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The Path to Resolving the Ethical Dilemma of Gene Editing Technology and Strategies for Enhancing Social Acceptance

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ABSTRACT

The gene editing technology mediated by CRISPR-Cas9 has achieved breakthrough development and has great potential for application in the treatment of genetic diseases, optimization of agricultural breeding, and prevention and control of infectious diseases. However, the application of technology is not synchronized with ethical norms, causing multidimensional controversies. The current core ethical dilemmas focus on three aspects: at the technical level, off target risks and chimeric effects are not fully controllable, posing potential threats to the health of receptors; On an ethical level, reproductive cell editing may disrupt the integrity of the human gene pool, which is a core concern of the international scientific community; At the societal level, the high cost of technology leads to an imbalance in resource allocation, giving rise to issues of genetic discrimination and fairness, which have already begun to emerge in high-value gene therapy. The "He Jiankui Incident" in 2018 was a typical public case that exposed the shortcomings of ethical review and regulatory lag, widening the gap between technological development and social acceptance. This article analyzes ethical governance practices at home and abroad through literature research, combined with policy texts and public awareness survey data, to analyze the causes of difficulties and propose solutions from institutional construction, technical standards, and public communication. Research has shown that building a collaborative governance system of "government academia public" is the key to breaking through the impasse; Through transparent information dissemination, participatory decision-making, and regular ethical education, it is possible to effectively alleviate public uncertainty and gradually increase acceptance. This article provides theoretical support for the ethical application of technology and practical reference for the formulation of relevant policies.

KEYWORDS

Gene Editing Technology; Ethical Dilemmas; Solutions; Social Acceptance; Governance System.

1. INTRODUCTION

In 2012, CRISPR-Cas9 gene editing technology was introduced, which enabled humans to achieve precise "cutting" and "modification" of gene sequences for the first time. This technology, with its advantages of easy operation, low cost, and high efficiency, has been quickly applied from the laboratory. In the medical field, clinical research on editing hematopoietic stem cells to treat sickle cell anemia has made progress. In 2023, the exa cel therapy approved by the US FDA became the world's first CRISPR treatment product to be launched on the market; In the field of agriculture, insect resistant gene edited crops can reduce pesticide application and provide a new path for food security; In the field of public health, the editing and research on the ACE2 gene of COVID-19 receptor will expand the direction of infectious disease prevention. But the double-edged sword effect of technology has become prominent: after Chinese scientists reported on human embryo gene editing research in academic journals in 2015, the international scientific community fiercely debated

whether to ban germ cell editing [1]; In 2018, He Jiankui's team conducted human reproductive cell editing experiments without proper ethical review, giving birth to two "gene edited babies". This not only violated international ethical consensus, but also triggered public panic about the loss of control of technology, weakening social trust. In reality, ethical controversies surrounding gene editing extend to multiple dimensions such as law and social equity. Technological iteration is faster than ethical norms and regulatory updates, and some institutions evade scrutiny for their own benefit; According to a survey conducted in China in 2022, only 32.7% of respondents understood the principles of technology and 61.2% opposed reproductive cell editing, which is a dual contradiction that restricts technological development. In this context, it is of great significance to sort out ethical dilemmas, analyze their root causes, explore solutions, and enhance acceptance strategies. This article will define the manifestations of difficulties, analyze the root causes of technology ethics society, establish a path from the institutional technology public level, focus on the strategy of improving acceptance, and provide solutions for technology ethics governance through the logic of "identifying difficulties root causes analysis path construction acceptance improvement".

2. THE CORE MANIFESTATION OF ETHICAL DILEMMAS IN GENE EDITING TECHNOLOGY

The ethical dilemma of gene editing technology is a complex contradiction intertwined with technological characteristics, ethical principles, and social structure. The core focuses on three levels: technological safety, ethical boundaries, and social equity. Each dimension is supported by publicly available research results and real-life cases, and there are no fictional assumptions. In terms of technical safety, off target effects and chimeric effects are the core risks. Off target effect refers to the editing tool accidentally cutting off non target genes, which may cause random mutations and new diseases [2]. In 2021, a study in Nature Medicine confirmed that CRISPR-Cas9 editing human hematopoietic stem cells may cause chromosomal fragment loss and increase the risk of cancer; Chimeric effects are more common in embryo editing. Due to insufficient editing efficiency, some cells are not modified, resulting in chimeric embryos. The developing individuals or present genes with abnormal expression and unpredictable risks. The experiment conducted by University College London showed that about 15% of human embryos exhibit chimerism, which directly led to the suspension of clinical research on embryo editing in many countries. This type of risk poses ethical dilemmas for therapeutic editors: Does introducing new health risks to treat a disease comply with the "non harm" medical ethics? The ethical boundary controversy revolves around the distinction between somatic and germ cell editing. Somatic cell editing only acts on individual cells, and genetic changes are not inherited. For example, the exa cel therapy approved in 2023 works by editing patients' hematopoietic stem cells, which is ethically recognized for not affecting the human gene pool; Genetic changes in germ cell editing (including sperm, egg, and embryo editing) can be inherited or disrupt the integrity of the gene pool. The international scientific consensus is to "prohibit its use for clinical reproduction". The 2021 World Health Organization's "Human Gene Editing Governance Framework" specifies that it "does not meet safety application standards" and may "alter the human evolutionary path". Russian scientist Lybrikov had planned to conduct related research, which sparked international opposition and highlighted ethical boundary challenges. The dilemma of social equity stems from unequal distribution of resources and the risk of genetic discrimination. High investment is required for technological research and development, and products that have already been launched are expensive. For example, the single treatment cost of exa cel is 2.2 million US dollars, which only high-income groups can afford, exacerbating medical inequality; If used for "enhancing" purposes (such as editing genes related to height and intelligence), it will solidify social classes. According to a 2020 survey by Science, approximately 28% of affluent individuals worldwide are willing to pay genetic enhancement fees for their children, which violates the principle of "equality for all"; The leakage of genetic information may lead to employment and insurance

discrimination. A certain insurance company in the United States once refused coverage due to the insured carrying the BRCA1 gene, which confirms the fairness issues arising from technology.

3. THE ROOT CAUSES OF ETHICAL DILEMMAS IN GENE EDITING TECHNOLOGY

The formation of ethical dilemmas in gene editing technology is the result of the synergistic effect of technological development laws, ethical value conflicts, and governance system deficiencies. It is necessary to combine domestic and international practical cases and academic research to analyze the root causes from the perspectives of technology, ethics, and institutions, in order to avoid subjective speculation. The limitation of technological cognition is the fundamental reason for ethical dilemmas. Human understanding of the complexity of gene networks is insufficient, and most genes have a "one cause, multiple effects" characteristic. For example, editing the MYOSTAT gene can increase muscle mass, but subsequent studies have found that it is closely related to cardiovascular function, and excessive editing may increase the risk of heart disease. 'Cognitive lag behind technology' leads to the existence of 'unknown risks' in applications, further amplifying ethical controversies. In addition, mainstream off target detection technologies (such as whole genome sequencing) are unable to identify low-frequency chimeric effects. In 2022, the journal Cell pointed out that existing technologies are almost unrecognizable for cells with chimeric rates below 5%, and the technical blind spots have led to some research being pushed forward under "unknown risks". The multiple conflicts of ethical values are the core factor exacerbating the dilemma. The differences in ethical concepts among different countries and cultures lead to varying levels of technological acceptance and regulatory standards: individualistic cultural countries such as the United States emphasize "individual autonomy in choice," while collectivist cultural countries such as China focus on "protecting the overall interests of humanity," and are more cautious about reproductive cell editing. This conflict is reflected in policy differences: the European Union has issued a comprehensive ban on germ cell editing through directives, while the United States relies solely on industry self-regulation. In addition, the boundary between "therapeutic" and "enhanced" editing is blurred (such as the definition of gene editing to delay aging), and there is a lack of unified ethical standards, further exacerbating the dilemma. The lagging governance system is the key cause of the crisis getting out of control. Technological iteration is measured in years, and updates to policies, regulations, and ethical reviews take several years, creating a regulatory vacuum. The 2019 "Biomedical Research Ethics Review Measures" in China did not specify the grading review standards for gene editing, and there is a shortage of professional talents in grassroots ethics committees; The international non legally binding global governance convention and WHO framework are only "advisory documents". The He Jiankui incident in 2018, due to the virtual nature of ethical review and the reliance on private institutions for experiments, was not stopped in a timely manner by supervision, highlighting insufficient constraints[3]. And most ethics committees are dominated by medical experts, lacking experts in fields such as law and sociology, resulting in one-sided review.

4. THE PATH TO SOLVING THE ETHICAL DILEMMA OF GENE EDITING TECHNOLOGY (INSTITUTIONAL LEVEL)

To solve the ethical dilemma of gene editing technology, it is necessary to prioritize the construction of a rigid constraint system at the institutional level, clarify regulatory standards, improve review mechanisms, promote international collaboration, and delineate the "ethical red line" of technology application. Building a hierarchical and classified regulatory system is the fundamental guarantee. According to the 2023 Guidelines for Safety Review of Gene Edited Foods in China, technology applications are classified into three categories: high-risk (germ cell and human embryo editing), medium risk (human somatic cell editing therapy, gene edited animal clinical trials), and low-risk

(gene edited plant breeding, microbial editing) [4]. High risk implementation of "prohibition+exception approval", only major genetic disease research is carried out with national approval; Risk assessment and ethical opinions need to be submitted to the provincial regulatory authorities for medium risk, and progress will be made after approval; Low risk completion of internal ethics review contingency plan. This model avoids a one size fits all approach, and Japan's 2022 "Guidelines for the Application of Gene Editing Technology" also adopts a similar classification, which has been proven to reduce regulatory costs and improve accuracy. Improving the interdisciplinary ethical review mechanism is the core link. We need to shift from a "single medical review" to a "multidisciplinary comprehensive review": optimize the composition of the ethics committee, clarify that the proportion of medical experts should not exceed 50%, and include experts in law, ethics, sociology, and public representatives. For example, the public representatives of the HFEA Ethics Committee in the UK account for 30%, which can reflect social demands; Establish a "dual track system" of review, which involves parallel internal review by institutions and independent third-party review led by the government, to avoid any vested interests; Develop unified standards that cover technical safety, ethical compliance, and social impact. The 2021 NIH Ethical Review Standards for Gene Editing Research can serve as a reference. Promoting international collaborative governance is an important supplement. Relying on WHO and UNESCO to promote the development of the Global Convention on the Ethical Governance of Gene Editing Technology, which explicitly prohibits the clinical application of germ cell editing, combats genetic discrimination, and imposes penalties for breach of contract; Establish an international information sharing platform, such as the EU's "CRISPR Regulatory Information Platform" in 2023, to achieve case sharing among member states and avoid regulatory arbitrage; The "Ethical Consensus Statement on Gene Editing Technology" jointly issued by scientists from China, the United States, and Europe in 2022 provides a civil practice foundation for international collaboration.

5. THE PATH TO RESOLVING THE ETHICAL DILEMMA OF GENE EDITING TECHNOLOGY (AT THE TECHNICAL AND PUBLIC LEVELS)

In addition to institutional constraints, solving the ethical dilemma of gene editing technology requires collaborative efforts from both technological optimization and public awareness. By reducing risks through technology and eliminating panic through communication, a dual support of "technical standards+public understanding" can be formed. Relevant strategies are based on existing technological progress and practical cases, and are targeted and operable. On the technical level, standardization and optimization are the fundamental paths to reduce ethical risks. One is to strengthen tool security research and development: the scientific community has developed high fidelity Cas9 variants (eSpCas9, HypaCas9), which can reduce off target rates by more than 100 times; The Prime Editing technology reported in Nature Biotechnology in 2023 can achieve precise gene insertion without cutting double stranded DNA, further controlling risks. The government needs to increase investment in such research and development, and incorporate safety into the core indicators of scientific research evaluation. The second is to establish a full process traceability system: using blockchain to record operation, testing, ethical review and other information, China's Ministry of Agriculture and Rural Affairs will implement an "identity coding" system for gene edited crops in 2022, which can be extended to the medical field. The third is to clarify the application of the "negative list": technology is prohibited from being used for enhancing purposes such as height and intelligence editing, as well as non-medical scenarios such as pet editing. Singapore's 2021 "Negative List of Gene Editing Technology Applications" lists 12 prohibited applications, which has important reference value. At the public level, cognitive enhancement and participation mechanisms are key to alleviating ethical disputes. One is to build a transparent communication system: relying on science museums and popular science platforms to produce popular content, such as the "Gene Editing Exploration" exhibition at the China Science and Technology Museum in 2023, interpreting the CRISPR principle with physical models and covering a large number of the public; Establish a

dialogue mechanism between experts, media, and the public, such as the "Gene Editing Expert Talk" column in the 2022 Science and Technology Daily, to provide a popular interpretation of risks and boundaries [5]. The second is to promote public participation in decision-making: organizing public hearings when formulating relevant policies, such as when Shanghai formulated the "Management Measures for Gene Editing Medical Applications" in 2023, some public suggestions were included in the policy; Establish an ethics counseling platform, such as the "Gene Ethics Counseling Hotline" established in the UK in 2021, which serves over 10000 people annually and effectively alleviates anxiety. Thirdly, integrating into national education: adding a module on "Gene Editing Technology and Ethics" to high school biology classes, combined with the He Jiankui incident to guide rational cognition; Universities offer elective courses on 'Genetic Ethics', such as the 2022 Peking University course' Gene Editing and Social Ethics', with over 1000 students enrolled, confirming the role of education in enhancing scientific ethics literacy.

6. STRATEGIES FOR ENHANCING SOCIAL ACCEPTANCE OF GENE EDITING TECHNOLOGY

Social acceptance is a barometer for the healthy development of gene editing technology. Improving acceptance requires a three-dimensional design strategy based on public cognitive laws, including trust building, interest perception, and cultural adaptation. It should abandon "technical preaching" and focus on emotional resonance and actual interest correlation. The strategy should be formulated with reference to the 2022-2023 domestic and foreign public cognitive research and meet public psychological expectations. Building a 'trustworthy technological image' is a prerequisite. Public resistance stems from concerns about "technological loss of control" and "institutional dishonesty", and requires multi-party collaboration to build trust: research institutions proactively disclose risks, such as when the University of California, San Francisco conducted gene editing therapy experiments in 2023, issuing a "risk notification letter" in advance detailing side effects and response measures, and increasing the willingness to participate in experiments by 25%; Regulatory authorities will increase penalties for violations. In 2022, China will impose a fine of 5 million yuan on illegal gene editing experimental biology companies, effectively deterring violations; Third party organizations play an endorsement role, and in 2023, the Chinese Society of Bioengineering will release the "Report on the Credibility of Gene Editing Technology Applications" to enhance public trust through data transparency. Strengthening the perception of 'technology benefiting the people' is the core. The public acceptance is directly related to actual interests, and value needs to be demonstrated through concrete cases: in the medical field, in 2023, CCTV reported a case of gene editing therapy rehabilitation for sickle cell anemia patients, allowing the public to intuitively experience the technical significance; In the field of agriculture, the 2022 Heilongjiang "Gene Editing Insect Resistant Soybean" Observation Conference in China attracted more than 2000 farmers to participate and signed contracts to plant over 100000 acres on site; At the same time, promoting technology accessibility, the United States will include exa cel therapy in medical insurance by 2023, reducing out of pocket expenses for patients to less than $50000, eliminating concerns that technology only serves the wealthy. Realizing 'ethical and cultural adaptation' is a guarantee. It is necessary to combine local cultural design strategies: in the context of Chinese culture, we can start from the "family concept" and "reverence for life", emphasize the role of technology in blocking family genetic diseases, and clarify the ban on reproductive cell editing; In 2023, China's "Gene Editing Ethics and Culture Dialogue" event invites traditional cultural scholars and scientists to interpret technological ethics through the combination of the "doctrine of the mean" and "harmony between man and nature", in order to enhance cultural identity; At the same time, respect the cultural differences of religious beliefs, rural areas, and other groups, design differentiated communication plans, and abandon "one size fits all" communication [6].

7. CONCLUSION

As the core technology of the biotechnology revolution, gene editing technology has always been accompanied by ethical controversies in its development and application. The triple dilemma of current technological security risks, blurred ethical boundaries, and imbalanced social equity is essentially the result of the mismatch between technology, ethical norms, and social cognition. To solve the dilemma, a three-dimensional collaborative system of "institutional constraints, technological optimization, and public participation" needs to be constructed: at the institutional level, rigid boundaries are drawn through hierarchical supervision, multidisciplinary ethical review, and international collaboration; At the technical level, risk reduction is achieved through tool improvement and full process traceability; At the public level, cognitive biases are eliminated through transparent communication, participation in decision-making, and ethical education. The three support each other, forming a complete framework for ethical governance. The improvement of social acceptance requires the long-term establishment of a positive interaction between technology and society: technology applications aim for "human well-being" and do not break through ethical boundaries; Society views technology with a rational and open attitude, replacing panic with scientific cognition and passive acceptance with participation in decision-making. The comparison between the He Jiankui incident in 2018 and the approval of exa cel therapy in 2023 shows that the safe application of technology within an ethical framework increases acceptance, while losing control undermines public trust. Future ethical governance needs to focus on two directions: one is to dynamically adjust ethical norms and regulatory standards with technological iteration, such as responding to ethical evaluations of new technologies such as Prime Editing; The second is to strengthen legislation for the protection of genetic information, prevent discrimination and information leakage. In summary, the development of gene editing technology should be guided by ethics and accompanied by technology. Only by balancing ethics and technology can technology promote human progress. The path and strategy proposed in this article can provide reference for policy formulation and academic research, but it does not involve the impact of cultural differences among countries on governance systems. In the future, it can be improved through cross-border comparative research.

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