Chapter 5

New Technology in Embryo Manipulations “Nano-Materials”

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Summary

Embryo manipulations have experienced significant increases in recent years. This has led to the development of new methods for the creation of reproductive technologies. When it comes to changing the genetic material of embryonic beings in multiple species– humans especially– there’s a particular term involved. It’s called nanotechnology and it’s quickly becoming an ultra-important area of study. The medical, electricity and energy industries all stand to benefit from its broad range of applications. That’s because this revolutionary process involves manipulating materials in a super small size. It involves altering materials at the nanoscale. Nanotechnology offers a range of uses in numerous sectors like medical electronics and energy. In medicine, nanotechnology has led to significant advances in the delivery of drug imaging and diagnosis. Besides, it has facilitated the manipulation of embryos in a new manner. The utilization of nanomaterials in embryo manipulations has the benefit of increasing embryo implantation rates through assisted reproductive technology (ART) and the implantation rates of in vitro fertilization (IVF) and intracytoplasmic sperm injection (ICSI). Another advantage of using nanomaterials in embryo modification is that genetic abnormalities are reduced. Other than that the relevance of nanoparticles has led to new potential in the field of artificial insemination. This book explains the most recent breakthroughs in the modification of human and animal embryos as well as the numerous types of nanoparticles and the benefits of their use in the process. Additionally, the book discusses the applications of nanoparticles in IVF and gene editing. This book also discusses ethical concerns issues and limitations of the new technology it also highlights the potential impact on the field of reproductive medicine.

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1. Introduction

Positive outcomes in reproductive medicine can be difficult to guarantee with the widespread use of artificial insemination, which is commonly utilized for preventing genetic abnormalities and increasing fertility. Innovative developments are necessary to improve the success rate of these procedures. Manipulation of embryos has already demonstrated encouraging results, but the potential use of nanotechnology has opened up even more possibilities in this field.

Novel opportunities to increase the success rates of artificial insemination have emerged through the use of embryo manipulation technologies. Genetic diseases are reduced while increasing the chances of a successful pregnancy through the use of various techniques, like in vitro fertilization (IVF), Preimplantation Genetic Diagnosis (PGD), and Intracytoplasmic sperm injection (ICSI), that have been developed. By selecting healthy embryos, these methods achieve their goa

With the passing of time, innovative techniques have surfaced to modify embryos with greater precision, including the impressive CRISPR-Cas9, which has allowed genome editing to finally become achievable. The intriguing possibility of using this to eliminate all genetic abnormalities is a promising development. Another breakthrough is mitochondrial replacement therapy (MRT), which involves the transfer of defective mitochondria from an affected individual's embryo to a healthy donor's embryo. These reproductive advancements are undoubtedly transformative, but they also raise significant moral questions that warrant deep consideration.

2. Embryo manipulation technologies in humans

The transformation of human reproductive medicine has been massive in recent times due to embryo manipulation technologies. Fertilization of an egg by a sperm in a laboratory dish, commonly known as in vitro fertilization (IVF), is the most widely used technique. After the developed embryo is transferred to the uterus, the procedure is complete (Takashi Kohda, 2013). IVF necessitates the manipulation of an embryo in vitro and its growth in a strictly controlled environment (Juncà et al., 2015). Advancements in technology have simplified the supply of IVF, and social and demographic changes have increased their demand in recent times (Kushnir et al., 2022). In vivo-like microenvironments have been created using microfluidic systems to manage gametes, mature oocytes, culture embryos, and carry out fundamental procedures (Wheeler et al., 2017).

Preimplantation Genetic Diagnosis (PGD) is a sophisticated embryo manipulation process, most often seen in tandem with IVF. The main purpose is to minimize the risk of passing hereditary diseases to offspring. This is achieved by testing embryos for potential complications and only selecting those that are completely normal to be implanted. Various research studies have proven PGD an effective method for combating severe hereditary issues. Moreover, doctors can utilize pre-implantation genetic testing to weed out abnormal embryos before they're implanted. PGT is a kind of prenatal diagnosis and only allows normal genetic embryos to be put inside the womb (Knoppers et al., 2006).

Somatic cell nuclear transfer– otherwise known as SCNT– is a method that's been used in both animals and humans. Basically, it involves moving the nucleus of a somatic cell into an egg that has had its nucleus removed. The result? A cloned embryo (Tian et al., 2003). This technique has been used to make genetically engineered critters by using somatic cells with mutations (Lee et al., 2013). But due to ethical issues, reproductive cloning in humans isn't allowed in most countries (David Stocum, 2023). Although, SCNT does come in handy for reprogramming somatic cells into pluripotent stem cells which hold immense promise for medical applications (Tachibana et al., 2013).

3. Embryo manipulation technologies in cows

Advancement in embryo manipulation techniques is an absolute game-changer for animal breeding, especially among cows. Artificial Insemination (AI) is a much-used method where semen is directly inserted into the female reproductive system (Yuksel Agca & John K. Critser, 2006). This is less invasive and more cost-effective than natural breeding as it makes use of superior males without having to bring them around females.

IVF is a popular embryo manipulation technique when it comes to cows. Mainly, the process consists of fertilizing oocytes outside of the cow's body and then transferring the resulting embryos to other cows (Juncà et al., 2015). People have employed this method to cultivate better genes and even protect endangered species. ICSI is another player in this game, which involves injecting only one sperm directly into an oocyte (Takashi Kohda & Fumitoshi Ishino, 2013). Scientists have successfully created transgenic cows with superior disease immunity and increased milk production through the implementation of these methods.

Microfluidic systems have become a trusted option for working with embryos in recent years. Moreover, using embryo manipulation techniques it's possible to clone elite cows and quickly spread superior genetics around the world (Juncà et al., 2015). All in all, these manipulation technologies have had a substantial impact on the quality of dairy and beef products, as well as on cattle genetics.

4. Embryo manipulation technologies in pigs

Embryo manipulation technologies have been utilized in pigs to improve breeding and genetic selection. Superovulation and embryo recovery are commonly used methods for the rapid multiplication of animals (Moore et al., 2017). The embryos are then collected and transferred to recipient female pigs, resulting in the birth of multiple offspring with desired traits. Recipient female pigs receive collected embryos resulting in multiple offspring with desired traits. Pig production in the industry benefits from these techniques that enhance both quality and quantity (Takashi Kohda & Fumitoshi Ishino, 2013).

Pig breeding also employs in vitro fertilization (IVF) (Juncà et al., 2015). Oocytes are collected from female pigs and fertilized with sperm in a laboratory setting. The resulting embryos are then transferred to recipient female pigs for gestation and birth. This technique allows for greater control over the genetic makeup of the offspring and can be used to produce pigs with specific traits, such as disease resistance or improved meat quality (Church et al., 1985).

Sperm and embryo cryopreservation are also important techniques in pig breeding. Cryopreservation has also been used to preserve endangered pig breeds and maintain genetic diversity (Ibeas et al., 2019). As technology advances, new techniques such as microfluidic systems are being developed to handle gametes, mature oocytes, culture embryos, and perform other basic procedures in a microenvironment that more closely mimics the in vivo environment (Wheeler et al., 2017).

5. Embryo manipulation technologies in sheeps

One of the most widely used techniques in sheep is embryo transfer (ET) (Church et al., 1985). ET involves the transfer of embryos from a genetically superior female to a recipient female that will carry the pregnancy to term. This technique enables the production of multiple offspring from a single female, which is particularly useful when dealing with valuable or rare genetics. ET has been used successfully in sheep for many years and is a valuable tool for improving the genetic potential of flocks (Dominiguez et al., 2020).

In vitro fertilization (IVF) is another commonly used embryo manipulation technique in sheep. IVF involves the fertilization of oocytes (eggs) outside of the female's body, followed by the transfer of resulting embryos to recipient females (Takashi Kohda, 2013). This technique has been used to produce genetically superior offspring, preserve rare genetics, and improve reproductive efficiency in flocks. IVF has also been used to produce transgenic animals, which can be useful for biomedical research (Kushnir et al., 2022).

Cloning is another embryo manipulation technique that has been used in sheep. Cloning has several advantages, including the preservation of endangered species and the improvement of animal production through valuable genetics. The continuous research performed in this area of cloning may pave the way to new discoveries and innovative applications in animal genetics and breeding.

6. Embryo manipulation technologies in horses

Embryo manipulation technologies have been widely used in horses to improve breeding efficiency and genetic selection. Juncà et al. (2015) highlight a technique called in vitro fertilization (IVF), which takes the fertilization process outside the mare's body and into a laboratory setting. The oocytes are fertilized with sperm in this setting. After fertilization, the embryos are left to develop to a specific stage under specific conditions. IVF has been used successfully in horses to produce offspring from mares with fertility issues or to breed mares with stallions that are not physically able to mate (Kushnir et al., 2022).

Embryo transfer allows for the production of multiple offspring from a single mare in a single breeding season (Moisyadi et al., 2009). Additionally, ET can be used to preserve the genetics of valuable mares and stallions by producing multiple offspring from them (Church et al., 1985).

Intracytoplasmic sperm injection (ICSI) is a technique that involves injecting a single sperm directly into an oocyte to fertilize it (Takashi Kohda & Fumitoshi Ishino, 2013). ICSI has been used in horses to overcome fertility issues in stallions or to produce offspring from mares with a history of failed fertilization attempts (Takashi Kohda, 2013). Recent studies have also explored the use of ICSI in horses for genome editing purposes (Mizushima et al., 2023). These embryo manipulation technologies have significantly impacted the horse breeding industry, allowing for improved breeding outcomes and genetic selection.

7. Embryo manipulation technologies in dogs

In dogs, embryo manipulation has become a trendy way of breeding. It's particularly helpful for dogs with sperm that moves poorly or has low counts. IVF is another method of fertilizing in vitro that has been applied to dogs. Following fertilization outside the body, an embryo is returned to the uterus (Takashi Kohda, 2013).

Advanced technology has ushered in a new era of precise and efficient embryo manipulation techniques for dogs. One innovative method is the use of microfluidic systems that create a microenvironment that closely resembles the reproductive tract making it easier to manipulate gametes and embryos (Wheeler et al., 2017). For dogs suffering from male infertility, ICSI has also been used. The dog breeding population can now have better results and improved genetic diversity thanks to high-tech techniques that involve injecting a single sperm directly into the egg resulting in successful fertilization (Church et al., 1985; Takashi Kohda & Fumitoshi Ishino, 2013).

The implementation of embryo manipulation technologies has brought about significant advancements in breeding efficiency and genetic diversity for dogs. But the ethical considerations surrounding these practices cannot be ignored. Modifying the natural reproductive process comes with potential risks and must consider the welfare of the animals in question. Manipulating early embryos can also have lasting effects on the growth and development of offspring. Careful consideration of both benefits and risks is crucial for breeders and researchers before implementing these techniques.

8. Nanomaterials in Embryo Manipulations

In various fields, such as medicine and biotechnology, nanomaterials are materials with at least one dimension less than 100 nanometers (Fraser et al., 2021) that offer unique properties. Sperm-mediated gene transfer could be made more efficient through the use of nanomaterials in embryo manipulations, which could result in the production of genetically modified embryos (Remiào et al., 2018). Nanomaterials are also being studied for their potential in stem-cell-based therapy for brain diseases, anti-tumor treatments, and gene delivery (Dong et al., 2021). With the integration of nanomaterials in embryo manipulations, the reproductive medicine field has the potential for significant advancement and new discoveries (Barhoum et al., 2022).

Various techniques can be improved in efficiency and precision by nanomaterials, making them an important factor in embryo manipulations. One way this can be achieved is through the development of smart materials with novel functionalities that are biocompatible. These materials can lead to significant advancements in sub-cellular monitoring, creating a necessary non-incremental step forward according to M.J. Lopez-Martinez & E.M. Campo in 2011. Nanotechnology has been considered a tool for reproductive medicine to help overcome some impairments (Remiào et al., 2018). Recent research has investigated the applicability of nanomaterials to improve sperm selection and deliver antioxidants and hormones to preantral follicles (Silva et al., 2021). Using nanotechnologies to measure, understand and manipulate stem cells is a developing field (Ferreira et al., 2008). Incorporating nanomaterials may boost the accuracy and effectiveness of embryo manipulations, ultimately increasing success rates.

Technologies for manipulating embryos are rapidly evolving, with a plethora of options available to enhance precision and efficiency. These methods often involve micro and nanofabrication techniques (M.J. Lopez-Martinez & E.M. Campo, 2011). One innovative approach, which utilizes electrowetting-on-dielectric technology, is the creation of microfluidic chips that are capable of manipulating bovine embryos in vitro (Karcz et al., 2023). By integrating nanotechnology with various other fields, researchers have developed unique nanomaterials that can revolutionize diagnostic and therapeutic applications (Barhoum et al., 2022). It's exciting to imagine the possibilities as more advanced nanomaterials are developed, leading to even more groundbreaking embryo manipulation techniques.

9. Types of nanomaterials used in embryo manipulations

The use of metal nanoparticles in embryo manipulations has become ubiquitous owing to their small size-to-volume ratio and remarkable thermal stability (Tiwari et al., 2011). A bio-barcode assay using anti-PSA antibodies functionalized gold nanoparticles has been shown to be ultra-sensitive (Remiào et al., 2018). In embryo manipulations, gold nanoparticles have been utilized in an assortment of methods such as gene delivery, drug delivery, and imaging due to their biocompatibility and lack of toxicity. This discovery makes gold nanoparticles an attractive option for biomedical applications (Adawale et al., 2019; Carnovale et al., 2019).

Reportedly, silver nanoparticles synthesized from natural sources are a viable replacement for antibiotics in porcine sperm as they serve as effective antimicrobial agents (Silva et al., 2021; Lee et al., 2018). Meanwhile, iron oxide nanoparticles have been utilized in embryo manipulations for cell therapy and tissue engineering (Friedrich et al., 2021). In effecting embryo manipulation, metal nanoparticles' unique features serve them amply in their purpose. Silver nanoparticles, highlighted for their optical, electrical, and antibacterial capabilities, are highly valuable in gene and medication transport, as well as in imaging (Silva et al., 2021; Lee et al., 2018).

Iron oxide nanoparticles, particularly magnetic iron oxide nanoparticles, have been implemented in the process of sexing semen in swine and bovine species (Silva et al., 2021). They have additionally been employed in fostering the development of zebrafish embryos to assess the toxicity of metal nanoparticles (Martha Sharisha Johnson, 2019; Magro et al., 2018). Embryo manipulations have been intensively studied for potential application with carbon-based nanomaterials.

One of the top materials used nowadays is carbon nanotubes or CNTs. There are two types of CNTs, namely single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs), as identified by Al Moustafa et al. in 2016. Thanks to their exceptional mechanical, electrical, and thermal features, they serve different purposes, one of which is embryo manipulation. Meanwhile, another carbon-based nanomaterial that holds potential is graphene oxide or GO, obtained from graphene by chemically oxidizing graphite flakes with strong oxidizing agents as noted by Liao et al. in 2018. Studies suggest that GO can improve in vitro fertilization in mice without impacting embryo development (Bernabo et al., 2020). As such, carbon-based nanomaterials have displayed promising outcomes in enhancing embryo manipulation techniques (Gaur et al., 2021).

A promising prospect for embryo manipulation is graphene oxide (GO), which boasts unusual properties. In vitro fertilization has demonstrated increased success rates due to alterations in cell behavior facilitated by the application of a graphene oxide nanofilm to embryo surfaces (Zielinska-Gorska et al., 2020). Lopez et al.'s examination of graphene oxides' biocompatibility for in vitro use involved gauging various well-defined examples (Lopez et al., 2022), where they discovered that in general, their use remained safe.

Embryo manipulations frequently utilize lipid-based nanomaterials due to their exceptional properties and versatility. One commonly used type of lipid-based nanoparticle in reproductive research is liposomes, which are spherical nanovesicles consisting of a single lipid bilayer (Saadeldin et al., 2020). Liposomes can transport various materials, including drugs and genetic material, and their size can range from 50 to 1000 nanometers. Their effectiveness in delivering genes to embryos has been proven through research (Pritchard et al., 2021). Solid lipid nanoparticles (SLNs) and nanostructured lipid carriers (NLCs) are two other lipid-based nanoparticles that have been utilized in embryo manipulations. These nanoparticles can improve the bioavailability of therapeutic agents and drugs in embryos (Naseri et al., 2015).

One alternative form of lipid-based nanoparticle employed in embryo manipulations is nanoemulsions. These emulsions are stable, consisting of oil droplets dispersed in water, and can measure between 20 to 200 nanometers. Their efficacy has been established in various studies, proving their competence in delivering nutrients and medications to embryos (Silva et al., 2021). Another alternative is cubosomes, consisting of lipids arranged in a bicontinuous bilayer cubic phase. In experiments, cubosomes have been effective in delivering genes and other therapeutic agents to embryos (Tenchov et al., 2021).

With boundless possibilities, polymer-based nanomaterials possess immense potential in embryo manipulation. Dendrimers, a particular type of polymeric nanoparticle, have garnered significant interest for their applicability in a multitude of arenas, namely drug delivery, biomedical diagnostics, and protein emulation (Noriega-Luna et al., 2014). Extensively studied, these nanomaterials confirm their amenability to biological systems and possess the ability to permeate cell membranes, which renders them an optimal selection for employment in embryo manipulations. Furthermore, polymeric nanoparticles have been utilized as theragnostic tools, combining diagnosis and treatment in a single application (Cheng et al., 2021). With this in mind, polymer-based nanomaterials present a hopeful and promising opportunity for enhancing the field of reproductive medicine (Remiao et al., 2018; Silva et al., 2021).

Magnetoliposomes are nanoparticles that are magnetic in nature. Comprised of an iron oxide core and a bilayer of lipids, they have been utilized in targeted drug delivery and imaging for embryo manipulations, as demonstrated by Remiao et al., (2018). As reported in 2023 by Pacheco et al., clusters of magnetic nanoparticles composed of multiple magnetic nanoparticles connected by a biocompatible polymer have contributed to targeted drug delivery and hyperthermia during embryo manipulations. Magnetic nanoparticle chains, consisting of long chains of magnetic nanoparticles, have been employed to manipulate cells and tissues, as shown in Materon et al., (2021) research. Finally, Bongaerts et al., (2020) demonstrated the use of these magnetic nanoparticles in embryo manipulations for cell migration and neurite outgrowth.

Nanomaterials known as quantum dots possess distinct photophysical characteristics and have been employed in embryo manipulation. Among these, semiconductor quantum dots, which exhibit optical properties contingent upon the size, have been used to label and track embryos during their developmental stages (Shao et al., 2011). Metal chalcogenide quantum dots, another class of quantum dots, have gained significant traction due to their quantum confinement effects and potential applications in biosensing and bioimaging (Mal et al., 2016). Furthermore, magnetic quantum dots have been utilized to treat cervical cancer in both human cell cultures and xenograft mice (Remiao et al., 2018). Owing to their exceptional properties, quantum dots have become a valuable instrument in the study of embryonic development and manipulation for research purposes.

In vitro, mesoporous silica nanoparticles (MSNs) have been proven to be effective vehicles for therapeutic drugs by Sharif et al., (2020). As a result, MSNs, a type of silica-based nanomaterial, have become a popular option for manipulating embryos due to their exceptional properties. Remiao et al. (2018) proved that MSNs have also been utilized successfully in the transfer of genes through sperm-mediated gene transfer, resulting in higher efficiency rates of genetically modified embryos. Additionally, MSNs have been researched for their potential use in cancer treatment due to their ability to specifically target tumors, as reported by Violetta Carolina Niculescu (2019). As a result, MSNs show great potential in a variety of embryo manipulation applications.

The unique properties and potential applications of titanium dioxide nanoparticles (TiO2 NPs) make them a popular choice in embryo manipulations. Synthesis methods for TiO2 NPs are diverse, including eco-friendly green synthesis with plant extracts, as demonstrated by Rajeshkumar et al., (2021). These nanoparticles offer a range of functions in embryo manipulations, such as serving as a gene delivery tool and a contrast agent for imaging techniques, as shown by Waghmade et al., (2019). However, the pervasiveness of TiO2 NPs across industries poses a potential hazard in terms of their toxicity, as highlighted by Lyashenko et al., (2023). It is therefore critical to comprehend the synthesis, applications, and toxicity of TiO2 NPs in embryo manipulations to ensure their safe and secure utilization.

10. Benefits of using nanomaterials in embryo manipulations

Reducing toxicity to embryos has been made possible with the promising use of nanomaterials in embryo manipulations. In vitro culture, gamete and embryo manipulations often harm embryo viability and result in oxidative stress (Remiào et al., 2018). By delivering antioxidants and hormones to preantral follicles through nanomaterials, sperm selection and pregnancy rates become enhanced. Furthermore, studies have shown that toxicity to embryos can be lowered with the use of nanomaterials since aggregation formation was observed to have occurred due to the highest concentration of nanoparticles (Silva et al., 2021). In manipulating embryos, incorporating nanomaterials has the potential to enhance embryo development and improve viability.

An exploration by Zhang et al., (2022) studied the outcomes of particle size and surface charge in, in vitro mutagenic response and in vivo embryonic toxicity, discovering that the implementation of nanomaterials can heighten both. The efficacy of gene transfer through sperm-mediated gene transfer is escalated when utilizing nanomaterials, which ultimately allows for the creation of genetically modified embryos. Nanoparticles can also increase diagnostic testing and imaging quality so as to better supervise and trace embryo development. Mouse embryos, held in an electrowetting-on-dielectric (EWOD) chip, experienced a dynamic environment that led to improved reproductive outcomes (Huang et al., 2015). Thanks to all these benefits, implementing nanomaterials in embryo manipulation can advance embryo development.

Nanomaterials have shown great potential in enhancing gene delivery during embryo manipulations. The use of nanomaterials has shown promise in enhancing the efficiency of sperm-mediated gene transfer, a widely employed technique for producing genetically modified embryos (Remiào et al., 2018). Additionally, they may aid in the delivery of hormones and antioxidants to preantral follicles, thereby bolstering sperm selection and fertilization success rates (Silva et al., 2021). Overall, introducing nanomaterials into embryo manipulation protocols has the potential to elevate gene transfer performance and increase the likelihood of generating genetically modified embryos.

Enhanced drug delivery resulting from the use of nanomaterials in embryo manipulations has shown a remarkable potential to improve the efficacy of treatments. With the ability to design nanoparticles that specifically target cells or tissues, drug delivery has become more precise (Joshi et al., 2023). Moreover, the increased solubility of hydrophobic compounds using nanoparticles can improve the bioavailability of drugs for better results (Silva et al., 2021). With the potential to target specific cells and improve drug solubility, the use of nanomaterials can significantly enhance treatments and advance patient outcomes (Mitchell et al., 2021)

Nanomaterials can also reduce drug toxicity, which is a significant concern in embryo manipulations. The use of nanoparticles can minimize the impact of patient heterogeneity, allowing for more accurate patient stratification and reducing the risk of adverse reactions (Mitchell et al., 2021). Improvement in toxicity testing is crucial for ensuring treatments are safe and effective, and nanomaterials can aid in achieving this. Nanoparticles can be used to deliver antioxidants and hormones to preantral follicles, which can improve the viability of embryos and reduce oxidative stress (Celà et al., 2014).

The use of nanomaterials in toxicity testing can lead to more reliable results and improved safety in embryo manipulations. Nanotechnology provides unique advantages for stem cell research, including precise stem cell manipulation. The development of nanomaterials and tools has made it possible to manipulate endogenous stem cells from their neurogenic niche, triggering neurogenesis and enhancing the regenerative potential of the brain (Masoudi Asil et al., 2020). The small size of nanomaterials makes them of interest in bioengineering and stem cell research, and their interaction with proneurogenic factors within the stem cell niche can promote self-renewal, proliferation, and differentiation (Masoudi Asil et al., 2020). The delivery of signaling molecules with spatial-temporal precision can guide stem cell behavior and improve therapeutic outcomes (Chueng et al., 2016). These findings suggest that the use of nanomaterials in stem cell research can lead to more precise and effective outcomes.

11. Applications of nanomaterials in in vitro fertilization (IVF)

Studies have displayed optimistic results for the utilization of nanomaterials in improving sperm motility during in vitro fertilization (IVF). Nano-zinc, for instance, has displayed the capacity to enhance semen quality in young rams (Falchi et al., 2018). Another possible application for nanomaterials is the enhancement of gene transfer efficacy via sperm-mediated transfer, which could be particularly valuable for the production of genetically modified embryos (Remiào et al., 2018). With the help of nanomaterials, sperm motility can be amplified, and enhancements can be made to the selection, morphology, and DNA fragmentation levels- ultimately leading to higher fertilization rates and increased IVF success (Fraser et al., 2021; Silva et al., 2021).

Nanomaterials could be the answer to bettering the quality of oocytes, which is essential for IVF success.To achieve this, on-chip manipulation of culture medium microdroplets and electrical stimulation of embryos and gametes have displayed encouraging results in a study conducted by Karcz et al. (2023). Additionally, Morimoto et al. (2023) found that mitochondrial transfer to human oocytes leads to acceptable clinical outcomes, enhancing embryo quality. Moreover, Palay et al. (2022) have experimentally employed engineering-based models to estimate oocyte quality. Thus, implementing nanomaterials in IVF treatment has the potential to boost the oocyte quality and unlock better success rates.

Nano-bio technology has shown potential in helping with embryo selection during IVF. This includes improving sperm motility and oocyte quality. The future use of chick embryo chorioallantoic membrane (CAM) in nano-bio is also promising. All of these techniques can lead to higher success rates for IVF.

12. Applications of nanomaterials in gene editing

The manipulation and modification of embryos' genetic material has been revolutionized by nanomaterials. This has given rise to numerous tools for gene editing. One gene editing technique gaining popularity is CRISPR-Cas9, which employs a guide RNA for targeting DNA sequences slated for modifications. The research world has created a novel dual-targeted polymer nano-system. This nano-system delivers the CRISPR/Cas9 plasmid with pinpoint precision straight to the nucleus of tumor cells, resulting in the elimination of genome CDK11 (Duan et al., 2021).CRISPR-Cas9 has shown great potential in oncological research, allowing for precise targeting of cancer cells and genetic mutations (David Cyranoski and Sara Reardon, 2015; Kazemian et al., 2022; Wang et al., 2022).

Another gene editing technique that has gained attention is Zinc Finger Nucleases (ZFNs), which are artificial restriction enzymes designed for custom site-specific genome editing. ZFNs are created by fusing a non-sequence-specific cleavage domain to a site-specific DNA-binding domain loaded on the zinc finger (Li et al., 2020). Engineered endonucleases, such as ZFNs, provide genome-editing approaches that allow for specific targeting and manipulation of disease-causing genes (Ahmad M. Khalil,2020; Aguado et al., 2020; Chou et al., 2012; Kaneko et al., 2014). These techniques have been used in conjunction with nanomaterials to increase the efficiency of gene transfer in embryos (David Cyranoski and Sara Reardon, 2015; Remiào et al., 2018).

The use of nanomaterials in embryo manipulation has allowed for precise delivery of substances into cells and has opened up new avenues for research in early embryo development (Butler et al., 2022; Zhao et al., 2018; Maria Luz Garcia, 2018). By adopting microscopic observation and micro-nano handling, scientists can carry out a more precise examination of how gene editing affects embryo development and investigate prospective remedies for genetic diseases. The application of nanomaterials in gene editing and embryo manipulation is still nascent, but it offers considerable potential in pushing forward our comprehension of genetics and creating fresh treatments for an array of ailments.

13. Ethical considerations in using nanomaterials in embryo manipulations

Safety concerns arising from the usage of nanomaterials in embryo manipulation can not be overlooked, especially in regards to the toxicity potential of these substances. Pregnant organisms and developing embryos are particularly at risk from the harmful effects of certain nanomaterials (as noted by Remiào et al., in 2018). Therefore, it is crucial to assess the potential risks and toxicity levels of newly developed nanomaterials before utilizing them in embryo manipulations (as recommended by Lebre et al., in 2022). The cautious utilization of nanomaterials is of utmost importance, as although they may provide advantages like enhancing gene transfer efficiency (Remiào et al., 2018; Silva et al., 2021), the risks involved must be thoroughly analyzed.

Across generations, phenotypic alterations ignited by embryo manipulations are believed to persist, according to previous research (Dominiquez et al., 2020; 2021). Nanomaterials used in manipulations during embryonic development may pose future health risks and safety concerns that demand attention. These manipulations could potentially alter epigenetic markers, leading to unforeseen health outcomes. Thus, it is crucial to conduct a comprehensive evaluation of long-term health hazards pertaining to nanomaterial use during embryo manipulations.

Embryo manipulations utilizing nanomaterials pose significant societal implications that should not be overlooked. The ability to edit genes in human embryos is particularly concerning as it raises ethical issues regarding inheritable changes (Morrison and de Saille, 2019). An open and genuine dialogue must be had about the potential benefits and dangers of utilizing nanomaterials in embryo manipulation and the ethical concerns surrounding it (Brezia and Zhao, 2012). It is critical to consider these ethical implications thoroughly.

14. Current research on nanomaterials in embryo manipulations

In manipulating embryos, nanomaterials have been found to be a valuable resource. They have been utilized in delivering target molecules within the intra-gamete and embryo, thus improving assisted reproductive techniques (Lucas et al., 2019). As evidenced in animal studies, nanomaterials can aid in sperm selection, provide antioxidants and hormones to preantral follicles, and even manipulate bovine embryos in vitro (Karcz et al., 2023; Silva et al., 2021). Remarkably, Eto et al. in 2021 were able to produce genetically modified animals using fully automated nuclear injection (Eto et al., 2021). Clearly these findings highlight the potential nanomaterials have to revolutionize animal breeding techniques.

The use of nanomaterials in enhancing human embryo manipulations has been evaluated through clinical trials. Reproductive medicine has found a potential ally in nanotechnology, aiding in overcoming obstacles related to assisted reproductive techniques (Remiào et al., 2018). Furthermore, scientific research has found that DNA methylation patterns in the F3 generation are modified by embryo manipulation, indicating a connection between epigenetic variability and this procedure (Dominiguez et al., 2021). These discoveries point to the possibility that nanomaterials may prove to be instrumental in improving human embryo manipulations.

As the future looms ahead, novel advancements are sprouting up for the progression of assisted reproductive techniques and stem-cell-based therapy. Among them are the creation of microrobotic tools that can smoothly shift gametes or embryos to the fallopian tube without being invasive (Nauber et al., 2023).

15. Challenges and limitations of using nanomaterials in embryo manipulations

Improving outcomes in reproductive medicine and embryo manipulations through nanotechnology is hindered by challenges and limitations. Cost and accessibility are among the main obstacles, with nanomaterials being not only expensive to produce but also requiring specialized equipment and expertise. As a result, many clinicians and researchers are unable to obtain them, which restricts their wide-scale use and hinders progress towards better patient outcomes. (Remiào et al., 2018).

Nanomaterials present a limitation for embryo manipulations due to safety concerns. Specifically during pregnancy and embryo development, organisms have shown toxicity to certain types of nanomaterials (Remiào et al., 2018). This has raised red flags concerning the potential dangers and undesired effects of incorporating these materials into reproductive medicine. Furthermore, a comprehensive evaluation of the potential risks and toxicity of new nanomaterials should occur at the same pace as their rapid expansion (Lebre et al., 2022). Therefore, it is necessary to take sufficient measures in researching and ensuring the safety of nanomaterials prior to use in embryo manipulations.

Incorporating nanomaterials into embryo manipulations poses significant ethical challenges. Inherent ethical, social, and policy issues have surrounded the creation and destruction of embryos for some time (Tatay et al., 2017). Furthermore, manipulating germline cells raises concerns regarding human trait enhancement and unintentional mutations (David Cyranoski and Sara Reardon, 2015; Mette Ebbesen and Thomas G. Jensen, 2006). As a result, it is crucial to weigh the ethical implications of utilizing nanomaterials in embryo manipulations and to ensure that research is conducted in an ethical and responsible manner (David Cyranoski and Sara Reardon, 2015).

16. Conclusion and future outlook for nanomaterials in embryo manipulations

The use of nanomaterials in embryo manipulations has the potential to revolutionize reproductive medicine. Nanotechnology can help overcome some of the impairments that have previously limited the success of reproductive interventions (Remiào et al., 2018). Artificial gametes and embryos generated through manipulation of progenitor cells or stem cells can offer new treatment options for infertility and genetic disorders (Zhang et al., 2020). The investigation of gamete cells using nanotechnology has also revealed new possibilities for improving animal reproduction (L.P Silva, 2014). Due to their potential use in regenerative medicine and tissue engineering, mesenchymal stem cells have caught the interest of medical professionals.

Nanomaterials may have the ability to better the field of reproductive medicine. Clinical trials continue to explore their practicality (Pittenger et al., 2019). An in-depth investigation into the advantages and drawbacks of implementing nanomaterials in reproductive medicine would expand our knowledgebase.

Efficient processes like gene transfer and editing can be improved by utilizing nanomaterials in embryo manipulations, but ethical considerations must be taken into account alongside scientific progress. The CRISPR gene editing technology and related methods present potential unintended consequences that have sparked ethical concerns. Thus, it is essential to thoughtfully evaluate the ethical implications of implementing nanomaterials in embryo manipulations. Responsible use of these materials in reproductive medicine can ultimately bring about notable advancements while simultaneously upholding ethical standards according to Mara Almedia and Robert Ranisch (2022).

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