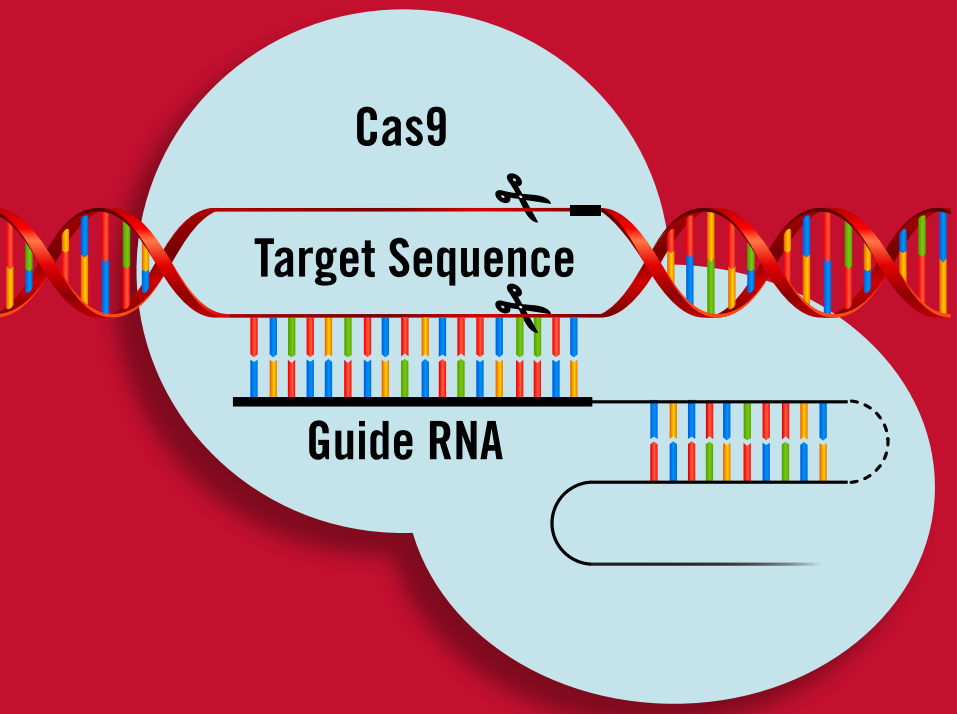
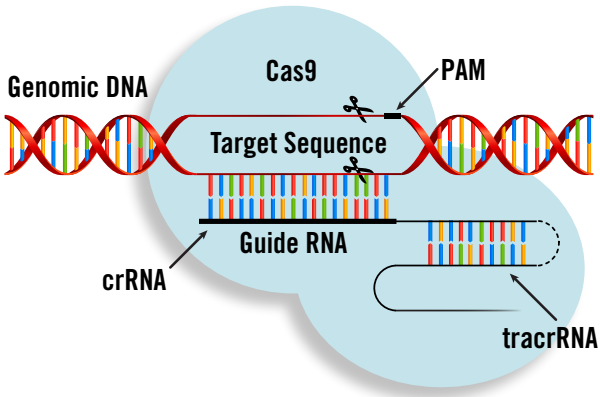
Mirus mirusbio.com

GENOME EDITING: CRISPR/CAS9 DELIVERY METHODS



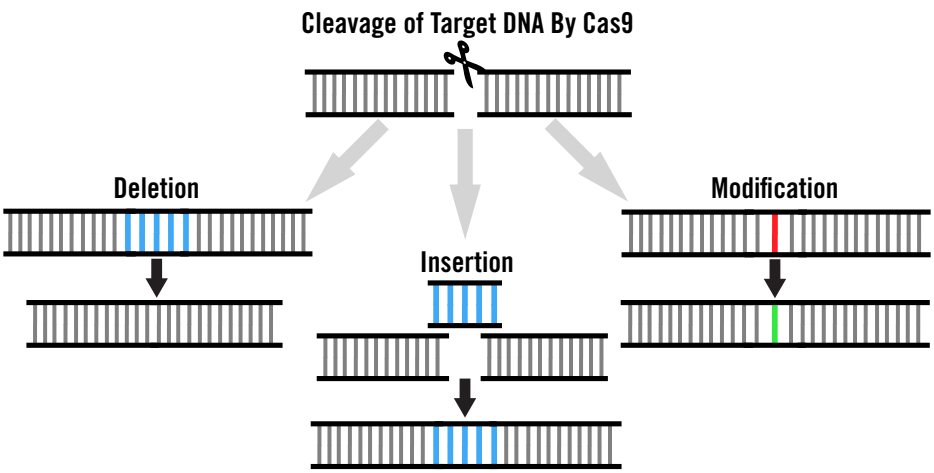
What is CRISPR/Cas9 Genome Editing?

The CRISPR/Cas9 system is a powerful tool for genome editing in mammalian cells that allows researchers to generate genetic variants at lower cost and with higher throughput than alternative methods like zinc finger nuclease (ZFN) or transcription activator-like effector nuclease (TALEN) genome editing.



The CRISPR/Cas9 RNP Complex. The CRISPR associated protein 9 (Cas9) endonuclease (blue) is targeted to DNA by a guide RNA (gRNA), which can be supplied as a two-part system consisting of CRISPR RNA (crRNA) and trans-activating crRNA (tracrRNA) or as a single guide RNA (sgRNA), where the crRNA and tracrRNA are connected by a linker (dotted line). Target recognition is facilitated by the protospacer-adjacent motif (PAM). A double strand break (DSB) occurs 3 bp upstream of the PAM.

CRISPR Facilitates Multiple Types of Genome Modification

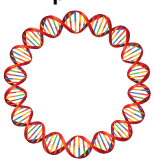
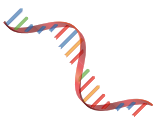


Multiple Genomic Alterations are Possible Following Cleavage of Target DNA by Cas9. Variable length insertions and/or deletions (indels) can result near the DNA break due to mistakes in DNA repair by the endogenous non-homologous end joining (NHEJ) pathway. These indels frequently result in disruption of gene function. Alternatively, by supplying a DNA repair template, researchers can leverage the homology-directed repair (HDR) pathway to create defined deletions, insertions or other modifications.

Glossary of CRISPR Terms

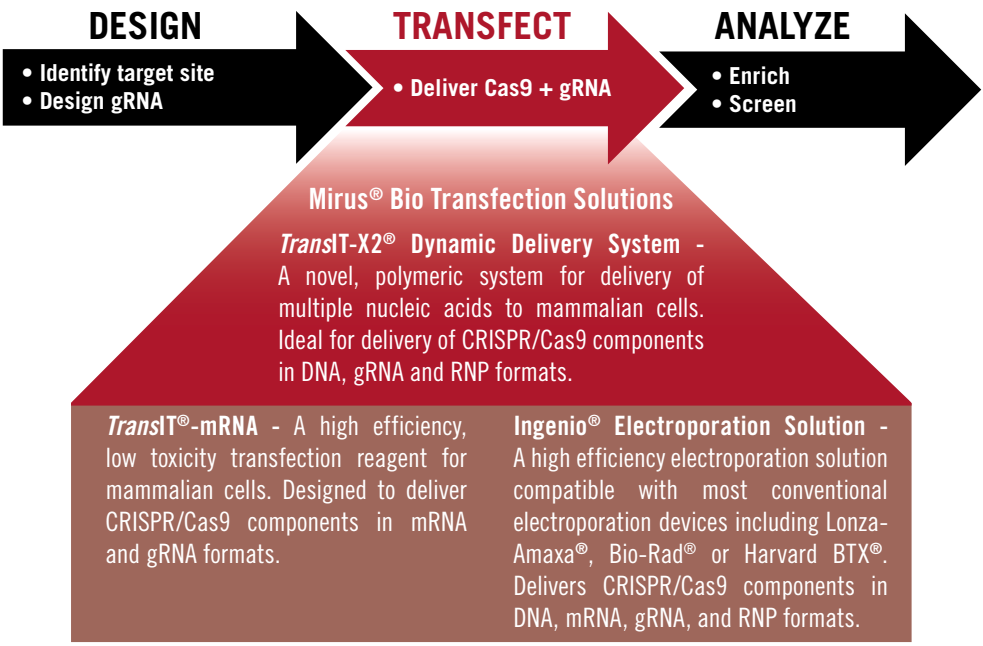
Term	Definition
Cas9	**C**RISPR **As**sociated Protein **9** - Cas9 is an RNA-guided DNA endonuclease from the type II CRISPR system of *Streptococcus pyogenes* that has been adapted for use in genome editing applications.
CRISPR	**C**lustered **R**egularly **I**nterspaced **S**hort **P**alindromic **R**epeats - CRISPR refers to prokaryotic DNA elements involved in adaptive immunity which are characterized by clusters of identical repeats interspaced with non-identical segments called spacers. CRISPR has evolved to refer more generally to the use of Cas9 for genome editing.
crRNA	**CR**ISPR **RNA** - One of two RNAs required to form a functional gRNA. The crRNA contains the sequence complementary to the DNA target and a segment of RNA that base pairs with the tracrRNA.
DSB	**D**ouble **S**trand **B**reaks result from endonucleolytic cleavage of both strands of DNA. This can be achieved through the use of wild type Cas9 or by employing two Cas9 nickases targeting opposite DNA strands.
gRNA	**G**uide **RNA**s bind to Cas9 and direct the complex to a specific genomic location. Naturally occurring guide RNAs consist of two parts: a CRISPR RNA (crRNA) and a trans-activating crRNA (tracrRNA). Alternatively, the crRNA and tracrRNA can be combined into a single chimeric oligonucleotide called a single guide RNA (sgRNA).
HDR	**H**omology **D**irected **R**epair is a mechanism of DNA repair that uses a homologous DNA template to rebuild sites of genomic damage. HDR can be leveraged in genome editing experiments to make precise genomic alterations by supplying the desired sequence for insertion flanked by segments of DNA that are homologous to the sequence surrounding the Cas9-induced DSB.
indel	(**In**sertion/**Del**etion) Following creation of a DSB by Cas9, the cell initiates DNA damage repair. Repair by the error-prone NHEJ pathway can result in small insertions and/or deletions at the site of cleavage. These indels can cause frameshift mutations or premature stop codons resulting in a genetic knock-out.
Mismatch Assay	A method for detection of indel mutations following Cas9 cleavage. Targeted genomic DNA is amplified by PCR. The PCR products are melted and reannealed to allow heteroduplexes to form between wild-type and mutant DNA. The hybridized products are then incubated with an enzyme that cleaves heteroduplexes but not perfectly matched DNA. The resulting DNA fragments are analyzed by electrophoresis to determine the percentage of cleavage events that results from indel formation.
NHEJ	**N**on-**H**omologous **E**nd-**J**oining is the predominant DNA DSB repair mechanism in mammalian cells. Unlike HDR, NHEJ directly ligates the ends of the DSB and does not require a homologous repair template. Researchers capitalize on the error-prone nature of NHEJ to create indels following targeted cleavage with Cas9.
PAM	**P**rotospacer-**A**djacent **M**otif - In the naturally occurring prokaryotic CRISPR/Cas system, the DNA sequences recognized by gRNA are called protospacers. The PAM is a short sequence next to the target site that is required for Cas9 targeting both in prokaryotic adaptive immunity and in mammalian genome editing experiments.
sgRNA	**S**ingle **G**uide **RNA**, a chimeric RNA composed of crRNA and tracrRNA, connected by a short RNA linker.
Target Sequence	A 20 nucleotide genomic DNA sequence which base-pairs with gRNA and is cleaved by Cas9.
tracrRNA	**Tr**ans-**A**ctivating **crRNA**, one of two RNAs required to form a functional gRNA. The tracrRNA forms base pairs with the crRNA and is required for Cas9-mediated target cleavage.

Comparison of Cas9 Formats: DNA, RNA and Protein

	pDNA	mRNA	Protein
			
High Efficiency	++++	++++	++++
Low Cost	++++	++++	+++
Specificity	++++	++++	++++

Pros and Cons of DNA, RNA and Protein Formats for Genomic Editing. Cas9 can be delivered as plasmid DNA for a simple, low-cost approach. Cas9 mRNA enables rapid gene expression and eliminates the risk of insertional mutagenesis. Cas9/guide RNA ribonucleoprotein (RNP) complexes exhibit the most rapid pulse of genome editing activity and reduce the possibility of off-target cleavage events. Cas9 mRNA and RNP formats present an alternative strategy to cell types that are resistant to transfection with plasmid DNA.

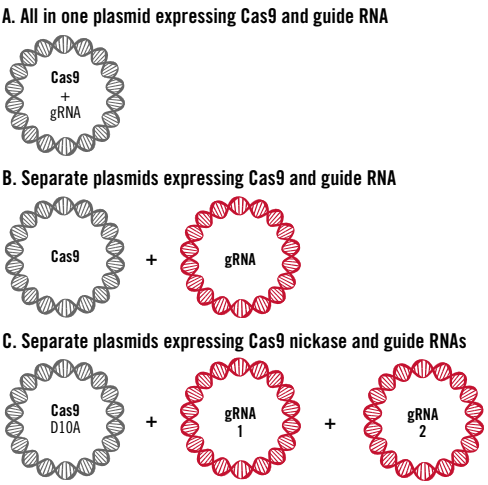
CRISPR Gene Editing Workflow



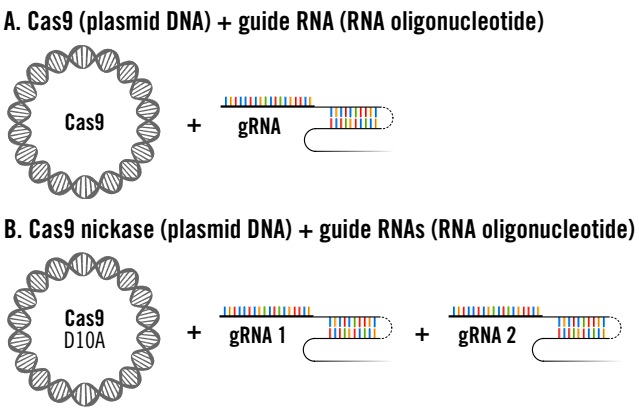
Plasmid DNA and Guide RNA Oligonucleotide Transfection

Cas9 protein and guide RNA can be encoded by plasmid DNA for transfection. Alternatively, Cas9 can be delivered as plasmid DNA, and guide RNA can be supplied as an RNA oligonucleotide. Benefits of these approaches include:

- **Low Cost** - Plasmid DNA is a renewable, cost-effective format
- **Flexibility** - Cas9 and guide RNA plasmids are suitable for stable or transient transfection
- **Ease-of-use** - Guide RNA oligonucleotide format enables simple retargeting of Cas9 to different loci

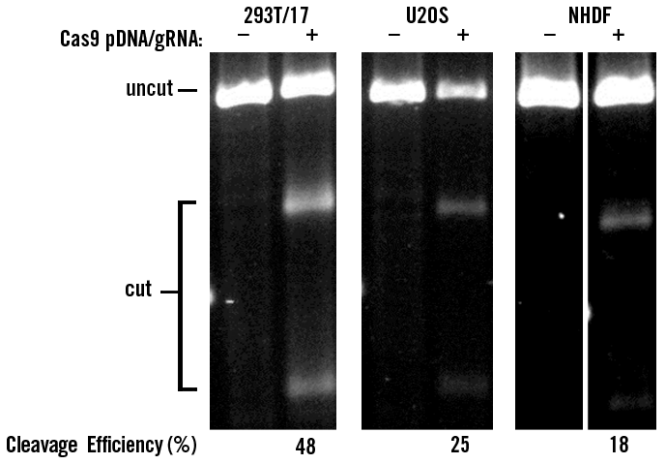


Cas9 + Guide RNA Plasmids. (A) Cas9 and guide RNA are encoded on the same plasmid. (B,C) Cas9 and guide RNA(s) are encoded on separate plasmids. (A,B) The wild-type Cas9 enzyme contains two endonuclease domains which cleave the target DNA on both strands when programmed with a guide RNA. (C) The D10A mutation converts Cas9 to a nickase that generates single-stranded breaks in the target DNA. For improved target specificity, Cas9 D10A can be used with paired guide RNAs targeting opposite strands to create staggered double-stranded breaks.



Cas9 Plasmid + Guide RNA Oligonucleotides. Cas9 is supplied as plasmid DNA, and guide RNA(s) are supplied as either synthetic or *in vitro* transcribed RNA oligonucleotides. (A) The wild-type Cas9 enzyme contains two endonuclease domains which cleave the target DNA on both strands when programmed with a guide RNA. (B) The D10A mutation converts Cas9 to a nickase that generates single-stranded breaks in the target DNA. For improved target specificity, Cas9 D10A can be used with paired guide RNAs targeting opposite strands to create staggered double-stranded breaks.

Plasmid DNA and Guide RNA Oligonucleotide Transfection



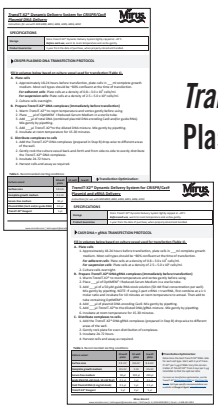
Efficient Genome Editing with Cas9 Plasmid DNA + Guide RNA Oligonucleotides. HEK293T/17, U2OS and NHDF cells were co-transfected with 0.5 µg of Cas9 encoding pDNA (MilliporeSigma) and 50nM PPIB targeting two-part gRNA (Dharmacon) using *Trans*IT-X2® Dynamic Delivery System (2 µl/well of a 24-well plate, Mirus Bio). A T7E1 mismatch detection assay was used to measure cleavage efficiency at 48 hours post-transfection.

TransIT® Certified Transfection

I was recently tasked with developing a CRISPR protocol for primary and bone-derived cell lines. *Trans*IT-X2® was simple to use, 2-3 times better for transfection and much gentler on my cells than other products! I feel I have hit the jackpot and have already passed this exciting information on to my colleagues.

Joshua Chou, Ph.D.
Harvard School of Dental Medicine

CRISPR Transfection Protocols Available Online



*Trans*IT-X2® Dynamic Delivery System for CRISPR/Cas9 Plasmid Delivery: mirusbio.com/CRISPRpDNA

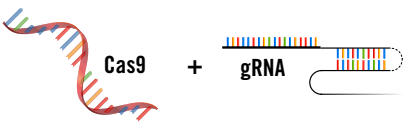
*Trans*IT-X2® Dynamic Delivery System for CRISPR/Cas9 Plasmid and gRNA Delivery: mirusbio.com/CRISPRgRNA

mRNA and Guide RNA Oligonucleotide Transfection

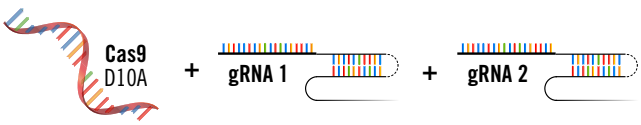
In order to avoid off-target cleavage and unwanted genomic integration of plasmid DNA, Cas9-encoding mRNA can be co-transfected with guide RNA oligonucleotides. Benefits of RNA-based genome editing include:

- **High Specificity** - Rapid gene expression generates a transient pulse of genome editing activity
- **Ease-of-use** - Deliver mRNA and guide RNA with a single reagent
- **DNA Free** - No risk of insertional mutagenesis

A. Cas9 (mRNA) + guide RNA (RNA oligonucleotide)

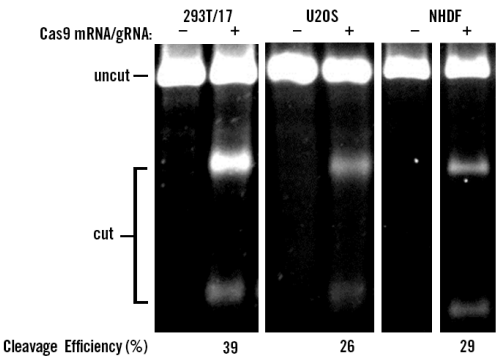


B. Cas9 nickase (mRNA) + guide RNAs (RNA oligonucleotide)

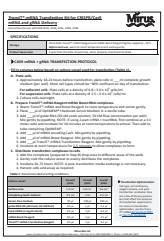


Cas9 mRNA + Guide RNA Oligonucleotides. Cas9 is supplied as messenger RNA, and guide RNAs are supplied as either synthetic or *in vitro* transcribed RNA oligonucleotides. (A) The wild-type Cas9 enzyme contains two endonuclease domains which cleave the target DNA on both strands when programmed with a guide RNA. (B) The D10A mutation converts Cas9 to a nickase that generates single-stranded breaks in the target DNA. For improved target specificity, Cas9 D10A can be used with paired guide RNAs targeting opposite strands to create staggered double-stranded breaks.

Efficient Genome Editing with Cas9 mRNA + Guide RNA Oligonucleotides. HEK293T/17, U2OS and NHDF cells were co-transfected with 0.5 µg of Cas9 encoding mRNA, 5meC, (Trilink Biotechnologies) and 25nM of PPIB targeting two-part gRNA (Dharmacon) using *Trans*IT®-mRNA Transfection Kit (0.5 µl/well of 24-well plate of both mRNA Reagent and Boost, Mirus Bio). A T7E1 mismatch detection assay was used to measure cleavage efficiency at 48 hours post-transfection.



DNA-Free Transfection Protocol Available Online

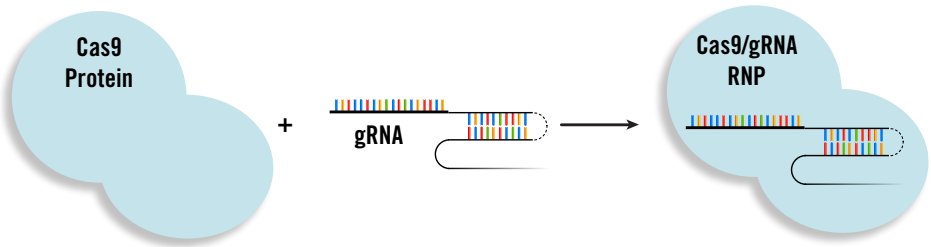


***Trans*IT®-mRNA Transfection Kit for CRISPR/Cas9 mRNA and gRNA Delivery: mirusbio.com/CRISPRmRNA**

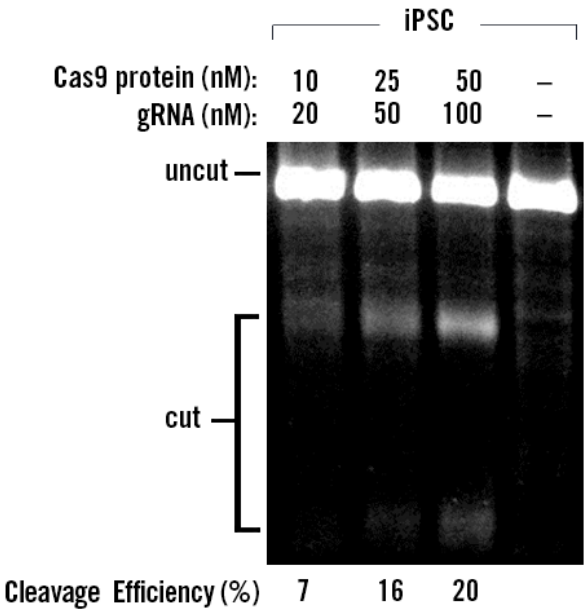
Cas9/gRNA Ribonucleoprotein (RNP) Transfection

Purified Cas9 protein can be combined with guide RNA to form an RNP complex to be delivered to cells for rapid and highly efficient genome editing. Benefits of RNP-based genome editing include:

- **High Efficiency Delivery** - Deliver Cas9/gRNA complexes to multiple cell types, including hard to transfect cells such as immune and stem cells
- **High Specificity** - Pre-formed RNP complexes provide a rapid pulse of genome editing activity
- **DNA Free** - No risk of insertional mutagenesis

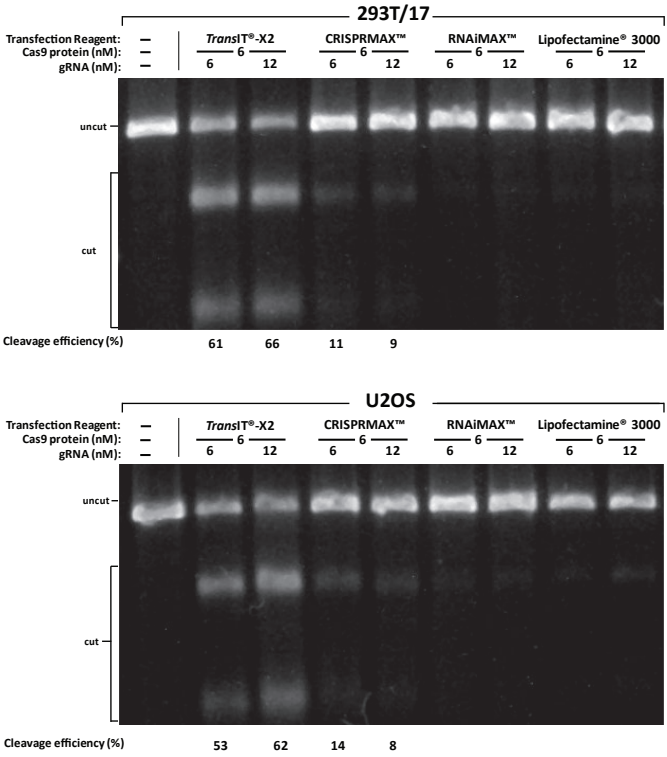


Cas9 RNP. Purified Cas9 protein and guide RNA oligonucleotides are combined to form a ribonucleoprotein (RNP) complex.



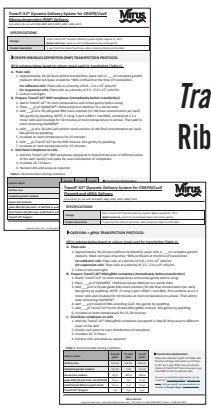
Genome Editing in iPS Cells with Cas9 + Guide RNA Ribonucleoprotein Complexes. *Trans*IT-X2® Dynamic Delivery System was used to deliver Cas9 protein/guide RNA ribonucleoprotein (RNP) complexes into human induced pluripotent stem cells (iPSCs). A T7E1 mismatch assay was used to measure cleavage efficiency at 48 hours post-transfection.

Cas9/gRNA Ribonucleoprotein (RNP) Chemical Transfection



***Trans*IT-X2® Outperforms Lipofectamine® for RNP Delivery.** Ribonucleoprotein (RNP) complexes were delivered into HEK293T/17 and U2OS cells using *Trans*IT-X2® Dynamic Delivery System (1 µl/well, Mirus Bio) or Lipofectamine® CRISPRMAX™ (1.5 µl/well and 1 µl/well of Lipofectamine® Cas9 Plus™ Reagent, ThermoFisher) or Lipofectamine® RNAiMAX (1.5 µl/well, ThermoFisher) or Lipofectamine® 3000 (1.5 µl/well and 1 µl/well of P3000™ Reagent, ThermoFisher) in a 24-well format according to the manufacturers' protocol. Varying levels of gRNA (6 nM or 12 nM) were tested with 6 nM Cas9 protein (PNA Bio). A T7E1 mismatch detection assay was used to measure cleavage efficiency at 48 hours post-transfection.

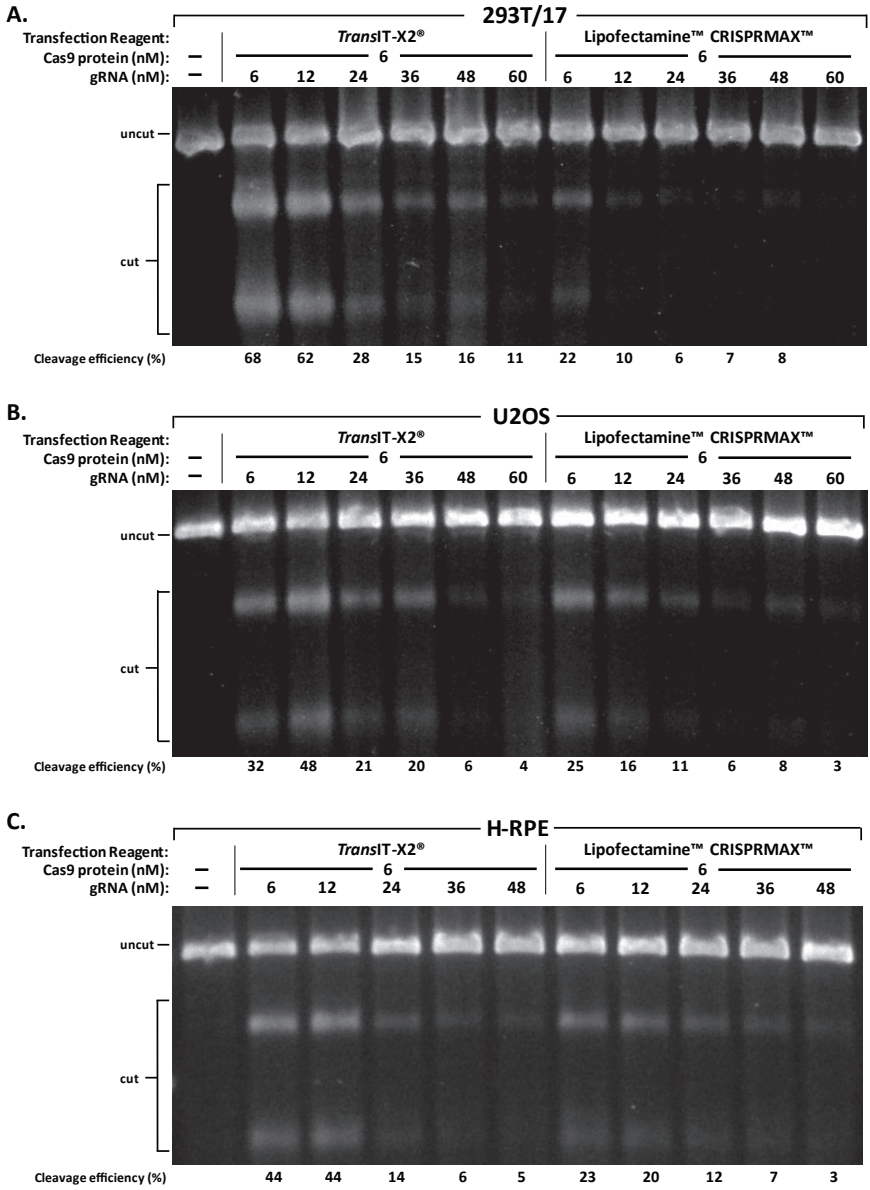
RNP Transfection Protocols Available Online



***Trans*IT-X2® Dynamic Delivery System for CRISPR/Cas9 Ribonucleoprotein (RNP) Delivery: mirusbio.com/CRISPRX2RNP**

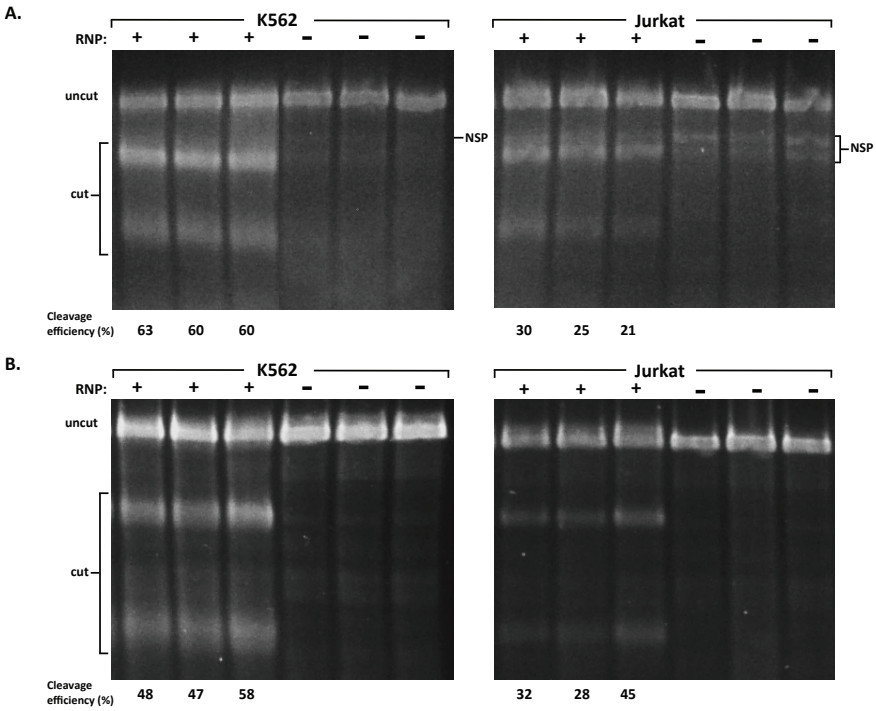
***Trans*IT-X2® Dynamic Delivery System for CRISPR/Cas9 Ribonucleoprotein (RNP) + DNA Oligo (ssODN) Delivery: mirusbio.com/CRISPRoligo**

Cas9/gRNA Ribonucleoprotein (RNP) Chemical Transfection



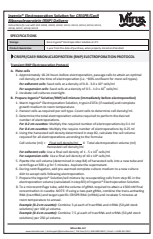
***Trans*IT-X2® Outperforms Lipofectamine® CRISPRMAX™ for RNP Delivery.** Ribonucleoprotein (RNP) complexes composed of PPIB targeting 2-part gRNA (IDT) and Cas9 protein (PNA Bio) were delivered into HEK293T/17 **(A)**, U2OS **(B)**, and primary H-RPE **(C)** cells using *Trans*IT-X2® Dynamic Delivery System (1 µl/well, Mirus Bio) or Lipofectamine® CRISPRMAX™ (1.5 µl/well and 1 µl/well of Lipofectamine® Cas9 Plus™ Reagent, ThermoFisher) in a 24-well format according to the manufacturers' protocol. Varying levels of gRNA (6 nM – 60 nM) were tested with 6 nM Cas9 protein. A T7E1 mismatch detection assay was used to measure cleavage efficiency at 48 hours post-transfection.

Cas9/gRNA Ribonucleoprotein (RNP) Electroporation



Efficient CRISPR RNP Delivery with Ingenio® Electroporation Solution. Ribonucleoprotein (RNP) complexes targeting **(A)** PPIB or **(B)** WTAP were electroporated into K562 and Jurkat cells. The RNP complex, composed of 750 nM Cas9 protein (EnGen® Cas9 NLS, New England Biolabs) and 1500 nM pre-complexed two-part gRNA (IDT), was electroporated using the Ingenio® Electroporation Solution (Mirus Bio) and a Gene Pulser Xcell™ Eukaryotic System (Bio-Rad® Laboratories). Exponential pulse conditions of 130V **(A)** & 150V **(B)**, 950 µF for K562 and 150V, 950 µF for Jurkat cells were applied to triplicate 0.2 cm cuvettes, 100 µl volume, 10 x 106 cells/ml +/- RNP complex. A T7E1 mismatch assay was used to measure cleavage efficiency at 48 hours post-transfection. Non-specific bands (NSP) were observed in the negative control of both cell lines. Cleavage efficiency was calculated based on the ratio of cleaved band intensities to the sum of cleaved and uncleaved band intensities minus the average signal of the non-specific band(s) in negative control lanes.

RNP Electroporation Protocol Available Online



Ingenio® Electroporation System for CRISPR/Cas9 Ribonucleoprotein (RNP) Delivery:
mirusbio.com/CRISPRelectroporation

Product List

PRODUCT	DESCRIPTION	PRODUCT NO.	QUANTITY
*Trans*IT-X2® Dynamic Delivery System 	A novel, polymeric system for delivery of multiple nucleic acids to mammalian cells. Delivers CRISPR/Cas9 components in the following formats: • **DNA** -Deliver plasmid DNA expressing Cas9 or guide RNA • **Guide RNA** -Deliver gRNA oligonucleotides targeting your gene of interest • **RNP** -Deliver Cas/gRNA ribonucleoprotein complexes	MIR 6003	0.3 ml
		MIR 6004	0.75 ml
		MIR 6000	1.5 ml
		MIR 6005	5 x 1.5 ml
		MIR 6006	10 x 1.5 ml
*Trans*IT®-mRNA Transfection Kit 	A high efficiency, low toxicity transfection reagent for mammalian cells. Delivers CRISPR/Cas9 components in the following formats: • **mRNA** -Deliver messenger RNA expressing Cas9 • **Guide RNA** -Deliver gRNA oligonucleotides targeting your gene of interest	MIR 2225	0.4 ml
		MIR 2250	1 ml
		MIR 2255	5 x 1 ml
		MIR 2256	10 x 1 ml
Ingenio® Electroporation Solution 	A high efficiency electroporation solution compatible with most conventional electroporation devices including Lonza-Amaxa®, Bio-Rad® or Harvard BTX®. Delivers CRISPR/Cas9 components in the following formats: • **DNA** -Deliver plasmid DNA expressing Cas9 or guide RNA • **mRNA** -Deliver messenger RNA expressing Cas9 • **Guide RNA** -Deliver gRNA oligonucleotides targeting your gene of interest • **RNP** -Deliver Cas9/gRNA ribonucleoprotein complexes	Ingenio® Electroporation Kits for Amaxa Nucleofactor® II/2b Device (solution, 0.2 cm cuvettes, cell droppers)	
		MIR 50112	25 RXN
		MIR 50115	50 RXN
		MIR 50118	100 RXN
		Ingenio® Electroporation Kits for other devices, such as Bio-Rad® or Harvard-BTX® (solution, 0.4 cm cuvettes, cell droppers)	
		MIR 50113	25 RXN
		MIR 50116	50 RXN
		MIR 50119	100 RXN
		Ingenio® Electroporation Solution	
		MIR 50111	25 RXN (6.25 ml)
		MIR 50114	50 RXN (12.5 ml)
		MIR 50117	100 RXN (25 ml)

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