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POPULAR ARTICLE

CRISPR-Cas9: The tiny tool rewriting the code of life

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Introduction

Imagine opening a book, finding one misspelled word among three billion letters, and fixing it without disturbing anything else on the page. That is what CRISPR-Cas9 lets scientists do with DNA. Once a strange discovery in bacteria fighting off viruses, it has become the most powerful gene-editing tool ever built, now reshaping medicine, farming, and biotechnology at remarkable speed.

Why CRISPR beat older tools

Older tools like zinc finger nucleases (ZFNs) and TALENs could also cut DNA, but building them for each target was slow and expensive like custom-engineering a key for every lock. Because CRISPR's targeting is handled by an easily redesigned RNA rather than a re-engineered protein, it is far cheaper, faster, and simpler to use, which is a big part of why it spread across labs worldwide so quickly.

Higher precision: generally more accurate than ZFNs or TALENs, though no gene-editing tool is completely perfect.

Lower cost: only the guide RNA needs to change, not an entire protein, opening the door to smaller labs.

A whole family of tools

Easier to use: standard labs can now do what once needed specialized protein engineering expertise.

Greater design flexibility: researchers can more easily retarget CRISPR to new sequences compared to older tools.

Wider reach: simplicity has democratized genome editing worldwide, not just in specialized labs.

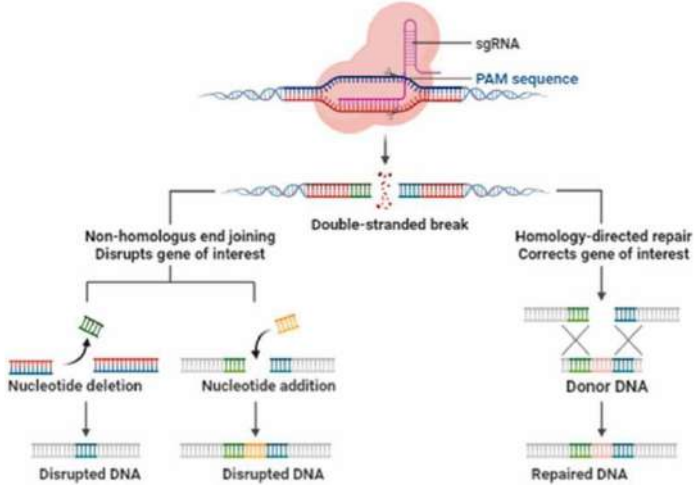
Beyond cutting: Base and prime editing

Target, checking for a nearby DNA landmark called a PAM. Cas9 then cuts both DNA strands, creating a double-strand break. The cell rushes to repair the break through one of two pathways. Non-homologous end joining (NHEJ) stitches it back together quickly but imperfectly, usually disabling the gene. Homology-directed repair (HDR) uses a supplied DNA template to patch in a corrected sequence instead. Break it, and the cell either turns the gene off or lets scientists write in a fix.

This system wasn't invented from scratch it was borrowed from bacteria, which evolved CRISPR as a defence against invading viruses. Scientists simply reprogrammed this ancient bacterial immune system to target any DNA sequence they choose.

Cas9 is just one member of a larger CRISPR family. Class 1 systems use multiple proteins working together; Class 2 systems, including Cas9, do the job with a single, all-in-one protein part of why Cas9 became so popular. It is simply easier to work with one component than several. Cas12a is a close cousin that cuts DNA slightly differently and is also prominent for genome editing in complex, eukaryotic cells. Cas13 targets RNA instead of DNA, offering temporary, non-permanent edits useful for diagnostics and research where a permanent genetic change isn't desired. Standard CRISPR cuts both DNA strands effective, but sometimes too blunt. Base editing fuses a deactivated Cas9 with an enzyme that directly converts one DNA letter into another (like C to T), without a full double-strand break, reducing errors. Two main versions exist: cytosine base editors (CBE) and adenosine base editors (ABE). Prime editing goes further, combining a Cas9 "nickase" with reverse transcriptase to directly write new genetic information at a target site inserting, deleting, or substituting sequences with remarkable precision and far fewer accidental side effects than standard Cas9 alone,

Fig. 1. Genomic navigation through prime editing in crispr-cas9: explore the groundbreaking proficiency to accurately insert, delete, or substitute genetic sequences with unparalleled precision, heralding a paradigm shift in the landscape of targeted genome engineering



The delivery challenge

Knowing where to cut is only half the battle Cas9 and its guide RNA must reach the right cells without being destroyed or triggering an immune reaction. This is one of the biggest hurdles to turning CRISPR into everyday medicine, and nanotechnology has become the leading solution.

Lipid nanoparticles: fat-based capsules that shield Cas9 and aid cellular uptake; their size,

Mesoporous silica and carbon nanotubes: offer large, customizable surfaces for loading charge, and coating are tunable for precision targeting.

Polymeric nanoparticles: biodegradable, body-friendly polymers that encapsulate and release cargo in a controlled way, influencing release speed and biocompatibility.

Gold nanoparticles and graphene oxide: improve Cas9 binding efficiency and, when fitted with targeting molecules, enable selective, cell-specific delivery.

CRISPR components and penetrating cell membranes.

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Viral vectors (AAVs, lentiviruses): highly efficient at infecting cells; AAVs offer long-term expression but face pre-existing immunity in some patients, while lentiviruses carry a small risk of disrupting other genes when they integrate into the genome. Researchers are also engineering "smart" nanoparticle surfaces cell-penetrating peptides, pH-responsive coatings, protective circulation shells, and targeting ligands and to make delivery more precise, though concerns about long-term toxicity and immune response remain active areas of research.

Medical breakthroughs

Sickle cell anemia: correcting the HBB gene mutation to restore normal hemoglobin one of CRISPR's clearest success stories, with documented applications affirming its ability to provide targeted therapy.
Inherited blindness: rectifying mutations behind retinitis pigmentosa, a cause of gradual vision loss that conventional approaches have struggled to reach.
Cystic fibrosis: targeting the faulty CFTR gene for personalized treatment tailored to each patient's specific mutation.
Cancer: combined with gene sequencing to identify saturation genome editing, systematically testing every position in a gene to separate harmless variants from dangerous ones. This is the heart of personalized medicine: using a patient's own genetic blueprint to design a therapy that fixes their exact problem, at its root, in their DNA.

Feeding the world

CRISPR is helping tackle food security by producing crop varieties rice, wheat, tomatoes with better yield, nutrition, and disease resistance, without the years of trial-and-error
What the experts are watching
traditional breeding requires. The process typically starts with a disease-susceptible elite variety, applies targeted genetic modification, and regenerates plants that keep all the traits farmers already value while adding new resilience. Still, regulations for gene-edited crops vary widely worldwide, and experts stress balancing innovation with environmental review and fair, equitable access to the technology's benefits.

Weighing the trade-offs

Strength — Precision and versatility: guide RNA targeting allows accurate edits, even across multiple genes at once.
Weakness — Off-target risk: the same targeting system can occasionally bind similar-looking, unintended sequences.
Strength — Cost-effectiveness: far cheaper than older editing tools, widely available and adopted.
Weakness — Manufacturing & immune concerns: large-scale production remains time-consuming, and Cas9 or its viral carriers can trigger immune responses.

What could go wrong

Off-target effects: Cas9 can occasionally cut similar-looking but unintended DNA sites. High-fidelity Cas9 variants and computational prediction tools help minimize this risk.
Delivery and immune concerns: Reaching the right cells, especially inside a living body, remains difficult, and viral vectors can trigger immune responses.
Ethical boundaries: germline editing changes passed to future generations demands extraordinary caution and robust oversight.
Uneven regulation: different countries apply very different rules, creating a patchwork that needs clearer global guidelines. Patient-specific mutations, disable cancer-driving genes, and engineer CAR-T immune

cells; also used in Researchers in the field offer a candid, forward-looking assessment. The ability to fix disease-causing mutations at the genetic level genuinely opens the door to personalized medicine, but translating laboratory breakthroughs into everyday clinical practice still confronts real challenges: ensuring safety and effectiveness, navigating complicated ethical questions, and building regulatory frameworks robust enough to keep pace not to mention making sure these treatments are actually affordable and accessible once they exist. Even with high-fidelity Cas9 variants and better-optimized guide RNA designs, there remains real room to improve precision further, especially for delivery inside living organisms rather than lab dishes.

What comes next

Researchers who track the field closely believe CRISPR-based therapies could become a standard, widely accepted part of clinical practice within roughly five to ten years provided delivery methods keep improving, safety testing stays rigorous, and the ethical and regulatory landscape evolves responsibly alongside the science. Base and prime editing hold the promise of even more accurate genome modifications that don't rely on double-strand breaks at all, while engineers are experimenting with "smart" nanoparticles that release their CRISPR cargo only under specific conditions. The technology's reach is expected to widen well beyond human therapeutics and crop improvement, into fields like regenerative medicine, environmental conservation, and even the genetic modification of disease-carrying vectors such as mosquitoes, as part of the broader fight against infectious disease. What began as a curious defence mechanism in bacteria has become a tool capable of rewriting the biological rulebook for better crops, for new medicines, and potentially for cures once thought impossible. The scissors are sharp and the GPS is precise. The real work now, as researchers in the field are quick to point out, is making sure this extraordinary power is used carefully, fairly, and for the benefit of as many people as possible — not just the ones who can afford it first.

References

1. Aljabali, A.A.A., El-Tanani, M., and Tambuwala, M.M. 2024. Principles of CRISPR-Cas9 technology. J. Drug Deliv. Sci. Technol., 92: 105338.
2. Anzalone, A.V., Koblan, L.W., and Liu, D.R. 2020. Genome editing with CRISPR-Cas9, base editors, and prime editors. Nat. Biotechnol., 38: 824-844.
3. Doudna, J.A. 2020. The promise and challenge of therapeutic genome editing. Nature, 578: 229-236.
4. Gostimskaya, I. 2022. CRISPR-Cas9: a history of its discovery and ethical considerations of its use in genome editing. Biochemistry (Moscow), 87: 777-788.
5. Guo, C., et al. 2023. Off-target effects in CRISPR/Cas9 gene editing. Front. Bioeng. Biotechnol., 11.
6. Jaganathan, D., et al. 2018. CRISPR for crop improvement: an update review. Front. Plant Sci., 9.
7. Kanu, G.A., et al. 2022. Gold nanoparticle-mediated gene therapy. Cancers, 14.
8. Kleinstiver, B.P., et al. 2016. High-fidelity CRISPR-Cas9 nucleases with no detectable genome-wide off-target effects. Nature, 529: 490-495.
9. Kumar, D., Yadav, A., Ahmad, R., Dwivedi, U.N., and Yadav, K. 2022. CRISPR-based genome editing for nutrient enrichment in crops. Front. Genet., 13.

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10. Li, T., et al. 2023. CRISPR/Cas9 therapeutics: progress and prospects. Signal Transduct. Target. Ther., 8: 36.
11. Liu, W., et al. 2021. Applications and challenges of CRISPR/Cas gene-editing to disease treatment. Precis. Clin. Med., 4: 179-191.
12. Rao, Y., et al. 2022. Advance of CRISPR-Cas9 and its application in crop improvement. Front. Plant Sci., 13.
13. Sahel, D.K., et al. 2023. CRISPR/Cas9 genome editing for tissue-specific in vivo targeting. Adv. Sci., 10.
14. Selvakumar, S.C., et al. 2022. CRISPR/Cas9 and next generation sequencing in personalized cancer treatment. Mol. Cancer, 21: 83.
15. Shinwari, Z.K., Tanveer, F., and Khalil, A.T. 2018. Ethical issues regarding CRISPR mediated genome editing. Curr. Issues Mol. Biol., 26: 103-110.
16. Tang, H., Zhao, X., and Jiang, X. 2021. Synthetic multi-layer nanoparticles for CRISPR-Cas9 genome editing. Adv. Drug Deliv. Rev., 168: 55-78.
17. Wang, D., Tai, P.W.L., and Gao, G. 2019. Adeno-associated virus vector as a platform for gene therapy delivery. Nat. Rev. Drug Discov., 18: 358-378.
18. Wang, S.W., et al. 2022. Current applications and future perspective of CRISPR/Cas9 gene editing in cancer. Mol. Cancer, 21: 57.
19. Xu, C.L., Ruan, M.Z.C., Mahajan, V.B., and Tsang, S.H. 2019. Viral delivery systems for CRISPR. Viruses, 11.
20. Zhen, S., and Li, X. 2020. Liposomal delivery of CRISPR/Cas9. Cancer Gene Ther., 27: 515-527.