**CRISPR/Cas9 and the Future of Genome Editing**

**What is genome editing?**

**Genome editing**, or gene editing, is a method by which DNA of an organism can be changed. This can be done in humans, animals, plants, and bacteria. Gene editing can be used to change **phenotypic traits**, or any observable trait, such as eye color and **genotypic traits** , or genetic makeup, to help fight cancer and diseases. Genome editing allows for genetic material and information to be added, deleted, replaced, or rearranged at different locations to change the structure or function of a particular gene. Even though gene editing technologies have only been around for a few decades, major breakthroughs in the study of gene editing have already been made.

**Types of genome editing**

Several methods of editing the genome already exist, and scientists are always exploring new ways to make the process more efficient and effective. Some of the most widely accepted technologies used in gene editing are ZFNs, TALENs, and CRISPR-Cas9. **Zinc Finger Nucleases (ZFNs)** are restriction enzymes made from natural eukaryotic proteins that are engineered to bind to specific parts of the DNA sequence and cut them to allow for recombination of the gene sequence. While they are effective, ZNFs are time consuming, and a single ZNF is only good for one location, so scientists must manufacture a new one for each DNA sequence they want to target. **Transcription activator-like effector nucleases**, or TALENs, are similar to ZNFs, but are easier to engineer. TALENs are another class of **restriction enzymes** that bind to specific sites in a DNA sequence and allow for the addition or subtraction of nucleotides. Like ZNFs, a single engineered TALEN is only good for one cut in the DNA sequence, so a new one must be produced for each desired sequence modification. Both ZNFs and TALENs are not very cost efficient and are somewhat complicated to apply in the lab. This leaves the third, and arguably most widely-accepted, form of genome editing which is the CRISPR technology.

**What is CRISPR/Cas9?**

**CRISPR-Cas9** is a genome editing technology developed in 2009. CRISPR, or clustered regularly interspaced short palindromic repeats, are developed from naturally occurring proteins in prokaryotes (like bacteria), unlike ZNFs and TALENs which are made from eukaryotic proteins. In this technology, RNA templates are manufactured to match the target DNA sequence. These RNA templates can be used time and time again, instead of the single-use enzymes produced by ZNFs and TALENS. While there are several enzymes that can be used with the CRISPR technology, Cas9 is the most researched one in use right now. The Cas9 enzyme binds to the target DNA sequence and cuts it, allowing for the desired modifications to be made. Because the same RNA sequence can be used many times over, CRISPR is said to be much more cost-effective, time-efficient, and effective than other genome editing technologies used right now. In fact, one group of scientists found that the CRISPR-Cas9 technology is nearly six times more productive than TALENs and ZNF. This allows for gene editing projects that once took years and bared a large financial burden to be completed in a very short amount of time at a fraction of the price.

**Applications of CRISPR/Cas9**

CRISPR-Cas9 can be used in the prevention and treatment of many different single-gene diseases including, sickle cell anemia, cystic fibrosis, hemophilia, and many more. There has also been a lot of research conducted to show the possibility of prevention and treatment of complex diseases such as cancers and HIV. There are two types of genes in which genome editing technology is being researched. **Somatic cell therapy** involves the alteration of non-reproductive genes. This means that changes made to the DNA in an organism will not be passed down to the following generations. In **germline cell therapy**, the reproductive genes are the ones to undergo change, and these changes can be heritable, or passed down to the subsequent generations. Germline therapy could prevent the inheritance of diseases and cancer if successful, whereas, somatic therapy will only benefit the organism receiving direct treatment. CRISPR/Cas9 has been proven to suppress the growth of HPV tumors, which has the potential to decrease the potential for contracting cervical cancer. There have also been studies that determine that CRISPR has the ability to change the mutated regulator protein that causes cystic fibrosis, leading to suppression of symptoms and even possible remission. In most recent research, the CRISPR-Cas9 technology has been used for the production of lab-grown meat. This research is even being backed by Bill Gates! In this process, CRISPR is used to generate rapid growth in the cells of animal muscle. If this technology improves, it could mean less consumption of actual animals, but could also cause profit loss in the farming industry. The hope behind this technology is that it can help to solve the hunger crisis that the world is now on the verge of. The prospects that CRISPR has is almost limitless. From disease prevention and treatment to the development of an alternative food supply, CRISPR/Cas9 seems to have a bright future in the field of genome editing.

**Is it Ethical?**

While the CRISPR-Cas9 technology seems to offer a lot of promising developments, there are always questions that arise about the ethics involved. Most of the ethical questioning revolves around the use of genome editing of the germline cell. Many bioethicists currently feel that germline editing is taboo due to its lasting effects that could be passed down from generation to generation. Most recently, a Chinese scientist, He Jankui, claims to have used the CRISPR technology to modify the genes of twin sisters in hopes to make them resistant to HIV in the future. While this sounds like a good thing, many other scientists have called into question Dr. Jankui’s method of altering embryos.

Safety is also called into question when genome editing is applied. There is always the risk of the CRISPR system placing the edit on the wrong sequence and creating an irreversible mutation. Something like this has the potential to cause accelerated cancer and disease growth, as well as organ malformation and failure.

There are other concerns such as informed consent and income equality when it comes to germline gene editing. Obviously, we cannot obtain consent from an embryo. However, many argue that parents already make most decisions for their children, so why can’t they make this decision as well? Also, many people fear that due to cost and availability, the luxury of genomic editing will only be available to the wealthy and elite. This poses concerns of even more extreme class separation than we already see today.

One last, but very important, concern is the idea of designer babies. While the CRISPR-Cas9 system was ultimately designed to prevent and treat diseases, it has recently been experimented with in an attempt to prevent **congenital malformations**, or permanent defects present at birth, that cause autism, down syndrome, and other birth defects. While the idea of eradicating these things sounds wonderful, some scientists are concerned that the technology will lead to the prospect of parents selecting certain traits for their unborn child, such as hair and eye color, height, build, etc. This again calls into question elitism. One scientist compared the idea of designer babies to that of purebred dog breeds. Breeders tend to breed dogs based on aesthetics, or physical appearance, rather than genetics, which leads to things like **brachycephaly**, or a shortened skull, making it difficult for certain breeds such as pugs and bulldogs to breathe. If we begin to focus on primarily on the traits that are pleasing to the eye, what happens to the development of the traits we can’t see? This is a question that remains unanswered for now.

**The Future of Genomic Editing**

There is no doubt that gene editing through the CRISPR/Cas9 system holds a lot of potential and offers a lot of promise to the fight against many different diseases. While so much has already been discovered, the technology is still relatively new, so the long-term effects of it have yet to be seen. Just like with every new scientific discovery, CRISPR/Cas9 will no doubt be subject to trials and tribulations, scrutiny, and regulation. This new technology is exciting and most scientists agree that it has a lot to offer the future of genome editing.

**References**

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