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The Science and Ethics Behind CRISPR

Can We Edit Our Future by Rewriting Our DNA?

Imagine a future where blindness can be cured, hereditary diseases are prevented before birth, and parents can even choose their children's traits. This is becoming possible thanks to CRISPR, which stands for *Clustered Regularly Interspaced Short Palindromic Repeats*. Through targeting and editing specific genes in the DNA, CRISPR is allowing what was once thought to be impossible. With CRISPR, scientists could prevent inherited diseases from passing through generations, improve cancer treatments, and even change how we understand human development. However, with this scientific power over DNA comes many moral dilemmas we cannot ignore.

But what exactly is CRISPR targeting?

The DNA, short for deoxyribonucleic acid. A double-stranded molecule shaped as a double helix, composed of repeating units called nucleotides (Kugler, 2024). A nucleotide consists of a sugar, a phosphate group, and one of four nitrogenous bases: adenine (A), thymine (T), cytosine (C), or guanine (G). The bases pair specifically (A with T, and C with G) and form the instructions for building and maintaining an organism. Sets of DNA coding for specific proteins are known as genes, and these make up the human genome. DNA is folded into 46 chromosomes consisting of 3.2 billion base pairs in humans (Kugler, 2024).

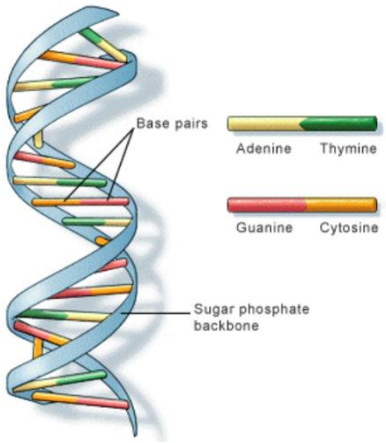

Figure 1: Structure of DNA showing double helix and base pairs (Nagpal, 2023)

For decades, scientists could only read DNA in order to understand how traits are passed down or how diseases develop. Now, they don't just read it, they can edit it. While this advancement offers tremendous medical benefits, it raises troubling ethical questions about our role in editing the building blocks of life: Should we tamper with the human genome? And most importantly, what happens if we go too far, such as creating genetically enhanced humans, leading to inequality or a revival of eugenics?

The Science behind CRISPR

The Mechanism of CRISPR in Bacteria

CRISPR is a pattern found in the DNA of bacteria and archaea (Baugh, 2025). These microorganisms use the CRISPR system as an adaptive immune response to protect themselves from viral infections (StandfordReport, 2024). When a virus infects a bacterium, it stores small fragments of the viral genome, called spacers, within its own DNA as a memory of the invader (Gostimskaya, 2015). These spacers, positioned between repeating DNA sequences known as repeats, allow the bacteria to recognize the virus if it attempts to infect again (Fridovich-Keil, 2025). Upon subsequent infection, the bacterium translates these spacer units into guide RNA (gRNA), which directs the Cas9 enzyme, a molecular "scissor", to the exact location of the viral DNA. Cas9 cleaves the viral DNA, inhibiting the replication of the virus. The mechanism acts as a genetic 'memory,' allowing bacteria to remember and inactivate previously encountered viruses. This natural defence mechanism is highly precise, allowing the bacteria to specifically target and destroy viral DNA without affecting its own genome (StandfordReport, 2024).

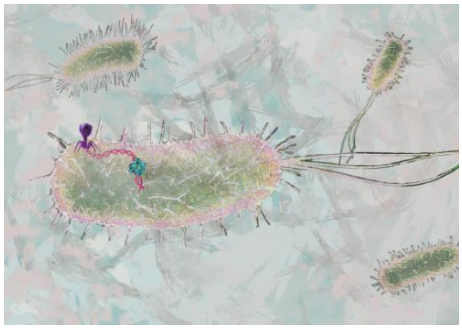

Figure 2: CRISPR under a microscope: cutting viral DNA to protect against future invasions (Crossley, 2018).

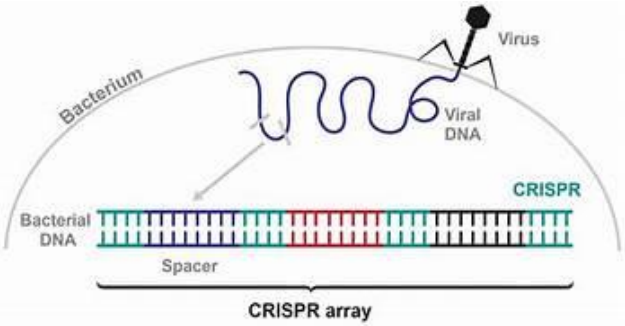

Figure 3: CRISPR immune defence: A virus injects its DNA into a bacterium, where it integrates into the CRISPR array. This process helps in genetic memory (Werner, 2022).

Adapting CRISPR for Human Use

When adapted for human use in 2012 by scientists Jennifer Doudna and Emmanuelle Charpentier, the CRISPR-Cas9 system was re-engineered to edit genes in eukaryotic organisms, including humans (Baugh, 2025). This re-engineering modified the system to direct Cas9 to specific locations in the human genome using guide RNA (gRNA). Similar to its bacterial counterpart, the human version relies on the recognition of a PAM (Protospacer Adjacent Motif) sequence adjacent to the target DNA (Werner, 2022). Once PAM is identified, Cas9 unwinds the DNA and checks for a match with the gRNA,

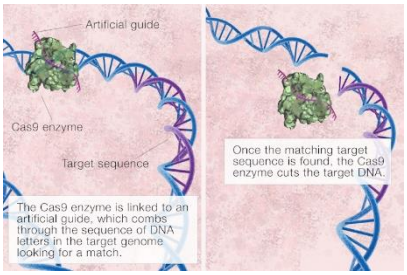

Figure 4: CRISPR-Cas9 finding, targeting and cutting the target DNA

forming an R-loop that activates its cutting function (Science Direct, 2025). Cas9 then induces a double-strand break (DSB), cutting both DNA strands (Werner, 2022). After the DSB, the cell's natural repair mechanisms are triggered (Baugh, 2025).

Repair can occur through non-homologous end joining (NHEJ), which may add or remove short DNA fragments or homology-directed repair (HDR), which uses a DNA template to correctly insert or edit sequences (Liao, et al., 2024). This ability to induce DSBs in specific locations makes it possible to create gene knockouts, deletions, replacements, and even single-nucleotide fixes with great precision (Gostimskaya, 2015).

With such power come ethical questions: Should we edit genes for cosmetic purposes or intelligence enhancement? This freedom may give parents more control, but will naturally born children be seen as “lesser”? Could society value engineered traits over human individuality?

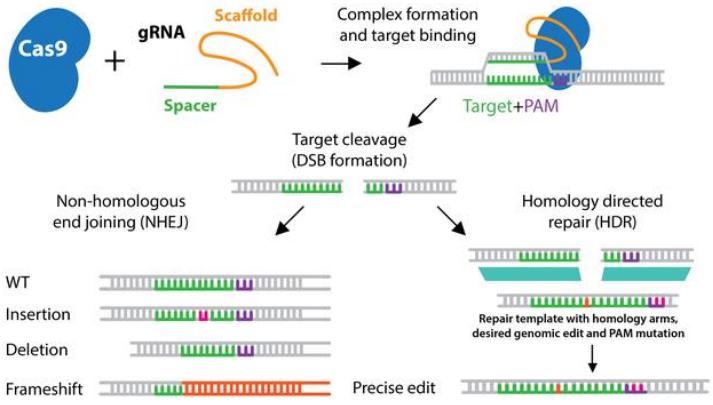

Figure 5: The visual process of CRISPR-Cas9 targeting and cutting DNA

CRISPR in the Real World

CRISPR in Medicine

CRISPR technology is most useful in the field of medicine. For instance, in sickle cell anaemia, the disease is caused by a mutation in the HBB gene, which encodes haemoglobin, the protein responsible for carrying oxygen in red blood cells (NIH, 2025). The mutation causes the haemoglobin to form sickle-shaped cells that can block blood flow and lead to organ damage (Mayo Clinic,

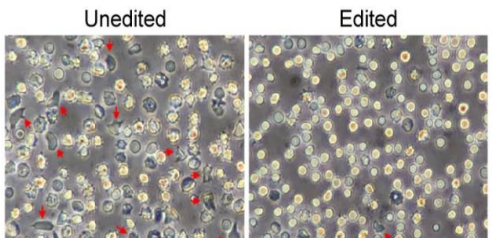

Figure 6: Red blood cells from patient with sickle cell disease.

2025). By using CRISPR to edit the HBB gene, scientists corrected the mutation in hematopoietic stem cells from her bone marrow and reintroduced them into her body, effectively curing the disease. A landmark trial in 2019, involving a patient named Victoria Gray, demonstrated the potential of CRISPR in treating sickle cell disease (Stein, 2021). Before treatment, she suffered from chronic pain and fatigue (Knibbs, 2023). After receiving CRISPR-based treatment, she showed no symptoms of the disease, marking a significant breakthrough in gene therapy.

CRISPR in Agriculture

Beyond genetic disorders, CRISPR has the potential to revolutionize agriculture. In agriculture, CRISPR is being used to make crops more resistant to things like drought, pests, and diseases (Bomgardner, 2020).

Unlike traditional breeding or older genetic modification techniques, CRISPR/Cas9 allows scientists to make precise internal edits without adding foreign genes, making the product more natural to consumers (Bomgardner, 2020). For instance, CRISPR/Cas9 was used to edit a specific RNA gene called *lncRNA1459* in tomatoes (Li, et al., 2020). By disabling this gene, researchers discovered that it plays a key role in controlling when the fruit ripens. Tomato edited plants with this gene edited showed a delay in ripening, offering longer shelf life and reducing food waste in the supply chain (Li, et al., 2020).

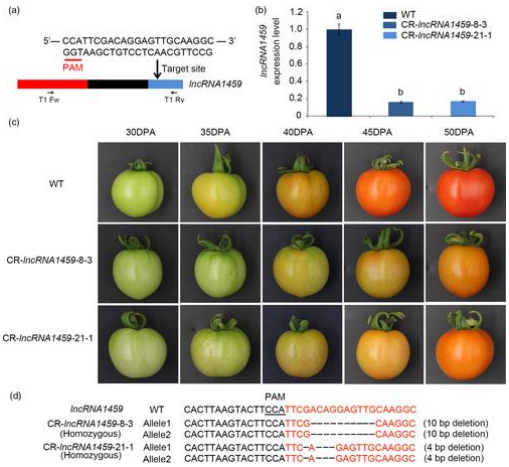

Figure 7: CRISPR/Cas9 editing of lncRNA1459 in tomatoes caused significant delays in fruit ripening (Li, et al., 2020)

In another example, Cibus, a company focused on plant gene editing, used CRISPR to develop a type of canola that is resistant to herbicides (Burwood-Taylor, 2018). This crop utilizes CRISPR technology without introducing foreign DNA, making it a more acceptable option for consumers concerned about traditional GMOs (Bomgardner, 2020).

But even in agriculture, what happens when gene-edited crops, while promising higher yields, end up diminishing biodiversity by outcompeting traditional varieties and creating unequal access for countries unable to afford these modified seeds?

And what unintentional ripple effects could this have on ecosystems, economic disparities, global trade, and local food cultures?

Plant	Gene(s) targeted	Traits	Method	References
Apple	MdDIPM4	disease resistance	gene inactivation	Pompili et al. 2020
Maize	*ZmPHYC1* *ZmPHYC2*	flowering time/plant height	gene knockout & overexpression	Li et al. 2020
Muskmelon	*CmPDS*	albinism (CRISPR trial)	gene knockout	Hooghvorst et al. 2019
Oil palm	*EgIFR* *EgMT*	disease resistance	base editing	Budiani et al. 2018
Oilseed rape	*BnALS1*	herbicide resistance	base editing	Wu et al. 2020
	BnaSDG8.A *BnaSDG8.B*	plant flowering	gene knockout/down	Jiang et al. 2018
Rice	*Os8N3* *OsProDH* *OsGS3* *OsNAC45*	disease resistance thermotolerance grain length salt tolerance	gene knockou gene knockout & overexpression site directed mutagenesis gene knockout & overexpression	Kim et al. 2019 Guo et al. 2020 Usman et al. 2021 X. Zhang et al. 2020
Soybean	*GmPRR37* *GmFT2a/5a*	flowering time & regional adaptability	site directed mutagenesis	Cai et al., 2018; Cai et al., 2020; Wang et al., 2020

Figure 8: Examples of successful genome editing of plant species

Scientific Challenges and Ethical Implications of CRISPR

While CRISPR technology is beneficial, just like all new technology, it faces significant challenges that must be addressed. One of them is off-target effects, where the Cas9 enzyme inadvertently cuts DNA at unintended sites, potentially causing harmful mutations (Liu, et al., 2021). This issue stems from imperfect guide RNA binding. To reduce errors, researchers developed advanced Cas9 variants like eSpCas9 and HypaCas9. Efficient delivery of the CRISPR components into the correct cells remains another obstacle, as many tissues are difficult to reach and may react negatively to components like the Cas9 protein. (Thorne, 2024). As researchers work to increase precision, safety, and delivery methods, these challenges must be overcome for CRISPR to be reliably used in real-world treatments.

Beyond technical challenges, CRISPR raises significant ethical issues. While it offers the potential to cure genetic diseases, it opens the door to creating “designer babies” or “superhumans” with enhanced traits, which could lead to social inequalities (Balch, 2021). Wealthy individuals may gain unfair advantages by using CRISPR for non-medical purposes, creating divides (Bansal, 2024). The possibility of germline editing, raises concerns about consent as germline errors not only impact the individual but the entire generation (Brokowski & Adli, 2020). Additionally, CRISPR could be misused for eugenics, which remove traits that seem “undesirable,” such as disabilities (Bansal, 2024). History has shown how the misuse of genetic selection like during the Nazi era where it was attempted to create a 'pure' Aryan race by removing those they saw as inferior. In the wrong hands, CRISPR could enable similar genetic discrimination, disguised as progress.

These ethical issues, alongside technical challenges, emphasise the need for strict guidelines and regulations to ensure CRISPR is used responsibly. However, to ensure global cooperation and avoid trade barriers, countries must adopt proper regulations for CRISPR technology. If countries have different laws, it could affect international research, trade, and the safe use of CRISPR technology.

CONCLUSION

CRISPR is a technological breakthrough in genetic discovery, not just enabling us to read our DNA but also to rewrite it with extraordinary precision. From curing inherited diseases like sickle cell anaemia to developing more resilient crops, the technology is already reshaping medicine and agriculture.

As Jennifer Doudna, one of CRISPR's pioneers, noted, “We have to be cognizant of how to be sure that everyone who can benefit from this technology has access to it (Balch, 2021).” In many cases, editing the human genome can prevent suffering and save lives, making it not only a scientific possibility but an ethical responsibility. But we must ask: Are we prepared for the social and moral consequences of this power? Will this technology be used only to heal, or will it become a tool for control, inequality, or even eugenics? The risks of off-target effects, unequal access, and the danger of using gene editing for non-medical enhancement present ethical hazards.

As we stand on the edge of this genetic revolution, the real challenge is not what CRISPR can do, but how wisely we choose to use it. The future of DNA editing is not just about scientific discovery, but our duty to make this powerful technology serve the common good without crossing ethical lines we might later regret.

Word Count (excluding references and captions): 1498

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