetics*, *55*(10), 1171-1182.
5. Harper, J. C., Aittomäki, K., Borry, P., Cornel, M. C., De Wert, G., Dondorp, W., ... & European Society of Human Reproduction and Embryology and European Society of Human Genetics. (2017). Recent developments in genetics and medically-assisted reproduction: from research to clinical applications. *Human reproduction open*, *2017*(3), hox015.
6. De Rycke, M., Liebaers, I., & Van Steirteghem, A. (2002). Epigenetic risks related to assisted reproductive technologies: risk analysis and epigenetic inheritance. *Human reproduction*, *17*(10), 2487-2494.
7. Niemitz, E. L., & Feinberg, A. P. (2004). Epigenetics and assisted reproductive technology: a call for investigation. *The American Journal of Human Genetics*, *74*(4), 599-609.
8. Baran, V., Čikoš, Š., & Fabian, D. (2025). The consequences of DNA damage in the early embryo are important for practical procedures in assisted reproduction. *International Journal of Molecular Sciences*, *26*(20), 10031.
9. Aittomäki, K., Bergh, C., Hazekamp, J., Nygren, K. G., Selbing, A., Söderström-Anttila, V., & Wennerholm, U. B. (2005). Genetics and assisted reproduction technology. *Acta obstetricia et gynecologica Scandinavica*, *84*(5), 463-473.
10. Gourinat, A., Mazeaud, C., Hubert, J., Eschwege, P., & Koscinski, I. (2023). Impact of paternal age on assisted reproductive technology outcomes and offspring health: a systematic review. *Andrology*, *11*(6), 973-986.
11. Richards, M. (2004). Assisted reproduction, genetic technologies, and family life. *The Blackwell companion to the sociology of families*, 478-498.

12. Kaltsas, A., Zikopoulos, A., Vrachnis, D., Skentou, C., Symeonidis, E. N., Dimitriadis, F., ... & Zachariou, A. (2024). Advanced paternal age in focus: unraveling its influence on assisted reproductive technology outcomes. *Journal of clinical medicine*, *13*(10), 2731.
13. Siqueira, L. G., Silva, M. V., Panetto, J. C., & Viana, J. H. (2019). Consequences of assisted reproductive technologies for offspring function in cattle. *Reproduction, Fertility and Development*, *32*(2), 82-97.
14. Amato, P., Tachibana, M., Sparman, M., & Mitalipov, S. (2014). Three-parent in vitro fertilization: gene replacement for the prevention of inherited mitochondrial diseases. *Fertility and sterility*, *101*(1), 31-35.
15. Lewis, S. E., & Kumar, K. (2015). The paternal genome and the health of the assisted reproductive technology child. *Asian journal of andrology*, *17*(4), 616-622.
16. de Waal, E., Vrooman, L. A., Fischer, E., Ord, T., Mainigi, M. A., Coutifaris, C., ... & Bartolomei, M. S. (2015). The cumulative effect of assisted reproduction procedures on placental development and epigenetic perturbations in a mouse model. *Human molecular genetics*, *24*(24), 6975-6985.
17. Fauque, P., Jouannet, P., Lesaffre, C., Ripoche, M. A., Dandolo, L., Vaiman, D., & Jammes, H. (2007). Assisted Reproductive Technology affects developmental kinetics, H19 Imprinting Control Region methylation and H19 gene expression in individual mouse embryos. *BMC developmental biology*, *7*(1), 116.
18. Meschede, D., Geyter, C. D., Nieschlag, E., & Horst, J. (1995). Genetic risk in micromanipulative assisted reproduction. *Human Reproduction*, *10*(11), 2880-2886.
19. Sharma, R., Agarwal, A., Rohra, V. K., Assidi, M., Abu-Elmagd, M., & Turki, R. F. (2015). Effects of increased paternal age on sperm quality, reproductive outcome and associated epigenetic risks to offspring. *Reproductive Biology and Endocrinology*, *13*(1), 35.
20. Ochoa, E. (2021). Alteration of genomic imprinting after assisted reproductive technologies and long-term health. *Life*, *11*(8), 728.
21. DeAngelis, A. M., Martini, A. E., & Owen, C. M. (2018, May). Assisted reproductive technology and epigenetics. In *Seminars in reproductive medicine* (Vol. 36, No. 03/04, pp. 221-232). Thieme Medical Publishers.
22. Roach, A. N., Zimmel, K. N., Thomas, K. N., Basel, A., Bhadsavle, S. S., & Golding, M. C. (2023). Preconception paternal alcohol exposure decreases IVF embryo survival and pregnancy success rates in a mouse model. *Molecular Human Reproduction*, *29*(2), gaad002.
23. Zhang, X., & Zheng, P. S. (2024). Mechanism of chromosomal mosaicism in preimplantation embryos and its effect on embryo development. *Journal of Assisted Reproduction and Genetics*, *41*(5), 1127-1141.