

# CRISPR-CAS

## A POWERFUL GENE-EDITING TOOL

**Panel 1:** HI!! I'M A BACTERIUM! BACTERIA ARE TINY SINGLE-CELLED ORGANISMS AND CAN BE FOUND ALMOST EVERYWHERE ON EARTH!  
*ESCHERICHIA COLI*

**Panel 2:** SOME OF US BACTERIA ARE GOOD, LIKE THOSE THAT HELP YOU DIGEST YOUR FOOD! AND OTHERS ARE NOT SO GOOD, LIKE THOSE THAT CAN MAKE YOU SICK!  
*BIFIDIO-BACTERIUM*      *STREPTOCOCCUS PYOGENES*

**Panel 3:** SOME OF US ARE A LITTLE BIT OF BOTH!

**Panel 4:** DID YOU KNOW BACTERIA CAN GET VIRUSES TOO?      I DON'T FEEL SO GOOD!

**Panel 5:** THE VIRUSES THAT ATTACK BACTERIA ARE CALLED BACTERIOPHAGES  
YOU CAN CALL US PHAGES FOR SHORT!

**Panel 6:** MOST PHAGES ATTACK ONLY A SPECIFIC TYPE OF BACTERIA  
WE ARE VERY PARTICULAR!  
HEY! GET OFF OF ME!

**Panel 7:** WE ATTACH OURSELVES TO THE BACTERIA'S SURFACE AND INJECT OUR DNA!

**Panel 8:** ONCE OUR DNA IS INSIDE THE BACTERIUM, NEW PHAGES START FORMING LIKE CRAZY!  
YEAH!  
WHOO-HOO!

**Panel 9:** LET'S GO INFECT ANOTHER ONE!  
YAHOO!  
BOOM!  
THE PHAGES CREATE A SWARM, CAUSING THE CELL TO EXPLODE WHEN THEY REACH CRITICAL MASS

**Panel 10:** LUCKY FOR THE BACTERIA, THEY HAVE DEVELOPED SOME WAYS TO DEFEND THEMSELVES...  
WARNING! INTRUDER ALERT!

**Panel 11:** GOT IT! CAS1      I'M HELPING CAS2

**Panel 12:** WANTED DEAD OR ALIVE BACTERIOPHAGE \$1,500,000,000.000 HATE TO SEE THIS DUMB

**Panel 13:** I'LL JUST PUT THIS HERE...

**Panel 14:** BETWEEN THESE REPEATED PATTERNS IT WILL BE EASY TO FIND!!  
THESE REPEATED PATTERNS ARE CALLED CRISPR  
TOGETHER IT'S CALLED A CRISPR ARRAY

**Panel 15:** **C** LUSTERED      MEANS THEY ARE FOUND TOGETHER ON THE GENOME.  
**R** EGULARLY      REFERS TO THE FACT THAT BETWEEN THESE REPEATS ARE UNIQUE PIECES OF DNA, CALLED SPACERS. THIS IS WHERE THE VIRAL DNA IS STORED!  
**I** NTERSPACED      MEANS THE SEQUENCE IS JUST 20 OR 40 BASE PAIRS LONG.  
**S** HORT      MEANS THE SEQUENCE CAN BE READ THE SAME FORWARD OR BACKWARD (LIKE THE WORD KAYAK!)  
**P** ALINDROMIC      MEANS THIS PALINDROMIC SEQUENCE IS REPEATED OVER AND OVER.  
**R** EPEATS

(IT'S ALSO WHERE THE CAS PROTEINS GET THEIR NAMES: CAS STANDS FOR CRISPR-ASSOCIATED PROTEIN)

**Panel 16:** THIS IS INHERITABLE: IF THE PHAGE ATTACKED ANY OF THE BACTERIUM'S ANCESTORS, IT WOULD BE ENCODED IN THEIR DNA AND PASSED DOWN  
THANKS GUYS!

**Panel 17:** BUT WAIT! THIS IS WHERE THE PROTEIN CAS9 COMES INTO ACTION...  
THIS GUIDE RNA CAN TAKE A COPY OF THE CRISPR ARRAY AND HELP ME SCAN THE INVADER'S DNA FOR A MATCH  
GOT IT!

**Panel 18:** IT'S A MATCH!  
COUNTERATTACK!

**Panel 19:** IF THERE IS A MATCH, CAS9 UNWINDS AND CUTS UP THE PHAGE'S DNA, DESTROYING THE VIRUS  
NOOOOOO!  
TAKE THAT!  
YEAH! TEAR IT APART!

**Panel 20:** NO VIRUSES ALLOWED!

**Panel 21:** SCIENTISTS HAVE FOUND A WAY TO USE THE CRISPR-CAS "FIND AND CUT" MECHANISM TO BOTH STUDY AND EDIT THE GENES IN OTHER ORGANISMS BESIDES BACTERIA--INCLUDING PLANTS, ANIMALS, AND EVEN HUMANS!

**Panel 22:** GOT A NEW JOB FOR YA, CAS9!  
NO PROBLEM  
THEY INSERT A SPECIFIC PIECE OF GUIDE RNA CREATED IN THE LAB, WHICH TELLS THE CAS9 PROTEIN WHERE TO CUT THE ORGANISM'S DNA.

**Panel 23:** THE CELL REPAIRS THE BROKEN DNA - BUT WITH ERRORS - AND WHOLE DNA SECTIONS THEN NO LONGER MAKE SENSE

**Panel 24:** ALTERNATIVELY, SCIENTISTS CAN ALSO INSERT A NEW HEALTHY PIECE OF DNA AT THE CUT SITE, REPAIRING IT. THIS CAN HELP TREAT DISEASES, IN PARTICULAR THOSE CAUSED BY INHERITED GENE VARIANTS.

### CURRENT USES:

CRISPR IS INVOLVED IN MANY DIFFERENT **FOOD PRODUCTION** STAGES, FROM SPECIALIZED CROPS, TO CELL-BASED MEATS, TO MODIFIED YOGHURT CULTURES.

IT HAS BEEN USED IN THE **BIOMEDICAL FIELD** TO COMBAT HEREDITABLE GENETIC DISEASES SUCH AS SICKLE-CELL ANEMIA AND BETA-THALASSEMIA, AND IN TREATING RETINAL DISEASES.

### FUTURE USES:

THERE IS A GREAT POSSIBILITY IN THE FUTURE TO FIND CURES AND TREATMENTS FOR MANY DIFFERENT DISEASES, IMPROVED TRANSPLANT METHODS, AND SMARTER T-CELLS.

CRISPR COULD BE USED AS A DIAGNOSTIC TOOL TO PREVENT THE SPREAD OF INFECTIOUS OUTBREAKS OR TREAT CHRONIC INFECTIONS.

CRISPR CAN BE USED TO ENGINEER CROPS AND LIVESTOCK THAT CAN WITHSTAND EXTREME WEATHER CONDITIONS, AND TO ELIMINATE PESTS AND WEEDS WITHOUT HARMFUL CHEMICALS.

IT COULD BE USED TO ENGINEER SUPERFOODS SUCH AS NUTS WITHOUT ALLERGENS, OILS WITH LESS TRANS-FAT, VEGETABLES WITH EXTRA VITAMINS, AND WHEAT WITH GLUTEN THAT CAN BE EASILY TOLERATED.

CRISPR COULD BE USED IN ANIMAL AND ENVIRONMENTAL CONSERVATION. FOR EXAMPLE, IN DETERMINING WHICH GENES ARE VITAL TO CORAL REEF SURVIVAL, GETTING RID OF INVASIVE SPECIES FROM NATIVE HABITATS, AND THE MANUFACTURE OF ENHANCED BIOFUELS.

### ETHICAL CONCERNS:

THERE ARE A LOT OF ETHICAL CONCERNS WHEN DISCUSSING THE USE OF CRISPR:

- WHO HAS THE RIGHT TO DECIDE WHICH SPECIES CAN BE ELIMINATED AND WHERE DOES THAT END?
- EDITING THE HUMAN GERMLINE, I.E., CREATING "DESIGNER BABIES" IS HIGHLY UNETHICAL AS IT COULD CREATE A GREAT DISBALANCE IN HUMAN EQUALITY AND THE DEFINITION OF WHAT MAKES ONE HUMAN COULD BE PUT FORTH FOR DEBATE.
- SOME GENE EDITS COULD SOLVE ONE PROBLEM WHILE CREATING ANOTHER: COULD IT BACKFIRE AND CREATE SUPERBUGS, OVERPOPULATION, OR DISRUPT THE FOOD CHAIN?