

[DESCRIPTION]

[Title of Invention] NOVEL NUCLEASE DOMAIN AND USE THEREOF

[Technical Field]

5 The present invention relates to a novel nuclease domain and an artificial nucleic acid-cleaving enzyme containing the nuclease domain.

[Background Art]

10 In recent years, as a genome editing tool, nucleases that specifically recognize a target sequence and can cleave in the vicinity thereof have become available, such as zinc-finger nuclease (ZFN), transcription activator-like effector nuclease (TALEN), and CRISPR/Cas (clustered regularly interspaced short palindromic repeat/CRISPR-associated) system. These nucleases
15 include a nucleic acid-binding domain and a nucleic acid-cleaving domain, and can result in a DNA double-strand break (DSB) at a specific base sequence of genomic DNA. As the repair of DSB brought about by these nucleases, non-homologous end joining (NHEJ) and
20 homologous recombination (HR), which are prone to repair errors, are known. When repairing DSB, cells mainly use the NHEJ pathway for repair, so that repair errors are likely to occur, frame shifts occur, and as a result, gene function is lost. In this way, genome editing technology
25 that can perform gene disruption and the like using the mechanism possessed by cells is being widely used in life

science such as disease research and application to agricultural products.

In a ZFN and a TALEN, a FokI nuclease domain (hereinafter also referred to as "FokI-ND") is usually used as a nucleic acid-cleaving domain. The FokI-ND has been shown to have the ability to bind to nucleic acids, but does not recognize the base sequence and cleaves the target nucleic acid by forming a dimer. Therefore, a ZFN and a TALEN require two target sequences of nucleic acid-binding domain, and FokI-ND acts in the spacer sequence sandwiched between the two target sequences to bring about DSB. In a ZFN, the two target sequences are referred to as a target half-site L and a target half-site R.

A ZFN is composed of a FokI-ND, a nucleic acid-binding domain made up of zinc-finger protein (ZFP), and an intermolecular linker connecting them. In a ZFN, there are strong restrictions due to the length of the spacer sequence and the properties of the linker, and it is necessary to devise the design. Therefore, as a technique related to ZFNs, modification of the length of the spacer sequence and the linker has been reported (NPL 1).

In addition, a fusion protein of a nucleic acid-binding domain such as TALE and a nuclease domain derived from *Clostridium spec.* 7_2_43 FAA strain has been

reported (PTL 1).

[Citation List]

[Patent Literature]

[PTL 1] U.S. Patent No. 9410134

5 [Non Patent Literature]

[NPL 1] Handel, E. M., Alwin, S. and Cathomen, T. (2009)

Expanding or restricting the target site repertoire of
zinc-finger nucleases: the inter-domain linker as a major
determinant of target site selectivity. Mol Ther, 17,
104-111

[Summary of Invention]

[Technical Problem]

An object of the present invention is to provide a
novel nuclease domain having high cleavage activity and
cleavage efficiency as well as fewer restrictions due to
a target sequence, spacer sequence, linker sequence, and
the like, and an artificial nucleic acid-cleaving enzyme
containing the nuclease domain.

[Solution to Problem]

20 The present inventors searched for a nuclease domain
different from FokI-ND, which is currently used as a
standard nucleic acid-cleaving domain for genome editing
enzymes, and have found as a result a novel nuclease domain
that surpasses the existing FokI-ND in functionality such
as cleavage activity, specificity, cytotoxicity, and
25 target sequence selectivity. Thus, the present invention

has been completed.

That is, the present invention provides the following aspects.

(1) An artificial nucleic acid-cleaving enzyme
5 comprising:

a nuclease domain which is a polypeptide containing an amino acid sequence set forth at positions 391 to 585 of SEQ ID NO: 1 or positions 389 to 579 of SEQ ID NO: 3, or a mutant polypeptide thereof; and

10 a nucleic acid-binding domain.

(2) The artificial nucleic acid-cleaving enzyme according to (1) above, further comprising: a linker located between the nuclease domain and the nucleic acid-binding domain.

(3) The artificial nucleic acid-cleaving enzyme according
15 to (1) or (2) above, wherein the nucleic acid-binding domain contains a zinc finger, TALE, CRISPR/Cas, or PPR.

(4) An isolated nucleic acid comprising: a nucleic acid sequence encoding the artificial nucleic acid-cleaving enzyme according to any one of (1) to (3) above.

20 (5) A vector comprising: the nucleic acid according to (4) above, or a transcription product or translation product thereof.

(6) A method for modifying a target nucleic acid, comprising: introducing into a cell the artificial nucleic
25 acid-cleaving enzyme according to any one of (1) to (3) above, the nucleic acid according to (4) above, or the

vector according to (5) above.

(7) The method according to (6) above, wherein the artificial nucleic acid-cleaving enzyme, nucleic acid, or vector is two or more kinds of artificial nucleic acid-cleaving enzymes, a nucleic acid encoding the two or more kinds of artificial nucleic acid-cleaving enzymes, or a vector containing the nucleic acid, a transcription product thereof, or a translation product thereof.

(8) A kit for modifying a target nucleic acid, comprising: the artificial nucleic acid-cleaving enzyme according to any one of (1) to (3) above, the nucleic acid according to (4) above, or the vector according to (5) above.

(9) The kit according to (8) above, wherein the artificial nucleic acid-cleaving enzyme, nucleic acid, or vector is two or more kinds of artificial nucleic acid-cleaving enzymes, a nucleic acid encoding the two or more kinds of artificial nucleic acid-cleaving enzymes, or a vector containing the nucleic acid, a transcription product thereof, or a translation product thereof.

(10) A polypeptide containing an amino acid sequence set forth at positions 391 to 585 of SEQ ID NO: 1 or positions 389 to 579 of SEQ ID NO: 3, or a mutant polypeptide thereof.

(11) An isolated nucleic acid comprising: a nucleic acid sequence encoding the polypeptide or the mutant polypeptide thereof according to (10) above.

(12) A vector comprising: the nucleic acid according to

(11) above, or a transcription product thereof, or a translation product thereof.

[Advantageous Effects of Invention]

The nuclease domain according to the present invention provides a nucleic acid cleaving action superior to the conventional FokI-ND in terms of functionality such as cleavage activity, specificity, and target sequence selectivity. By binding the nuclease domain of the present invention to a nucleic acid-binding domain, a nucleic acid-cleaving enzyme having high activity and flexibility in the target sequence is provided, which specifically cleaves the target sequence. Such a nucleic acid-cleaving enzyme is very useful as a genome editing tool.

[Brief Description of Drawings]

[Fig. 1A] Fig. 1A is a schematic diagram of ZFA36-ND. The upper part shows that the two ZFN target sites are separated by a spacer sequence. The lower part shows that the ZFNs each contain three zinc finger molecules, a short 7-amino acid TGAAARA linker, and a FokI nuclease domain. When a pair of ZFNs binds to a target half site separated by a spacer sequence of a given length, the nuclease domain is dimerized and the nucleic acid can be cleaved.

[Fig. 1B] Fig. 1B shows an amino acid sequence alignment of the FokI nuclease domain homolog. Amino acid sequences were aligned using MAFFT. The amino acids that define the

heterodimer nuclease domain and the corresponding point mutations are indicated by arrows, asterisks, and colons. In the figure, "Fok1" means FokI-ND.

[Fig. 1C] Fig. 1C shows the results of cell activity by the HEK293T cell-based SSA assay performed in Example 2. The data are shown as mean $\pm$ SEM (n = 3), where + and - indicate the presence or absence of the zinc finger target sequence reporter plasmid.

[Fig. 2A] Fig. 2A shows the cleavage activity of a nuclease domain against a target genome. CHO-K1 cells transfected with ZFA36-ND were incubated at 37°C and harvested after 72 hours to prepare a genomic DNA template. The PCR product containing the ZFA36 target site was cleaved by GeneArt Genomic Cleavage Detection Kit. Cleaved fragments were analyzed by electrophoresis (MultiNA System). The cleavage efficiency was calculated from the molar concentrations of uncut bands and larger cleaved fragments. In the figure, "FokI" means FokI-ND.

[Fig. 2B] Fig. 2B shows the results of the cleavage activity test for the target genome of the nuclease domain performed in Example 3 in terms of cleavage efficiency.

[Fig. 3] Fig. 3 shows the results of Western blot analysis showing the expression level of ZFA36-ND. AcV5 tag-ZFA36-ND was expressed by HEK293T cells. Transfected cells were harvested after 72 hours, and cell lysates were probed with antibodies against both AcV5 tag and α -tubulin.

In the figure, "FokI" means FokI-ND.

[Fig. 4] Fig. 4 shows LSM images of ZFA36-ND-EGFP in HEK293T cells, and a photomicrograph of ZFA36-ND-EGFP overexpressing cells. DNA was visualized by DAPI staining. Scale bar: 40 μ m. In the figure, "FokI" means FokI-ND.

[Fig. 5] Fig. 5 shows reporter activity profiles of ZFA36-ND linker mutants at different spacer lengths, and shows the results of the SSA reporter assay performed in Example 5. ZFN linker mutants and spacer lengths are shown as 6 bp (A), 5 bp (B), and 7 bp (C). The data are normalized to the luciferase activity of FokI's TGAAARA-linker with a 6bp spacer length. The data are shown as mean $\pm$ SEM (n = 3). In the figure, "FokI" means FokI-ND.

[Fig. 6] Fig. 6 shows a reporter activity profile of the ZFA36-ND-Sharkey mutant. In the figure, "FokI" means FokI-ND. (A) Schematic diagram of ZFN. The sequences of ND1, ND2, and Sharkey mutants corresponding to the amino acid sequence at positions 414 to 445 of FokI-ND are shown. In the figure, the amino acid number is based on the full-length amino acid of each nuclease domain. (B) The results of the SSA reporter assay performed in Example 6 are shown, where - indicates that the ZFN plasmid is absent. The data are shown as mean $\pm$ SEM (n = 3).

[Fig. 7] Fig. 7 shows nuclease activity in single use of ZFNs with heterodimer type mutations measured by a

cell-based SSA assay. HEK293T cells were co-transfected with each ZFN expression plasmid, reporter plasmid, and reference plasmid to perform a dual luciferase assay. After transfection, cells were incubated for 24 hours, lysed, and analyzed for luciferase activity. (A) hPGRN_ZFL1-6bp-hPGRN_ZFL1 reporter. (B) ZFA36-6bp-ZFA36 reporter. In the figure, "FokI" means FokI-ND.

[Fig. 8A] Fig. 8A shows analysis of homodimer and heterodimer cleavage reactions by SSA reporter assay. HEK293T cells were co-transfected with each pair of ZFN expression plasmids, reporter plasmids, and reference plasmids to perform a dual luciferase assay. After transfection, cells were incubated for 24 hours, lysed, and analyzed for luciferase activity. The data are shown as mean $\pm$ SEM (n = 3). In the figure, "FokI" means FokI-ND.

[Fig. 8B] Fig. 8B shows analysis of homodimer and heterodimer cleavage reactions by the Cel-I assay. CHO-K1 cells transfected with each ZFN plasmid were incubated at 37°C for 72 hours. Genomic DNA was then prepared from the transfected cells to amplify the fragments containing the ZFA36-ZFL1 target site. The PCR product was cleaved with GeneArt Genomic Cleavage Detection Kit. The cleaved fragments were analyzed by agarose gel electrophoresis. In the figure, "FokI" means FokI-ND.

[Fig. 9] Fig. 9 shows the nuclease activity of hybrid ZFNs as measured by a cell-based SSA assay. A HEK293T cell-based SSA assay. HEK293T cells were co-transfected with each pair of ZFN expression plasmids, reporter plasmids, and reference plasmids to perform a dual luciferase assay. After transfection, cells were incubated for 24 hours, lysed, and analyzed for luciferase activity. The white and gray bars indicate the absence of ZFA36-FokI and ZFN, respectively. (A) ZFL1-FokI-DDD and appropriate nuclease domain. (B) ZFL1-ND1-DDD and appropriate nuclease domain. (C) ZFL1-ND2-DDD and appropriate nuclease domain. The data are shown as mean $\pm$ SEM (n = 3). In the figure, "FokI" means FokI-ND.

[Fig. 10] Fig. 10 shows the results of sequence analysis of the target site performed in Example 9. In the figure, "FokI" means FokI-ND.

[Fig. 11A] Fig. 11A shows the results of a cleavage test of an artificial nucleic acid-cleaving enzyme containing the novel nuclease domain of the present invention and TALE, which was performed in Example 10. In the figure, "FokI" means FokI-ND.

[Fig. 11B] Fig. 11B shows the results of a cleavage test of an artificial nucleic acid-cleaving enzyme containing the novel nuclease domain of the present invention and TALE, which was performed in Example 10. In the figure, "FokI" means FokI-ND.

[Fig. 12A] Fig. 12A shows the results of detecting by SSA reporter assay the nuclease activity of ZF-ND1 and ZF-FokI introduced into plant cells by the electroporation method.

5 [Fig. 12B] Fig. 12B is a graph of the results of Fig. 12A.

[Fig. 13] Fig. 13 shows the results of detecting by SSA reporter assay the nuclease activity of ZF-ND1 and ZF-FokI introduced into plant cells by the protein transduction method.

10 [Description of Embodiments]

1. Novel Nuclease Domains

In order to develop a novel nuclease domain with higher performance than FokI-ND, the present inventors searched for homologous natural materials by protein-protein BLAST based on the amino acid sequence of FokI-ND. The present inventors selected several types from the homologous sequences having homology with FokI-ND in the range of 35% to 70% to further proceed with the analysis, and have found nuclease domain 1 (hereinafter referred to as "ND1") and nuclease domain 2 (hereinafter referred to as "ND2") having nuclease activity superior to that of FokI-ND.

25 The amino acid sequence of the full-length protein containing ND1 (derived from Bacillus SGD-V-76) is set forth in SEQ ID NO: 1, and its base sequence is set forth

in SEQ ID NO: 2. The amino acid sequence of the full-length protein containing ND2 (derived from Clostridium botulinum) is set forth in SEQ ID NO: 3, and its base sequence is set forth in SEQ ID NO: 4. ND1 is typically
5 a partial peptide corresponding to positions 391 to 585 of SEQ ID NO: 1, and ND2 is typically a partial peptide corresponding to positions 389 to 579 of SEQ ID NO: 3.

ND1 has an amino acid sequence identity of 70% with FokI-ND, and ND2 has an amino acid sequence identity of
10 57% with FokI-ND, both being novel polypeptides isolated for the first time in the present invention.

Therefore, the present invention provides a nuclease domain which is a polypeptide containing an amino acid sequence set forth at positions 391 to 585 of SEQ ID NO:
15 1 or positions 389 to 579 of SEQ ID NO: 3, or a mutant polypeptide thereof (hereinafter also referred to as "nuclease domain of the present invention"). The nuclease domain of the present invention includes a nuclease domain which is a polypeptide composed of an amino
20 acid sequence set forth at positions 391 to 585 of SEQ ID NO: 1 or positions 389 to 579 of SEQ ID NO: 3, or a mutant polypeptide thereof. In other words, the present invention provides use of a polypeptide containing an amino acid sequence set forth at positions 391 to 585 of
25 SEQ ID NO: 1 or positions 389 to 579 of SEQ ID NO: 3, or a mutant polypeptide thereof, for example a polypeptide

composed of an amino acid sequence set forth at positions 391 to 585 of SEQ ID NO: 1 or positions 389 to 579 of SEQ ID NO: 3, or a mutant polypeptide thereof, as a nuclease domain.

5 In the present specification, a mutant polypeptide of a polypeptide containing an amino acid sequence set forth at positions 391 to 585 of SEQ ID NO: 1 or positions 389 to 579 of SEQ ID NO: 3 is a polypeptide having an amino acid sequence similar to the amino acid sequence set forth
10 at positions 391 to 585 of SEQ ID NO: 1 or positions 389 to 579 of SEQ ID NO: 3 and having nuclease activity. Examples of the mutant polypeptide include a polypeptide containing an amino acid sequence in which one to several amino acid residues are substituted, deleted, inserted,
15 or added in the amino acid sequence set forth at positions 391 to 585 of SEQ ID NO: 1 or positions 389 to 579 of SEQ ID NO: 3 and having nuclease activity, and a polypeptide composed of an amino acid sequence in which one to several amino acids are substituted, deleted, inserted, or added
20 in the amino acid sequence set forth at positions 391 to 585 of SEQ ID NO: 1 or positions 389 to 579 of SEQ ID NO: 3 and having nuclease activity. Here, "one to several" is, for example, 1 to 10, preferably 1 to 6, and is, for example, 1, 2, 3, 4, or 5.

25 In addition, as another example, the mutant polypeptide may be a polypeptide containing an amino acid

sequence having at least 70%, at least 75%, at least 80%,
at least 85%, at least 90%, at least 95%, and at least 98%
sequence identity with the amino acid sequence set forth
at positions 391 to 585 of SEQ ID NO: 1 or positions 389
5 to 579 of SEQ ID NO: 3 and having nuclease activity, for
example may be a polypeptide composed of an amino acid
sequence having at least 70%, at least 75%, at least 80%,
at least 85%, at least 90%, at least 95%, and at least 98%
sequence identity with the amino acid sequence set forth
10 at positions 391 to 585 of SEQ ID NO: 1 or positions 389
to 579 of SEQ ID NO: 3 and having nuclease activity. In
addition, further examples of the mutant polypeptide
include a polypeptide containing an amino acid sequence
encoded by a base sequence having at least 50%, at least
15 55%, at least 60%, at least 65%, at least 70%, at least
75%, at least 80%, at least 85%, at least 90%, at least
95%, and at least 98% sequence identity with the base
sequence set forth at positions 1171 to 1755 of SEQ ID NO:
2 or positions 1165 to 1737 of SEQ ID NO: 4 and having
20 nuclease activity, and a polypeptide composed of an amino
acid sequence encoded by a base sequence having at least
50%, at least 55%, at least 60%, at least 65%, at least
70%, at least 75%, at least 80%, at least 85%, at least
90%, at least 95%, and at least 98% sequence identity with
25 the base sequence set forth at positions 1171 to 1755 of
SEQ ID NO: 2 or positions 1165 to 1737 of SEQ ID NO: 4 and

having nuclease activity.

In the present invention, the "sequence identity" of an amino acid sequence is determined by comparing two sequences aligned to maximize sequence matching. Methods for determining the numerical value (%) of sequence identity are known to those skilled in the art. As an algorithm for obtaining optimum alignment and sequence identity, any algorithm known to those skilled in the art (such as BLAST algorithm and FASTA algorithm) may be used. The sequence identity of an amino acid sequence is determined using, for example, sequence analysis software such as BLASTP or FASTA.

Furthermore, the above-mentioned mutant polypeptide may preferably contain an amino acid sequence having aspartic acid at the position corresponding to position 483 in the amino acid sequence of FokI (hereinafter referred to as "D483") and/or arginine at the position corresponding to position 487 in the amino acid sequence of FokI (hereinafter referred to as "R487"). In addition, the above-mentioned mutant polypeptide may preferably contain an amino acid sequence having aspartic acid, aspartic acid, and lysine at positions corresponding to positions 450, 467 and 469 in the amino acid sequence of FokI (hereinafter referred to as "D450," "D467," and "K469," respectively). More preferably, the mutant polypeptide contains an amino acid sequence having D483

and/or R487 and having D450, D467, and K469. D483 and R487 are amino acid residues believed to be essential for FokI-ND to form a cleavage-active dimer, and are retained in the amino acid sequences of ND1 and ND2. Furthermore, regarding the catalytic site of FokI-ND, analysis using amino acid substitutions has revealed that D450 and D467 are involved in the cleavage of nucleic acids. Furthermore, the sequence including K469 in the vicinity of these amino acids is a motif found in EcoRI and EcoRV, and it has been clarified that these amino acids are involved in the cleavage activity of the phosphate diester bond. D450, D467, and K469 are retained in the amino acid sequences of ND1 and ND2.

In addition, the above-mentioned mutant polypeptide may contain aspartic acid at positions corresponding to positions 483, 487, and 496 in the amino acid sequence of FokI (hereinafter referred to as "D483, D487, and D496") (hereinafter also referred to as "DDD-type mutant"), or may contain arginine at positions corresponding to positions 483, 487, and 537 in the amino acid sequence of FokI (hereinafter referred to as "R483, R487, and R537") (hereinafter, also referred to as "RRR-type mutant"), so that the nuclease domain of the present invention forms a heterodimer upon nucleic acid cleavage.

The chain length of the polypeptide containing an amino acid sequence set forth at positions 391 to 585 of

SEQ ID NO: 1 or positions 389 to 579 of SEQ ID NO: 3 or the mutant polypeptide of the present invention is usually 500 amino acids or less, for example, 400 amino acids or less, 300 amino acids or less, or 200 amino acids or less.

5 Further, in the present specification, the above-mentioned mutant polypeptides also include polypeptides containing modified amino acids and/or unnatural amino acids. The modified amino acids include, but are not limited to, methylation, esterification,
10 amidation, acetylation, alkylation, halogenation, and the like. The modified amino acids and the unnatural amino acids can be introduced by a known method.

The nuclease domain of the present invention has nuclease activity equal to or higher than that of FokI-ND.
15 For example, the nuclease domain of the present invention has at least 0.8 times, at least 0.9 times, at least 1 times, at least 1.3 times, at least 1.5 times, at least 1.8 times, at least 2 times, at least 2.3 times, at least 2.5 times, at least 2.8 times, at least 3 times, at least 3.3 times,
20 at least 3.5 times, at least 3.8 times, or at least 4 times more nuclease activity than FokI-ND. The nuclease activity can be confirmed by methods known in the art. For example, the nuclease domain may be incorporated into a ZFN system, and confirmed by measuring nucleic acid
25 cleavage activity, such as DNA cleavage activity, by the SSA (single-strand annealing) method and the Cel-I method.

As described later, the nuclease domain of the present invention has properties different from those of FokI-ND in the flexibility in the selection of a linker in the artificial nucleic acid-cleaving enzyme and the flexibility in the selection of a spacer as the target cleavage site (Example 5). In addition, even when a Sharkey mutation known to cause an increase in activity in FokI-ND was introduced into the nuclease domain of the present invention, no increase in activity was observed (Example 6). In addition, unlike FokI-ND, the ND1 of the present invention did not decrease in nuclease activity even when a heterodimer was formed (Example 7). Thus, the nuclease domain of the present invention is a nuclease domain that has superior properties and/or different properties as compared with conventional FokI-ND.

The nuclease domain of the present invention may be an isolated nuclease domain. The present invention also provides an isolated nucleic acid encoding the nuclease domain of the present invention. As used herein, the term "isolated" refers to a state separated from the natural world or a living body.

2. Artificial Nucleic Acid-Cleaving Enzyme

The artificial nucleic acid-cleaving enzyme of the present invention includes the nuclease domain and nucleic acid-binding domain of the present invention. The artificial nucleic acid-cleaving enzyme binds to a target

sequence on a nucleic acid via a nucleic acid-binding domain, and cleaves the nucleic acid at a target cleavage site by the nuclease domain. Therefore, the artificial nucleic acid-cleaving enzyme is a sequence-specific
5 nucleic acid-cleaving enzyme capable of specifically cleaving a target site in a nucleic acid.

In the present specification, the "nucleic acid" includes both DNA and RNA. Examples of the nucleic acid cleaved by the artificial nucleic acid-cleaving enzyme of
10 the present invention include double-stranded DNA, single-stranded DNA, and single-stranded RNA. Examples of the DNA include, but are not limited to, eukaryotic nuclear genomic DNA, mitochondrial DNA, plastid DNA, prokaryotic genomic DNA, phage DNA, plasmid DNA, and the
15 like. Preferably, the artificial nucleic acid-cleaving enzyme of the present invention cleaves double-stranded DNA on the genome. Examples of the RNA include, but are not limited to, single-stranded RNA, double-stranded RNA, or a DNA-RNA hybrid double strand composed of
20 single-stranded DNA and single-stranded RNA.

The nucleic acid-binding domain may be a protein domain that specifically binds to an arbitrary nucleic acid sequence (target sequence), and examples thereof include, but are not limited to, zinc fingers, TALE,
25 CRISPR/Cas (complex of Cas protein and guide RNA), pentatricopeptide repeat (PPR), and the like, and

DNA-binding domains containing combinations thereof. Examples of CRISPR/Cas include CRISPR-Cas9, CRISPR-Cpf1 (Cas12a), CRISPR-Cas12b, CRISPR-CasX (Cas12e), CRISPR-Cas14, CRISPR-Cas3, and the like. The nucleic acid-binding domain containing zinc fingers may preferably contain two or more zinc fingers, and examples thereof may include, but are not limited to, a zinc finger array composed of 3 to 9 zinc fingers (hereinafter also referred to as "ZFA"). It is known that one zinc finger recognizes a three-base sequence, for example, a zinc finger that recognizes GNN, ANN, CNN, or the like. The CRISPR/Cas preferably includes Cas with inactivated nuclease activity, such as dCas (Cas with inactivated nuclease activity, such as dCas9). Nucleic acid-binding domains are appropriately designed by those skilled in the art to bind to the desired target sequence. Note that in the present specification, "CRISPR/Cas" means a complex of a guide RNA and a Cas protein, and the guide RNA recognizes and binds to a target sequence.

In the artificial nucleic acid-cleaving enzyme of the present invention, the nuclease domain and the nucleic acid-binding domain may be directly linked or may be linked via a linker. The linker is composed of, for example, two or more amino acid residues, and the length thereof is not particularly limited, but may be, for example, a length of 2 to 20 amino acids, for example 2, 4, 6, 8, 9, 9, 12,

16, or 20 amino acids. The type of linker is not particularly limited either, and examples thereof include TGAAARA, GS, RPGEKP, TGPGAAARA, and the like. The presence or absence of a linker and the length and type
5 of the linker are appropriately selected by those skilled in the art in consideration of the type and the like of the nucleic acid-binding domain. It is known that the nuclease activity of conventional ZFNs including FokI-ND is greatly affected by the linker sequence connecting ZF
10 and FokI-ND, but in the case of the artificial nucleic acid-cleaving enzyme of the present invention, the dependence of its nuclease activity on the linker sequence is lower than that of the conventional ZFNs. In particular, in ND1, almost no decrease in nuclease activity was
15 observed by changing the linker sequence (Example 5). Therefore, the artificial nucleic acid-cleaving enzyme of the present invention has high flexibility in linker sequence.

The target sequence of the artificial nucleic
20 acid-cleaving enzyme of the present invention is an arbitrary sequence on the nucleic acid. The target sequence is preferably two sequences sandwiching a spacer sequence. The length of the spacer sequence, the length of the target sequences, and the base sequences are not
25 particularly limited. Those skilled in the art can appropriately set target sequences having desired lengths

and composed of base sequences. The two target sequences may be palindromic sequences or non-palindromic sequences with each other. When the two target sequences are non-palindromic sequences, two kinds of artificial nucleic acid-cleaving enzymes targeting the respective sequence are prepared. Furthermore, in the case of using a nucleic acid-binding domain containing CRISPR/Cas, sequences located in the vicinity of the protospacer adjacent motif (PAM) sequence are selected as the target sequences. That is, the target sequences are set so that the PAM is present outside of both target sequences or in the spacer sequence. The target sequences may be either a double-stranded sequence or a single-stranded sequence. In addition, in this specification, "vicinity" includes both adjacent positions or near positions.

In the artificial nucleic acid-cleaving enzyme of the present invention, when the nucleic acid-binding domain binds to a target sequence on a nucleic acid, the nuclease domain cleaves the nucleic acid at the target cleavage site. The target cleavage site is in or near the spacer sequence adjacent to the target sequences. The length of the spacer array is not particularly limited, and examples thereof include 1 to 20 bp, preferably 3 to 8 bp, and more preferably 5 to 7 bp. In the case of conventional ZFNs including FokI-ND, it is known that the optimum spacer length is 6 bp, and its nuclease activity

is greatly affected by the spacer length, but in the case of the artificial nucleic acid-cleaving enzyme of the present invention, the spacer length is more flexible than that of the conventional ZFNs. The artificial nucleic acid-cleaving enzyme of the present invention exhibits high cleaving activity even for short spacers and long spacers by changing the linker length (Example 5). On the other hand, in conventional ZFNs including FokI-ND, even when the linker length is changed, the cleavage activity is significantly lowered for spacers shorter or longer than the optimum spacer length. Since the spacer length defines the distance between recognition sequences, the artificial nucleic acid-cleaving enzyme of the present invention provides a wide choice of target cleavage sites and recognition sequences due to the high flexibility of spacer length.

The artificial nucleic acid-cleaving enzyme of the present invention can be produced in vitro or in vivo by a method known in the art. Examples thereof include a method of artificial synthesis based on amino acid sequence information, and a method in which a nucleic acid encoding the artificial nucleic acid-cleaving enzyme of the present invention or each nucleic acid encoding the nuclease domain and nucleic acid-binding domain of the present invention is artificially synthesized, inserted into a suitable expression vector, and then introduced

into a suitable host cell to express the artificial nucleic acid-cleaving enzyme in the cell. Alternatively, a method can be mentioned in which a nucleic acid encoding the artificial nucleic acid-cleaving enzyme of the present invention is synthesized by in-vitro or in-vivo translation to synthesize a protein, which is introduced into a suitable cell to allow the artificial nucleic acid-cleaving enzyme to act in the cell, or an RNA encoding the artificial nucleic acid-cleaving enzyme of the present invention is synthesized by in-vitro transcription, introduced into a suitable host cell to allow the artificial nucleic acid-cleaving enzyme to act in the cell. The expression vector is not particularly limited, and may be selected from vectors used in the art. Examples thereof include plasmid vectors, viral vectors, phage vectors, phagemid vectors, BAC vectors, YAC vectors, MAC vectors, HAC vectors, and the like.

The host cell is not particularly limited, and examples thereof include prokaryotes such as *Escherichia coli*, actinomycetes, and archaea, eukaryotes such as yeast, sea urchin, silkworm, zebrafish, mouse, rat, frog, tobacco, *Arabidopsis thaliana*, and rice, and cultured cells.

A further aspect of the present invention also provides an isolated nucleic acid containing a nucleic acid sequence encoding the artificial nucleic acid-cleaving enzyme of the present invention, as well as

a transcription product and translation product of the nucleic acid. The above nucleic acid may be an isolated nucleic acid composed of a nucleic acid sequence encoding the artificial nucleic acid-cleaving enzyme of the present invention. In addition, codon optimization may be performed. In the present specification, "nucleic acid" includes both DNA and RNA.

3. Method for Modifying Target Nucleic Acid

When the artificial nucleic acid-cleaving enzyme of the present invention is introduced into a cell, the enzyme cleaves the target site on the nucleic acid in the cell, and the cleavage is then repaired by non-homologous end joining (NHEJ), homologous recombination (HR), or the like. At this time, in the repair by NHEJ as the main repair pathway, one or more mutations are inserted into the cleavage site to modify the nucleic acid. Therefore, a further aspect of the present invention provides a method for modifying a target nucleic acid, including introducing into a cell the artificial nucleic acid-cleaving enzyme of the present invention or a nucleic acid encoding the artificial nucleic acid-cleaving enzyme. The enzyme or nucleic acid described above may be a transcription product of the nucleic acid or a translation product thereof. The nucleic acid may also be codon-optimized for high expression in the cell. In addition, in the present specification, "modification" includes deletion,

insertion, or substitution of at least one nucleotide, or a combination thereof. Also, in the present specification, the term "mutation" used with respect to nucleic acids means a nucleotide deletion, insertion, or substitution.

The introduction of the above-mentioned enzyme or nucleic acid into cells may be physical introduction, introduction via infection of a virus or an organism, or the like, and various methods known in the art can be used. Examples of the physical introduction method include, but are not limited to, an electroporation method, a particle gun method, a microinjection method, a lipofection method, a protein transduction method, and the like. Examples of the introduction method via infection of a virus or an organism include, but are not limited to, virus transduction, Agrobacterium method, phage infection, conjugation, and the like. The above introductions involve appropriate use of vectors. The vectors may be appropriately selected according to the type of cell for introduction, and examples thereof include, but are not limited to, plasmid vectors, viral vectors, phage vectors, phagemid vectors, BAC vectors, YAC vectors, MAC vectors, HAC vectors, and the like. Examples also include vectors such as liposomes and lentiviruses capable of carrying translation products (proteins) and transcription products (mRNAs), and peptide vectors such as

cell-permeable peptides capable of introducing fused or bound molecules into cells.

Therefore, a further aspect of the present invention provides a vector containing a nucleic acid encoding the
5 artificial nucleic acid-cleaving enzyme of the present invention, or a vector containing a transcription product of the nucleic acid or a translation product thereof. The vector containing a transcription product of the nucleic acid or a translation product thereof includes those
10 transcribed by the nucleic acid in the vector containing the nucleic acid, and those in which the translation product is produced.

The above-mentioned cells may be either prokaryotic cells or eukaryotic cells, and are not particularly
15 limited. Examples thereof include bacteria, archaea, yeast, plant cells, insect cells, and animal cells (such as human cells, non-human cells, non-mammalian vertebrate cells, and invertebrate cells). The cells may also be in-vivo cells, isolated cells, primary cells, or cultured
20 cells. The cells may also be somatic cells, germ cells, or stem cells.

Specifically, examples of prokaryotes from which the above cells are derived include *Escherichia coli*, actinomycetes, archaea, and the like. In addition,
25 examples of eukaryotes from which the above cells are derived include fungi such as yeast, mushrooms, and molds,

echinoderms such as sea urchins, sea stars, and sea cucumbers, insects such as silkworms and flies, fish such as tuna, bream, pufferfish, and zebrafish, rodents such as mice, rats, guinea pigs, hamsters, and squirrels, even-toed ungulates such as cows, wild boars, pigs, sheep, and goats, odd-toed ungulates such as horses, reptiles such as lizards, amphibians such as frogs, Lagomorphs such as rabbits, Carnivora such as dogs, cats, and ferrets, birds such as chickens, ostriches, and quails, and plants such as tobacco, *Arabidopsis thaliana*, rice, corn, banana, peanut, sunflower, tomato, rapeseed, wheat, barley, potato, soybean, cotton, and carnation. Examples of the "animal cells" include embryonic cells of embryos at various stages (such as 1-cell stage embryos, 2-cell stage embryos, 4-cell stage embryos, 8-cell stage embryos, 16-cell stage embryos, and mulberry stage embryos); stem cells such as induced pluripotent stem (iPS) cells, embryonic stem (ES) cells, hematopoietic stem cells; somatic cells such as fibroblasts, hematopoietic cells, neurons, muscle cells, osteocytes, hepatocytes, pancreatic cells, brain cells, and kidney cells; fertilized eggs, and the like.

The target nucleic acid may be any gene in the genomic DNA in the cell or DNA in an extra-gene region. In order to cleave the target sequence in the target nucleic acid, the artificial nucleic acid-cleaving enzyme of the present

invention is designed so that the nucleic acid-binding domain contained in the artificial nucleic acid-cleaving enzyme of the present invention binds to a sequence in the vicinity of the target sequence (selected as a target sequence of the nucleic acid-binding domain). As a result, the desired sequence in the target nucleic acid is cleaved, for example, the expression of the gene is reduced or eliminated, or the function of the gene is reduced or no function is expressed.

In the target nucleic acid modification method of the present invention, a donor polynucleotide may be introduced into cells in addition to the above-mentioned artificial nucleic acid-cleaving enzyme. The donor polynucleotide contains at least one donor sequence containing the modification desired to be introduced at the target cleavage site. The donor polynucleotide can be appropriately designed by those skilled in the art based on techniques known in the art. When a donor polynucleotide is present in the target nucleic acid modification method of the present invention, homologous recombination takes place at the target cleavage site, and the donor polynucleotide is inserted into the site or the site is replaced with the donor sequence. As a result, the desired modification is introduced at the target cleavage site.

In the absence of donor polynucleotide in the target

nucleic acid modification method of the present invention, the target cleavage site is repaired primarily by non-homologous end joining (NHEJ). Since NHEJ is error-prone, deletions, insertions, or substitutions of at least one nucleotide, or a combination thereof, can occur during repair of the cleavage. In this way, the nucleic acid is modified at the target cleavage site.

In the target nucleic acid modification method of the present invention, two or more kinds of the above-mentioned artificial nucleic acid-cleaving enzyme may be introduced into cells. Examples of the two or more kinds of artificial nucleic acid-cleaving enzymes include two or more kinds of artificial nucleic acid-cleaving enzymes with different nucleic acid-binding domains, two or more kinds of artificial nucleic acid-cleaving enzymes with different nuclease domains, two or more kinds of artificial nucleic acid-cleaving enzymes with different nuclease domains and nucleic acid-binding domains, two or more kinds of artificial nucleic acid-cleaving enzymes with different linker sequences, and the like. The two or more kinds of artificial nucleic acid-cleaving enzymes with different nucleic acid-binding domains include two or more kinds of artificial nucleic acid-cleaving enzymes having different target sequences bound with nucleic acid-binding domains, and two or more kinds of artificial nucleic acid-cleaving enzymes having different kinds of

nucleic acid-binding domains, and as an example, it is possible to mention two or more kinds of artificial nucleic acid-cleaving enzymes having different nuclease domains and different target sequences bound with nucleic acid-binding domains. For example, when no palindromic sequence exists in the region to be modified on the nucleic acid, two kinds of artificial nucleic acid-cleaving enzymes targeting different sequences may be used. In this case, into the nuclease domains of the two kinds of artificial nucleic acid-cleaving enzymes, a mutation that promotes heterodimer formation of the nuclease domains may be further introduced. This makes it possible to increase the recognition sequences of the artificial nucleic acid-cleaving enzymes and reduce the probability of off-targeting. Such mutations are, for example, substitutions into D483, D487, and D496 (hereinafter also referred to as "DDD-type mutations") and substitutions into R483, R487, and R537 (hereinafter also referred to as "RRR-type mutations"), where a DDD-type mutation is introduced into the nuclease domain of one artificial nucleic acid-cleaving enzyme, and an RRR-type mutation is introduced into the nuclease domain of the other artificial nucleic acid-cleaving enzyme. Note that if the nuclease domain sequence before the introduction of the mutation already has an amino acid residue of either the DDD-type mutation or the RRR-type mutation shown above,

only the other amino acid substitutions need to be performed. The two kinds of nuclease domains introduced with a pair of mutations (such as DDD-type mutation and RRR-type mutation) that promote the formation of such heterodimers may be the same nuclease domains except for the above-mentioned mutations, or may be originally different nuclease domains before the above-mentioned mutations are introduced. For example, an artificial nucleic acid-cleaving enzyme containing a DDD-type mutant of ND1 and an artificial nucleic acid-cleaving enzyme containing an RRR-type mutant of ND1 may be used in the method of the present invention. In addition, for example, an artificial nucleic acid-cleaving enzyme containing a DDD-type mutant of ND2 and an artificial nucleic acid-cleaving enzyme containing an RRR-type mutant of ND1 may be used in the method of the present invention. According to the present invention, the combination of the DDD-type mutant of ND1 and the RRR-type mutant of ND1, or the combination of the DDD-type mutant of ND2 and the RRR-type mutant of ND1 showed particularly high specificity and nuclease activity (Example 8).

4. Kit

A further aspect of the present invention provides a kit for modifying a target nucleic acid, including the artificial nucleic acid-cleaving enzyme of the present invention, a nucleic acid encoding the artificial nucleic

acid-cleaving enzyme, or a vector containing the nucleic acid, a transcription product of the nucleic acid, or a translation product thereof. Furthermore, the kit may include two or more kinds of artificial nucleic acid-cleaving enzymes as described above. In addition, the kit may include a nucleic acid encoding the two or more kinds of artificial nucleic acid-cleaving enzymes, or a vector containing the nucleic acid, a transcription product of the nucleic acid, or a translation product thereof. Preferably, the kit of the present invention includes one or two kinds of artificial nucleic acid-cleaving enzymes, a nucleic acid encoding the one or two kinds of artificial nucleic acid-cleaving enzymes, or a vector containing the nucleic acid, a transcription product of the nucleic acid, or a translation product thereof. The two or more kinds of artificial nucleic acid-cleaving enzymes may be, for example, an artificial nucleic acid-cleaving enzyme containing a DDD-type mutant of ND1 and an artificial nucleic acid-cleaving enzyme containing an RRR-type mutant of ND1. Further, the two or more kinds of artificial nucleic acid-cleaving enzymes may be, for example, an artificial nucleic acid-cleaving enzyme containing a DDD-type mutant of ND2 and an artificial nucleic acid-cleaving enzyme containing an RRR-type mutant of ND1. The kit may further include one or more additional reagents, and examples of the

additional reagents include, but are not limited to, dilution buffers, reconstruction solutions, wash buffers, nucleic acid transfer reagents, protein transfer reagents, and control reagents. The kit usually comes with an instruction manual.

Unless otherwise stated, the meanings of the terms in the present specification are understood to be those commonly recognized in the fields of biology, molecular biology, biochemistry, genetics, and the like.

[Examples]

Hereinafter, the present invention is specifically described with reference to Examples, but the present invention is not limited to these Examples.

Note that the cells used in Examples were cultured as follows.

<Cell Culture>

HEK293T cells were maintained in D-MEM medium (Wako Pure Chemical Industries, Ltd.) containing 10% FBS (Difco), 1% streptomycin-penicillin (Wako Pure Chemical Industries, Ltd.), and 1% NEAA (Difco). CHO-K1 cells were maintained with Ham's-F12 (Difco) containing 10% FBS, 1% streptomycin-penicillin, and 5% kanamycin (Wako Pure Chemical Industries, Ltd.). Hereinafter, unless otherwise specified, the cultured cells were maintained at 37°C and a carbon dioxide concentration of 5%, and if the temperature was specified, the temperature was

followed. In addition, as for the culture solution, each of the above media was used unless otherwise specified.

Example 1: Search for Novel Nuclease Domains

Based on the amino acid sequence on the C-terminus side of FokI, a search for homologous natural materials was performed by protein-protein BLAST. In the obtained search results, four kinds of candidates were arbitrarily selected from those having a homology with FokI-ND of 35% to 70%. In descending order of high-homology sequence, they are referred to as ND1 (70% amino acid sequence identity; full-length amino acid sequence: SEQ ID NO: 1; corresponding base sequence: SEQ ID NO: 2), ND2 (57% amino acid sequence identity; full-length amino acid sequence: SEQ ID NO: 3; corresponding base sequence: SEQ ID NO: 4), ND3 (49% amino acid sequence identity; full-length amino acid sequence: SEQ ID NO: 5; corresponding base sequence: SEQ ID NO: 6), and ND4 (45% amino acid sequence identity; full-length amino acid sequence: SEQ ID NO: 7; corresponding base sequence: SEQ ID NO: 8).

When the amino acid sequences of ND1 to ND4 were compared with the amino acid sequence of FokI-ND, it was revealed that the lengths of FokI-ND and nuclease domain were almost the same, although there were amino acid deletions and substitutions. In addition, ND1 to ND4 carried amino acids (D483, R487) thought to be essential for FokI-ND to form a cleavage-active dimer, and amino

acids (D450, D467, and K469) presumed to be involved in the hydrolysis-induced cleavage of phosphodiester bonds in DNA (Fig. 1B). Therefore, ND1 to ND4 were considered to have nuclease activity.

Example 2: Cleavage Activity of Novel Nuclease Domains (SSA Method)

In order to evaluate the nuclease activity of ND1 to ND4, a ZFN plasmid (pSTL-ZFA36-ND) containing each of ND1 to ND4 was prepared, and the cleavage activity of each novel nuclease domain was measured by SSA reporter assay.

(1) Construction of ZFN Plasmid

The base sequences of ND1 to ND4 were codon-optimized and artificially synthesized by IDT. The ZFN plasmid used (pSTL-ZFA36) was a construct prepared by Ochiai et al (Ochiai et al. (2010) Targeted mutagenesis in the sea urchin embryo using zinc-finger nucleases. *Genes to Cells* 15: 875-885). In order to replace FokI-ND of pSTL-ZFA36 with the newly identified ND1 to ND4, PCR was performed by PrimeSTAR Max (Takara) with each nuclease domain replacement primer pair. PCR was performed at 98°C for 2 minutes, followed by 40 cycles of 98°C for 10 seconds, 60°C for 5 seconds, and 68°C for 40 seconds. The obtained PCR product and artificially synthesized ND1 to ND4 were reacted using In-Fusion (Clontech) and transformed into *Escherichia coli*. A plasmid was extracted from the obtained transformant and the base sequence was confirmed

to obtain each desired pSTL-ZFA36-ND plasmid. Fig. 1A shows a schematic diagram of the obtained ZFA (zinc finger array) 36-ND. The ZFA36-ND has a TGAAARA linker.

(2) SSA Reporter Assay

5 A 7.2 μ L plasmid solution was prepared containing 120 ng of the SSA reporter plasmid, 240 ng of each of the above pSTL-ZFA36-ND plasmids, and 24 ng of the reference plasmid pRL-CMV (Promega) (a plasmid for standardizing transduction efficiency). The SSA reporter plasmid was
10 prepared according to a known method so that the target sequence of the ZF array (ZFA36) containing the 6bp spacer sequence was inserted so as to be sandwiched between the overlapping regions of the Luc sequence (Ochiai et al. (2010) Targeted mutagenesis in the sea urchin embryo using
15 zinc-finger nucleases. *Genes to Cells* 15: 875-885). To a 96-well multiwell plate (Iwaki) treated with polylysine coat, 25 μ L of serum-free D-MEM culture solution was added, and 6 μ L of plasmid solution was mixed. To this, 25.7 μ L of a solution containing 0.7 μ L of Lipofectamine LTX (Life
20 Technologies) per 25 μ L of serum-free D-MEM culture solution was added, and the mixture was allowed to stand at room temperature for 30 minutes. During this period, HEK293T cells were dissociated from a 100 mm tissue culture dish (Iwaki) by trypsin treatment, centrifuged at 1000 rpm
25 for 3 minutes, the supernatant was removed, and the cells were suspended again in 5 mL of the culture solution. A

10 μ L cell suspension was dispensed, and the number of cells was counted. From the obtained number of cells, a culture solution was added and adjusted so that the number of cells in the cell suspension was 6×10^5 cells/mL. To the above 96-well plate allowed to stand at room temperature for 30 minutes, 100 μ L of the cell suspension was added. Then, the 96-well plate was transferred to 37°C and a carbon dioxide concentration of 5%, and cultured to carry out transduction.

As to the culture solution of HEK293T cells cultured for 24 hours after transduction, 75 μ L thereof was removed, 75 μ L of Dual Glo luciferase substrate attached to Dual Glo Luciferase Assay System (Promega) was added to each well, and the cells were treated in the dark at room temperature for 10 minutes. Then, the luciferase activity was measured by TriStar LB941 of a multi-well plate reader. After the measurement, 75 μ L of Dual Glo Stop & Glo Buffer containing 100-fold diluted Dual Glo Stop & Glo Substrate was added to each sample, and the mixture was treated in the dark at room temperature for 10 minutes, and the luciferase activity of the reference plasmid was measured with a plate reader in the same manner as before. As a control, ZFA36-FokI containing FokI-ND was used for the same measurement. As for the measurement results, the change in the value obtained by dividing the luciferase activity of the SSA reporter by the luciferase activity

of the reference plasmid was calculated, and the relative value in each sample when the value of ZFA36-FokI was set to 1 was obtained.

(3) Results

Fig. 1C shows the results. As is clear from Fig. 1C, ND1 and ND2 were higher by 20% or more in cleavage activity than the conventionally used FokI-ND. On the other hand, it was revealed that ND3 and ND4 have low cleavage activity and have only about 20% of FokI-ND.

Furthermore, it was confirmed, when the nuclease domain was not expressed intracellularly, whether the nuclease originally present in the cell targeted the luciferase reporter. As a result, it was found that the luciferase reporter could not be the target of various nucleases present in HEK293T cells because the relative activity against FokI-ND was extremely low. This analysis has revealed that ND1 and ND2 are novel nuclease domains derived from natural materials that surpass the cleavage activity of FokI-ND conventionally used in ZFNs.

Example 3: Cleavage Activity of Novel Nuclease Domains against Target Genome (Cel-I Method)

To confirm the extent to which the novel nuclease domains ND1 and ND2 confirmed to have nuclease activity in Example 2 bring about mutagenesis in genomic DNA in vivo, Cel-I assay was used to analyze the rate of mutagenesis into genomic DNA in cultured cells of the novel nuclease

domains. As a control, FokI-ND, ND3, and ND4 were analyzed in the same manner.

(1) Cel-I Assay

In cells transduced with genome editing tools such as TALEN and ZFN, the target DNA is cleaved by their nuclease domain and the cleavage site is repaired by the repair mechanism existing in the cell, but a repair error occurs in this process. When the region containing the target sequence of this genomic DNA is amplified by PCR, a mixture product of a PCR fragment of the wild-type allele and a PCR fragment containing the mutation is obtained. Reassociation of these products after dissociation yields a mismatched double-stranded DNA composed of a PCR fragment of the wild-type allele and the allele containing the mutation, which is cleaved with a mismatch-specific endonuclease (Cel-I nuclease). Mutagenesis can be evaluated by detecting the cleavage pattern.

CHO-K1 cells were dissociated by trypsin treatment, centrifuged at 1000 rpm for 3 minutes, the supernatant was removed, and the cells were suspended in 10 mL of the culture solution. The number of cells was measured using a 10 μ L cell suspension, a culture solution was added so that the number of cells was 1×10^5 cells/mL, and the cells were cultured overnight at 37°C and a carbon dioxide concentration of 5%.

Each ZFN plasmid prepared in Example 2 was added to

500 μ L of Opti-MEM (Difco) so as to have a weight of 800 ng, and the mixture was allowed to stand at room temperature for 5 minutes. To 500 μ L of Opti-MEM, 32 μ L of Lipofectamine LTX was added, and the whole amount was mixed with Opti-MEM medium containing the above plasmid, and allowed to stand at room temperature for 30 minutes. During this period, the culture solution of CHO-K1 cells grown overnight was replaced with 4 mL of Opti-MEM. To the cell culture solution, the whole amount of the plasmid solution allowed to stand at room temperature for 30 minutes was added, and the cells were cultured overnight at 37°C and a carbon dioxide concentration of 5%. In the morning of the next day, the culture solution was changed from Opti-MEM to 10 mL of the culture solution, and the culture was further continued at 37°C and a carbon dioxide concentration of 5%. In addition, puromycin (Wako Pure Chemical Industries, Ltd.) was added so that the final concentration was 500 μ g/mL after 24 hours. After that, the culture was carried out every day for 3 days while exchanging culture solutions and adding puromycin.

CHO-K1 cells transduced with the ZFN plasmid as described above were harvested from the culture dish by trypsin treatment. The harvested cells were washed once with PBS (-). The obtained cells were subjected to the treatment by a cell lysis buffer and a protein degrader contained in either a DNA purification kit (Qiagen) or

GeneArt Genomic Cleavage Detection Kit (Life Technologies) to prepare genomic DNA. With the prepared genomic DNA as a template, PCR was performed using KOD Fx Neo (ToYoBo) or AmpliTaq Gold (Life Technologies). In the case of KOD Fx Neo, PCR was performed at 95°C for 2 minutes, followed by 40 cycles of 95°C for 30 seconds, 60°C for 30 seconds, and 68°C for 30 seconds to amplify the target. In the case of AmpliTaq Gold, treatment was performed at 95°C for 10 minutes, followed by 40 cycles of 95°C for 10 seconds, 60°C for 30 seconds, and 72°C for 40 seconds, and finally treatment at 72°C for 7 minutes was performed to amplify the target. Equivalent amounts of each obtained PCR product were subjected to a cleavage reaction with a detection enzyme using GeneArt Genomic Cleavage Detection Kit according to the manual. In the solution after the reaction, cleaved fragments were detected by agarose gel electrophoresis or MultiNA (Shimadzu Corporation). Cleavage efficiency was calculated from the molar concentrations of the uncleaved bands and the larger cleaved fragments.

(2) Results

Fig. 2 shows the results of electrophoresis by MultiNA. Table 1 shows the candidate sequences for the ZFN genomic target (ZFA36-ZFA36) in CHO-K1 cells used in the analysis. Table 1 also shows the candidate sequences for the ZFN genomic target (ZFL1-ZFA36) used in Example

7 described later.

[Table 1]

Sequences of Target Sites	
Target Site	Target Site Sequence
ZFA36-ZFA36	ACCATCTTCnnnnnnnGAAGATGGT
1st site	ACCATCTTCcactctGAAGATGGA
2nd site	ACCATCTTCaagagaGAAGATGGC
3rd site	ACCATCTTCcttgatGAAGATGCC
ZFL1-ZFA36	GTCACCTTCnnnnnnnGAAGATGGT
1st site	GTCACCTTCaagtctGAAGATGGT
2nd site	TTCACCTTCttaagtGAAGATGGT

In all the target sequences analyzed, the target half
5 site (L) was in perfect agreement with the target sequence
of the ZF array. On the other hand, the target half site
(R) did not completely match the target sequence of the
ZF array, and there was a mismatch on the 3'-side.
Cleavage of these target candidate sequences by Cel-I
10 revealed that the cleavage efficiency of the novel
nuclease domains ND1 and ND2 was about 1.5 times higher
than that of FokI-ND, similar to the results of luciferase
reporter analysis (Figs. 2A and 2B). In particular, the
mutagenesis activity of ND1 had more stable and higher
15 cleavage activity than that of ND2 in all the target
candidate sequences analyzed. These results have
revealed that ND1 and ND2 are novel nuclease domains
derived from natural materials that are more active than
conventional FokI-ND also with respect to target genomic
20 sequences in vivo, similar to the results of the reporter

analysis using the luminescence of luciferase in Example 2.

On the other hand, in ND3, although the mutagenesis activity changed depending on the target candidate sequence, it was about 25 to 45% of the activity of FokI-ND. In addition, in ND4, no mutagenesis into the detectable target candidate sequences was observed in all the analyzed target candidate sequences.

Example 4: Analysis of Intracellular Accumulation Amount of Novel Nuclease Domains

To clarify whether or not the reason why the mutagenesis rate of the novel nuclease domain is higher than that of FokI-ND is that the apparent mutagenesis rate is higher because the intracellular accumulation amount is larger than that of FokI-ND, the amount of each nuclease domain accumulated was analyzed by adding a tag to ZFN and using an antibody that recognizes it. In order to perform this analysis, a construct in which an AcV5 tag was newly added to the N-terminus of ZFN was prepared and used for the analysis.

(1) Analysis of Intracellular Accumulation Amount (Western Blot Analysis)

In order to analyze the amount of ZFN accumulated in cells, PCR was performed using each pSTL-ZFA36-ND prepared in Example 2 as a template, and after an In-Fusion reaction, transformation into *Escherichia coli* was

performed to obtain each ZFN plasmid having an AcV5 tag added to the N-terminus side of the ZF array. A plasmid solution in an amount of 7.2 μ L containing 240 ng of the ZFN plasmid was prepared. The plasmid solution was transduced into HEK293T cells in the same manner as in the SSA assay described in Example 2, and cultured at 37°C and a carbon dioxide concentration of 5% for 3 days. The culture solution was changed every day.

The cultured HEK293T cells were treated with trypsin and centrifuged, and the supernatant was removed. The obtained precipitate was suspended in PBS, and added with a sample treatment solution composed of 2% SDS, 10% glycerol, 10 mM DTT, 0.005% BPB, and 62.5 mM Tris-HCl (pH 6.8), and the mixture was boiled at 95°C for 5 minutes. Then, nucleic acids and the like were cut by ultrasonic treatment. The obtained protein samples were quantified using a protein assay kit (Bio-Rad) using BSA as an external standard. Each sample prepared to be 10 μ g was separated by SDS-PAGE and transferred to a PVDF membrane by semi-dry transfer. Post-transcriptional PVDF membranes were blocked with PBS containing 5% skim milk and incubated with 2000-fold diluted α -tubulin antibody (Abcam) and AcV5-tag antibody (Sigma). After washing with PBST, they were incubated with 2000-fold diluted goat anti-mouse IgG antibody-conjugated HRP (Bio-Rad). After washing with PBST, they were made to emit light using

Supersignal West Dura Extended Duration Substrate (Thermo Fisher) and exposed to an X-ray film.

(2) Results

Figure 3 shows the results. When the amount of protein in the cell disruption solution was compared using a monoclonal antibody against α -tubulin as an internal standard, the amount of tubulin accumulated was large in the control cells that had not been transduced with ZFN. When ZFN containing each nuclease domain was expressed, FokI-ND and ND1 appeared to be slightly less, but showed approximately equal amounts of tubulin accumulation, and approximately equal amounts of protein separation by SDS-PAGE and transcription to PVDF membranes.

On the other hand, as can be seen from the accumulated amount of tubulin, in the control, although the analysis was performed with a larger amount of protein than the cell disruption solution expressing each nuclease domain, no non-specific signals derived from the AcV5 tag antibody were observed, and it was found that the AcV5 antibody specifically recognized the tag. When the amount of protein accumulated was analyzed using this AcV5 antibody, in the cell disruption solution transduced with each nuclease domain, a signal derived from the AcV5 tag was obtained in FokI-ND and ND1 to ND3 at around 35 kDa, which is the expected size. In addition, the signals of FokI-ND, ND1, and ND2 were almost the same. When considered in

combination with the amount of tubulin used as an internal standard, the intracellular accumulation amount of each nuclease domain of FokI-ND, ND1, and ND2 suggested that FokI-ND accumulated the most in the cell, followed by ND1 and ND2 in this order. On the other hand, for ND3, since the signal derived from the AcV5 tag was obtained significantly stronger than that of FokI-ND and the like, it was revealed that the amount of ND3 accumulated in the cells was larger than that of FokI-ND and the like.

(3) Analysis of Intracellular Accumulation Amount and Localization (ZFN-EGFP Expression Analysis)

Moreover, although the cleavage activity was lost, a construct in which EGFP was fused to the C-terminus was prepared in order to clarify the intracellular accumulation amount and localization of each ZFN. The prepared construct was used to perform transduction into HEK293T cells, and fluorescence derived from GFP was observed with a confocal laser scanning microscope to analyze the expression level of ZFN and to, at the same time, stain the nuclei with DAPI for clarification of intracellular localization.

PCR was performed using each pSTL-ZFA36-ND prepared in Example 2 as a template, and after an In-Fusion reaction, transformation into *Escherichia coli* was performed to obtain each ZFN plasmid having EGFP added to the C-terminus side of the ZF array. A plasmid solution in an amount of

7.2 μ L containing 240 ng of the ZFN plasmid was prepared. The plasmid solution was transduced into HEK293T cells in the same manner as in the SSA assay described in Example 2, and cultured at 37°C and a carbon dioxide concentration of 5% for 3 days. HEK293T cells were applied to a collagen-treated 24-well glass bottom plate.

The grown HEK293T cells were fixed with paraformaldehyde. After washing with PBS (-), nucleic acid was stained with DAPI. After washing with PBS (-) again, observation was performed with a confocal laser scanning microscope (FD-1000D, Olympus). Fluorescence images were obtained at Ex: 473 nm/Em: 510 nm for EGFP and at Ex: 405 nm/Em: 473 nm for DAPI.

(4) Results

Fig. 4 shows the results. In the negative control in which ZFN was not expressed, fluorescence derived from GFP was not observed, and only fluorescence derived from nucleic acid by DAPI was observed. In cells introduced with ZFN having EGFP fused in each nuclease domain, GFP-derived fluorescence was observed in the cytoplasm and nucleus, although there was a difference in GFP-derived fluorescence intensity.

When FokI-ND-EGFP was expressed, GFP fluorescence was observed in the cytoplasm for some cells and also in the nucleus for some other cells. When ND1-EGFP was expressed, GFP-derived fluorescence was observed in more

cells than in FokI-ND, but the intensity of each fluorescence was weaker than in FokI-ND. When ND2-EGFP was expressed, it was found that in the observed cells, the number of cells having GFP-derived fluorescence was smaller than that in FokI-ND, but it was localized in the cytoplasm and nucleus. When ND3-EGFP was expressed, GFP-derived fluorescence was observed in the nucleus and cytoplasm, as in FokI-ND and the like. In addition, since GFP-derived fluorescence was more strongly observed in ND3 than in other nuclease domains, it was considered that the expression level was higher in the cells. Analysis of ND3 by Western blotting also showed that the intracellular accumulation amount was higher than that of FokI-ND, but even though it could be localized in the nucleus, the apparent mutagenesis rate was low, and it was considered that the biochemical properties of the enzyme were also different, such as a different optimum temperature from that of FokI-ND.

(5) Summary

From the results of antibody analysis and GFP fluorescence analysis, it was revealed that FokI-ND, ND1, and ND2 were accumulated in cells to the same extent. This has revealed that the high cleavage activity of the novel nuclease domains ND1 and ND2 is not because of the large amount of intracellular accumulation, but because of the higher cleavage activity than that of FokI-ND, meaning

that ND1 and ND2 are nuclease domains derived from natural materials having cleaving activity that surpasses FokI-ND, which has been conventionally used in ZFNs and the like.

Example 5: Analysis of Target Sequence Selectivity of Novel Nuclease Domains

To further verify the usefulness of ND1 and ND2, an attempt was made to modify the linker sequence between the ZF array and the nuclease domain. In conventional ZFNs, it has been reported that when the linker sequence is modified, the length of the spacer sequence exhibiting cleavage activity and the toxicity given to cells are different. Therefore, in addition to the TGAAARA linker, which is a conventional linker sequence used in the analysis so far, ZFN vectors modified into GS linker, RPGEKP linker, and TGPGAAARA linker were constructed and used for the analysis.

(1) Experimental Method

As a ZFN vector having a TGAAARA linker, each pSTL-ZFA36-ND prepared in Example 2 was used. The selection of GS linker, RPGEKP linker, and TGPGAAARA linker was based on the reports of Handel et al. (2009) (NPL 1), Wilson et al. (2013) (Wilson et al. (2013) Expanding the Repertoire of Target Sites for Zinc Nuclease-mediated Genome modification. Mol. Ther-Nucleic Acids 2: e88), and Nomura et al. (2012) (Nomura et al. (2012) Effects of DNA Binding of the Zinc Finger and

Linkers for Domain Fusion on the Catalytic Activity of Sequence-Specific Chimeric Recombinase Determined by a Facile Fluorescent System. *Biochemistry*. 51: 1510-1517). The ZFN vector with each linker modified was subjected to PCR by PrimeSTAR Max (Takara) with each linker modification primer pair using pSTL-ZFA36-ND as a template. The obtained PCR product was reacted using In-Fusion (Clontech) and transformed into *Escherichia coli*. A plasmid was extracted from the obtained transformant, and the base sequence was confirmed to obtain the desired plasmid. In addition, SSA reporter plasmids with spacer lengths modified to 5 bp or 7 bp were used to perform SSA reporter assays as described in Example 2 to measure the nuclease activity of each ZFN.

(2) Results

Fig. 5 shows the results. Note that the cleavage activity includes the conventional linker and is shown by the relative activity when the cleavage activity of ZFA-FokI-ND of the spacer sequence 6bp is 100%.

When the length of the spacer sequence was 6 bp, in FokI-ND, the activity was reduced to 20% or less when modified to a GS linker or RPGEKP linker, as compared with the cleavage activity when the ZF array and the nuclease domain were connected by the conventional linker (TGAAARA). On the other hand, when modified to a TGPGAAARA linker, the cleavage activity of FokI-ND was about 90% of that

before the linker modification (Fig. 5A).

In ND1, when the spacer sequence was 6 bp, the cleavage activity was not affected even when the linker sequence was modified, and the cleavage activity was about 90% of that of FokI-ND before the linker sequence modification. In ND2, when the spacer sequence was 6 bp, the cleavage activity was reduced to about 60% when modified to the GS linker sequence and to about 35% when modified to the RPGEKP linker sequence, as compared with the cleavage activity of FokI-ND before the linker sequence modification. From these results, it has been clarified that, as previously reported, even when the spacer sequences have the same length, the linker sequence used in the analysis affects the cleavage activity of the nuclease domain.

When the length of the spacer sequence was set to 5 bp, the cleavage activity of FokI-ND was reduced to about 40% in the conventional linker sequence (TGAAARA linker) as compared with the case of 6 bp, but when modified to a GS linker, about 50% of cleavage activity remained. However, when modified to RPGEKP linker or TGPGAAARA linker, the cleavage activity of FokI-ND was about 20% of that of the conventional linker sequence, and almost no cleavage was possible. It was revealed that in ND1, when the spacer sequence was 5 bp, the cleavage activity remained high when modified to the GS linker, but the

conventional linker sequence reduced the cleavage activity to about 30%, and when converted to other linker sequences, almost no cleavage was possible.

In ND2, when the length of the spacer sequence was set to 5 bp, almost no cleavage activity was exhibited even when the linker sequence was modified. When the length of the spacer sequence was short, the influence of the linker sequence was large, and it was considered that the shorter the linker sequence, the easier it was to maintain the cleavage activity.

When the length of the spacer sequence was set to 7 bp, in FokI-ND, cleavage activity was observed only when modified to the TGPGAAARA linker, and this activity was about 50% of the cleavage activity of the conventional linker sequence having a spacer sequence length of 6 bp. Almost no cleavage activity was exhibited when converted to other linker sequences.

In ND1, it was found that when the length of the spacer sequence was set to 7 bp, the cleavage activity was not exhibited when modified to the GS linker sequence, but when modified to other linker sequences, the cleavage activity of about 50% or more was exhibited. In particular, the TGPGAAATA linker sequence was considered to be higher than the cleavage activity of the target FokI-ND. On the other hand, for ND2, the conventional linker sequence showed about 40% cleavage activity, but when modified to other

linker sequences, almost no cleavage activity was exhibited. When the length of the spacer sequence was long, the longer the linker sequence, the higher the cleavage activity tended to be.

5 From the above results, it has been clarified that ND1 is less susceptible to the modification of the linker sequence than FokI-ND, has less restriction on the spacer sequence, and exhibits higher cleavage activity than FokI-ND. This indicates that ND1 is a nuclease domain that
10 is more versatile than FokI-ND also in terms of target sequence selectivity and the like.

 So far, there have been reports on the modification of FokI-ND for ZFN. It has also been reported that the nuclease domain itself is modified from FokI-ND to
15 endonucleases such as PvuII and I-TevI. Although the modified ZFN using this I-TevI has a higher cleavage activity than FokI-ND, the spacer sequence is about 30 bp, which is longer than that of FokI because of the intramolecular linker and DNA binding motif existing in
20 I-TevI, in addition to the ZF array. Similarly, when modified to PvuII, the spacer sequence is long. As a result, it is considered that the DNA sequence acting on the ZFN is also long and easily restricted by the base sequence. On the other hand, when used in ZFN, the
25 nuclease domain of the present invention has the same protein structure as the conventional FokI-ND but has a

high mutagenesis rate, and the target DNA sequence acting on the ZFN is shortened to 24 bp as a whole. From this, the nuclease domain of the present invention is less restricted by the base sequence than I-TevI and the like, and is easy to handle as a simpler genome editing tool.

Example 6: Cleavage Activity of Novel Nuclease Domain Introduced with Sharkey Mutation

An amino acid substitution (Sharkey mutation) is known that increases cleavage activity when introduced into FokI-ND (Guo, J., Gaj, T. and Barbas, C. F., 3rd. (2010) Directed evolution of an enhanced and highly efficient FokI cleavage domain for zinc finger nucleases. J Mol Biol, 400, 96-107). Therefore, introduction was attempted of the same amino acid substitutions as the Sharkey mutation in the novel nuclease domains ND1 and ND2 for the purpose of further enhancing the cleavage activity.

(1) Experimental Method

ZFN vectors containing nuclease domains introduced with the Sharkey mutations (S418P and K441E amino acid substitutions in FokI-ND, and corresponding amino acid substitutions in other nuclease domains) was subjected to PCR by PrimeSTAR Max (Takara) with a Sharkey mutagenesis primer pair using each pSTL-ZFA36-ND as a template with reference to the report by Guo et al. The obtained PCR product was reacted using In-Fusion (Clontech) and

transformed into *Escherichia coli*. A plasmid was extracted from the obtained transformant, and the base sequence was confirmed to obtain the desired plasmid. An SSA reporter assay was performed as described in Example 2 to measure the nuclease activity of each ZFN. As a control having no Sharkey mutation, each pSTL-ZFA36-ND prepared in Example 2 was used.

(2) Results

By comparing the amino acid sequences of FokI-ND, Sharkey mutation, and ND1 and ND2, the amino acid substitution site brought about by the Sharkey mutation was identified (Fig. 6). Fig. 6 shows the results. Note that each of the cleavage activities is shown as a relative activity when the cleavage activity of ZFA-FokI-ND having no Sharkey mutation is 1.

In ND1, the amino acids corresponding to the positions S418 and K441 of FokI-ND, which are the amino acid sites required for the introduction of the Sharkey mutation, were the same as those of FokI-ND and were S424 and K447, respectively. On the other hand, in ND2, the amino acid corresponding to the position S418 of FokI-ND was the same as that of the Sharkey mutation (P422), but the amino acid corresponding to the position K441 of FokI-ND was S445. Therefore, ND1 and ND2, in which the same amino acid substitutions as the Sharkey mutation were introduced into the above amino acid sites, were

designated as ND1-Sharkey and ND2-Sharkey, respectively. When the cleavage activity was measured using a luciferase reporter using these, the cleavage activity was increased by about 1.5 times in the Sharkey mutation of FokI-ND (Fig. 6B). As already reported, the Sharkey mutation has been shown to enhance the cleavage activity of FokI-ND. However, in both ND1-Sharkey and ND2-Sharkey, the cleavage activity was lower than that before the introduction of the amino acid substitutions, and the expected high cleavage activity was not obtained. This result means that the cleavage mechanism of the nucleases ND1 and ND2 is different from that of FokI-ND. Therefore, the novel nuclease domains ND1 and ND2 are different nuclease domains from FokI-ND.

Example 7: Cleavage Activity Using Heterodimer Type Nuclease Domains

When the target sequence is cleaved by a ZFN, FokI-ND forms a dimer. Furthermore, it is known that, by substituting a specific amino acid, FokI-ND can be functionally converted into a mutant such as DDD-type/RRR-type and the like which exhibit cleavage activity only at the time of heterodimer formation. Therefore, further analysis was performed in order to clarify whether the functional modifications for maintaining the cleavage activity would be possible in the novel nuclease domains ND1 and ND2.

By making an alignment with FokI-ND, it was verified whether the amino acids involved in heterodimer formation were also conserved in ND1 and ND2 (Fig. 1B). As a result, amino acids other than the histidine residue presenting most on the C-terminus side in the amino acid substitution site for the heterodimer type nuclease revealed by FokI-ND were also conserved in ND1 and ND2. From this, it was possible to infer that ND1 and ND2 could be functionally converted to the heterodimer type in the same manner as FokI-ND. Therefore, in ND1 and ND2, the cleavage activity during heterodimer formation was measured.

(1) Experimental Method

Substitutions were introduced at the relevant amino acid sites as shown in Table 2 in order to perform functional conversion to the heterodimer type for ND1 and ND2. Note that in the table, "FokI" means FokI-ND. In the table, the amino acid numbers are based on the full-length amino acids of each nuclease domain.

[Table 2]

Amino Acid Sequences of FokI Nuclease Domains and Homologs

Nuclease		Amino Acid Sequence of Nuclease Domain
FokI	-	GQADEMQRYVE.. TRNKH ..RLNHITN
FokI-DDD	R487D/N496D	GQADEMQDYVE.. TRDKH ..RLNHITN
FokI-RRR	D483R/H537R	GQAREMQRYVE.. TRNKH ..RLNRITN
ND1	-	SQADEMQRYVD.. NRNAI ..RVSNLTK
ND1-DDD	R493D/N502D	SQADEMQDYVD.. NRDAI ..RVSNLTK
ND1-RRR	D489R/N543R	SQAREMQRYVD.. NRNAI ..RVSRLTK
ND2	-	SQADEMERYRE.. DENEH ..RISIDTG
ND2-DDD	R487D/N496D	SQADEMEDYRE.. DEDEH ..RISIDTG
ND2-RRR	D483R/I537R	SQAREMERYRE.. DENEH ..RISRDTG

In order to analyze the heterodimer formation, the target half-site L and the target half-site R, which are the target sequences of the ZF array, need to be different sequences. A construct was constructed using a ZF array whose target sequence was a sequence different from the ZF array used in the previous examples. As the ZF array, hPGRN_ZFL1 was artificially synthesized by IDT (hereinafter also referred to as "ZFL1"). In order to replace the ZF array of each pSTL-ZFA36-ND prepared in Example 2 with hPGRN_ZFL1, each pSTL-ZFA36-ND was used as a template with a ZF array replacement primer pair, and PCR was performed by PrimeSTAR Max. The obtained PCR product and hPGRN_ZFL1 were reacted using In-Fusion and transformed into Escherichia coli. A plasmid was extracted from the obtained transformant, and the base sequence was confirmed to obtain each desired pSTL-hPGRN_ZFL1-ND plasmid.

Furthermore, in order to functionally convert the amino acids of the novel nuclease domains corresponding to the amino acids (D483, R487, and N496) involved in the heterodimerization of FokI-ND to the DDD-type, each pSTL-hPGRN_ZFL1-ND was used as a template and a primer pair was used to perform PCR by PrimeSTAR Max. Further, in order to convert the function to the RRR-type, each pSTL-ZFA36-ND was used as a template to perform PCR in the

same manner. Each of the obtained PCR products was transformed into *Escherichia coli* after an In-Fusion reaction. Plasmids were extracted from the obtained transformants, and after sequence confirmation, target constructs (hereinafter also referred to as "DDD-type mutant ZFL1-ND" and "RRR-type mutant ZFA36-ND") were prepared. The DDD-type ZFL1-ND and RRR-type ZFA36-ND obtained were used to perform an SSA reporter assay as described in Example 2 to measure the nuclease activity of each ZFN. Note that the amount of each ZFN plasmid in 7.2 μ L of the plasmid solution used in the SSA reporter assay was changed to 120 ng for the target half-site L and 120 ng for the target half-site R. In addition, nuclease activity was measured by the Cel-I assay in the same manner as described in Example 3.

(2) Results

Figs. 7 and 8A show the results of the SSA reporter assay. The cleavage activity was calculated by using a 6bp spacer sequence as in the reporter analysis so far, and in terms of relative activity with respect to the cleavage activity of ZFA36-FokI which recognizes two target sequences on the left and right. Fig. 8B shows the results of the Cel-I assay.

The cleavage activity of the target sequence (ZFL1-ZFL1) on the reporter was measured with a construct in which each nuclease domain was connected to ZFL1 so as

to be a homodimer, and the activity of ND1 and ND2 was higher than that of FokI-ND, similar to the results shown in Fig. 1C (Fig. 7A). From this result, it has been clarified that the high cleavage activity of the novel nuclease domains ND1 and ND2 is universal even when different ZF arrays are used.

When a homodimer was formed using a construct connecting ZFL1 and nuclease domains to measure the cleavage activity of the target sequence (ZFL1-ZFA36) on the reporter, ND1 had about 40% cleavage activity, but in FokI-ND and ND2, almost no cleavage activity was observed (Fig. 8A). On the other hand, when a homodimer was formed by the construct connecting the ZF array (ZFA36) used in Examples 2 to 6 and the nuclease domains to perform the analysis in the same manner, cleavage activity was also observed in FokI-ND and ND2, which were about 35% and about 50%, respectively. Further, in ND1, the cleavage activity was higher, about 90% (Fig. 8A).

When a heterodimer was formed using a ZFN construct, in which the ZF arrays of the homodimer type nuclease domains were ZFA36 and ZFL1, to analyze the cleavage activity, the activities of ND1 and ND2 were higher than those of FokI-ND as in the case of analysis with ZFA36 alone (Fig. 8A). From this, it has also been found that ND1 and ND2 have high cleavage activity and are universal regardless of the ZF array.

Next, in order to verify whether a dimer is formed and exhibits cleavage activity when only each heterodimer type nuclease domain is expressed, the cleavage activity of the target sequence (ZFL1-ZFL1 or ZFA36-ZFA36) on the reporter was measured. A DDD-type mutation was introduced into each nuclease domain connected to ZFL1, and an RRR-type mutation was introduced into each nuclease domain connected to ZFA36, and as a result of reporter analysis, almost no cleavage activity was observed in each of the DDD-type mutant ZFL1-ND and the RRR-type mutant ZFA36-ND alone (Figs. 7A and 7B). From this, it has been clarified that even in the novel nuclease domains ND1 and ND2, homodimers cannot be formed by introducing amino acid substitutions into DDD-type/RRR-type, as in the case of FokI-ND.

Each nuclease domain was transduced to form a heterodimer type to measure the cleavage activity of the target sequence (ZFL1-ZFA36) on the reporter. Fig. 8A shows the results. The cleavage activity in FokI-ND was reduced to about 60% of the target. However, in ND1, even in the heterodimer type, no decrease in cleavage activity was observed, and the activity was as high as about 1.6 times that of the target. On the other hand, in ND2, the cleavage activity almost disappeared when the heterodimer type was used. From these results, it has been clarified that ND1 is capable of functional conversion to a

heterodimer type having higher cleavage activity than FokI-ND.

Furthermore, in order to clarify the mutagenesis efficiency of each heterodimer type nuclease into the genome target sequence, analysis by Cel-I was performed (Fig. 8B). As shown in Table 1, the target base sequences on the genome were completely identical at the 1st site. Genomes were prepared from CHO-K1 cells expressing homodimer type and heterodimer type nucleases, and PCR fragments containing these target sequences were treated with Cel-I. Then, in the homodimer type, each nuclease domain cleaved the target genomic DNA, similar to the results previously obtained. On the other hand, in the heterodimer type, mutagenesis was observed in FokI-ND as well as the results of SSA reporter analysis, but the mutagenesis rate was higher in ND1. In ND2, no detectable mutagenesis was observed even in the target genome sequence, and it was considered that the cleavage activity was lost.

These results suggest that, unlike FokI-ND, ND1 is capable of functional conversion to a heterodimer type that maintains high activity, and also that conversion to the heterodimer type may result in significant structural changes in ND2, which means that each structural property is different from FokI-ND.

Example 8: Effect on Cleavage Activity Using Combination

of Heterodimer Type Nuclease Domains

Further analysis was conducted to determine whether it is possible to exhibit higher cleavage activity than conventional FokI-ND by changing the combination of nuclease domains during heterodimer formation.

The DDD-type mutant ZFL1-ND and RRR-type mutant ZFA36-ND prepared in Example 7 were used in various combinations, and the nuclease activity was measured by the SSA reporter assay in the same manner as described in Example 2. Fig. 9 shows the results.

When analysis was performed with a DDD-type mutation FokI-ND and each nuclease domain introduced with the RRR-type mutation, no increase in the cleavage activity of the reporter was observed even when combined with ND1 having a high cleavage activity so far, and it was about 60% of the cleavage activity of the FokI-ND homodimer type. In addition, almost no cleavage activity was observed in combination with ND2 (Fig. 9A).

The DDD-type mutant ND1 had a cleavage activity of about 80% in combination with the RRR-type mutant FokI-ND, and meanwhile, in combination with the RRR-type mutant ND2, the cleavage activity was almost lost as in the case of the DDD-type mutant FokI-ND (Fig. 9B).

Unlike the results of the DDD-type mutant FokI-ND and the DDD-type mutant ND1, the DDD-type mutant ND2 showed high cleavage activity only in combination with the

RRR-type mutant ND1, and almost lost its cleavage activity in combination with the RRR-type mutant FokI-ND or the RRR-type mutant ND2 (Fig. 9C). As a result, it has been clarified that in the case of the heterodimer type of the RRR-type mutant ND2, the cleavage activity is lost regardless of the combination of nuclease domains.

It has been found that a combination of heterodimer type nuclease domains showing cleaving activity is possible, and in the amino acid substitution analyzed this time, it is possible to enhance the cleavage activity only in the combination of the DDD-type mutant ND1 and the RRR-type mutant ND1. In addition, it has been revealed that the combination of the DDD-type mutant ND2 and the RRR-type mutant ND1 also has the same cleavage activity as the homodimer of FokI-ND. From the above results, it has been found that when ND1 and ND2 form a dimer, structural properties different from those of FokI-ND take action.

Example 9: Analysis at Base Sequence Level of Mutagenesis by ZFN

Investigation was made as to what change would take place in the base sequence due to the mutagenesis into the target sequence by ZFN.

(1) Sequence analysis

In order to clarify what change would be brought to the base sequence by the mutagenesis by ZFN into the target

sequences (1st site and 2nd site) of ZFA36 existing on the genome sequence of CHO-K1 cells, sequence analysis of the genomic region containing the target sequences was performed as follows. In the same manner as in the Cel-I assay described in Example 3, PCR was performed using KOD Fx Neo with the CHO-K1 genomic DNA transduced with each ZFN as a template. The obtained PCR product was subjected to TA cloning after A-addition to the PCR product by TArget clone plus (Toyobo). The PCR product was cloned in Escherichia coli, at least 16 independent Escherichia coli transformants were randomly selected, and each plasmid thereof was extracted. M13-f primers were added so that the obtained plasmid had a final concentration of 6.4 pmol at 400 ng, and Fasmac was requested to carry out PCR and sequence analysis. From the obtained sequence, the mutant sequence of the target sequence in each ZFN and its ratio were calculated.

(2) Results

Fig. 10 shows the results. At the 1st site of ZFA36-ZFA36, FokI-ND obtained 1 clone with 1-base insertion and 3 clones with 4-base insertion among the 17 clones analyzed. Of the 14 clones that could be analyzed in ND1, there was 1 clone for each of 1-base insertion, 2-base deletion, and 8-base deletion. Furthermore, 2 clones of mutation were obtained with 2-base insertion and 1-base deletion, and 6 clones of mutation were obtained

with 4-base insertion, which was the largest number in this analysis. Of the 13 clones that could be analyzed in ND2, there was 1 clone obtained for each of 1-base insertion, 2-base insertion, 2-base deletion, and 4-base deletion.

5 In the 15 clones of ND3 and the 16 clones of ND4 that could be analyzed, no base insertion or deletion was observed in the analysis of the ZFA36-ZFA36 1st site this time. In addition, the mutagenesis of each nuclease domain at the 2nd site of the ZFA36 target sequence was analyzed. Then,

10 in FokI, of the 20 clones analyzed, there was 1 clone obtained for each of 2-base insertion, 5-base insertion, and 2-base deletion, and 1 clone was obtained with insertion exceeding 230 bases. In addition, similar to the ZFA36 1st site, the most mutations were 4-base

15 insertion, and 3 clones were obtained. In ND1, of the 17 clones analyzed, there were 2 clones obtained for each of 2-base deletion and 4-base deletion. In addition, 3 clones were obtained with 4-base insertion, and 6 clones were obtained with 2-base insertion which was most

20 frequent in this analysis. Of the 16 clones analyzed in ND2, 1 clone was obtained with 1-base insertion, 2 clones were obtained with 2-base insertion, and 5 clones were obtained with 4-base insertion which was most frequent in the analysis. In addition, 1 clone was obtained with as

25 large a base insertion as 71 bases. In ND3, unlike the 1st site, mutagenesis was present in the target sequence

at the 2nd site, and in the analyzed 16 clones, there was 1 clone obtained for each of 2-base insertion, 2-base deletion, and 8-base deletion. In ND4, in all 14 clones that could be analyzed, no mutagenesis was observed in the target sequence at the 2nd site as well as at the 1st site.

As a result of sequence analysis, as for the mutagenesis into the target sequence by ND1 and ND2, many clones were observed with 4-bases insertion similar to FokI-ND, but various patterns not seen in FokI-ND were seen as mutations to the genome. The overhang of the base generated by the novel nuclease domains may differ from the FokI nuclease domain. Table 3 shows the mutation rates of ZFA36 obtained by sequence analysis at each target site. Under these analysis conditions, it has been clarified that, also in the sequence analysis, the mutagenesis rate of each nuclease domain in the target genome sequence is similar to that in the Cel-I assay.

[Table 3]

Genome Editing Mutation Rate in Sequence Analysis		
ZFA36-ND	ZFA36-ZFA36 1st site	ZFA36-ZFA36 2nd site
FokI-ND	4/17 (23.5%)	7/20 (35.0%)
ND1	11/14 (78.6%)	13/17 (76.5%)
ND2	4/13 (30.8%)	9/16 (56.3%)
ND3	0/15 (0.0%)	3/16 (18.8%)
ND4	0/16 (0.0%)	0/14 (0.0%)

Example 10: Cleavage Activity of Novel Nuclease Domains Combined with Nucleic Acid-Binding Domain Other Than ZFA

In order to clarify whether the novel nuclease domains of the present invention have higher cleavage activity than FokI-ND even when using a nucleic acid-binding domain other than ZFA, an artificial nucleic acid-cleaving enzyme containing ND1 and TALE was prepared, and its cleaving activity was measured. Specifically, TALE-FokI-ND and TALE-ND1 were prepared using the Platinum TALEN (doi: 10.1038/srep03379) technology developed in the laboratory of the present inventors, and their cleavage activity was evaluated by the SSA reporter assay method.

(1) Construction of destination vector for TALE-ND1

Platinum	TALEN	destination	vector
ptCMV-153/47-VR-NG	(https://www.addgene.org/50704/)		

uninserted with the nucleic acid binding module was used as a template, and a ptTALE-nuclease domain replacement primer pair (for vector amplification) was used for amplification by PrimeStar Max, to thereby obtain vector fragments. In addition, a ptTALE-nuclease domain replacement primer pair (for insert amplification) was used to obtain insert fragments of ND1. These vector fragments and insert fragments were mixed to carry out an In-Fusion reaction. After transformation of Escherichia coli, a plasmid was extracted from the obtained transformant to obtain a target destination vector of TALE-ND1 (a vector in which FokI-ND in ptCMV-153/47-VR-NG

was replaced with ND1).

(2) Incorporation of Nucleic Acid Binding Module and Construction of SSA Reporter Plasmid

The nucleic acid binding module for recognizing the sequences of ROSA26 locus and HPRT1 locus of CHO-K1 cells was incorporated into the destination vector obtained in (1) above by the Golden Gate method (based on the method described in doi: 10.1038/srep03379). This was used to transform Escherichia coli, and the desired plasmids (TALE-ROSA26-ND1 and TALE-HPRT1-ND1) were obtained from the obtained transformants. In addition, for TALEN (TALE-FokI) holding the conventional FokI-ND, constructs (TALE-ROSA26-FokI and TALE-HPRT1-FokI) incorporating a nucleic acid binding module were prepared in the same manner. As for the SSA reporter plasmids, those containing the respective target sequences (SSA-CHO-ROSA26 reporter and SSA-CHO-HPRT1 reporter) were prepared by a conventional method. Table 4 below shows the target sequences for the ROSA26 locus and HPRT1 locus.

[Table 4]

Target Sequences at ROSA26 Locus and HPRT1 Locus of CHO-K1 Cells

ROSA26:
5'-TGCCCAGAAGACTCCCGcccatctccagaaaGCCTCGACTTGCAGATCA-3'
3'-ACGGGTCTTCTGAGGGCgggtagagggtctttCGGAGCTGAACGTCTAGT-5'

HPRT1:
5'-TGAACCAGGCTATGACCTagatttattttgtatTCCTAATCACTATGTCTGA

-3'

3'-ACTTGGTCCGATACTGGAtctaaataaaacataAGGATTAGTGATACAGCT

-5'

The underlines mean the DNA recognition sequences of TALEN (left side and right side) at each locus, and the lowercase letters mean the spacer sequence between the DNA recognition sequences.

(3) Introduction into Cells and Reporter Assay

By use of the TALEN plasmids (TALE-FokI-ND and TALE-ND1) incorporating the nucleic acid binding module for recognizing the target sequence, and the SSA reporter plasmids incorporating the target sequence prepared in (2) above, transduction was performed on HEK293T cells using Lipofectamine LTX, and using the cells 24 hours after transduction, SSA reporter assay was performed in the same manner as in Example 2. As controls, a ZFN plasmid containing FokI-ND (pSTL-ZFA36) and a plasmid pSTL expressing only FokI-ND were used to perform measurement in a similar manner. The cleavage activity of each TALE-ND was calculated as a relative activity when the value of the cleavage activity of ZFA36-FokI with respect to the reporter containing the target sequence of ZFA36 was set to 1.

(4) Results

Figs. 11A and 11B show the results. Fig. 11A shows the results when the sequence derived from the ROSA26 locus was the target, and Fig. 11B shows the results when the sequence derived from the HPRT1 locus was the target.

As is clear from Fig. 11A, in TALE-ROSA26-FokI in which the nuclease domain of Platinum TALEN is conventional FokI-ND, it has been revealed that the cleavage activity of the reporter targeting the sequence derived from the ROSA26 locus has an activity close to the cleavage activity of ZFA36-FokI targeting the ZFA36 reporter. On the other hand, in TALE-ROSA26-ND1 in which the nuclease domain of Platinum TALEN is replaced with ND1, it has been revealed that the cleavage activity of the reporter targeting the sequence derived from the ROSA26 locus is about twice as high as that of TALE-ROSA26-FokI. Based on the above, when targeting the ROSA26 locus-derived sequence of the endogenous genome of CHO-K1 cells, it has been revealed that TALE-ND1 has a higher cleavage activity in the nuclease domain than the conventional FokI-ND, TALE-FokI.

In addition, a sequence derived from the HPRT1 locus, which is a locus different from the ROSA26 locus, was targeted and analyzed in the same manner. As a result, as is clear from Fig. 11B, in TALE-HPRT1-FokI in which the nuclease domain of Platinum TALEN is conventional FokI-ND, it has been revealed that the cleavage activity of the reporter targeting the HPRT1 locus-derived sequence is about half of the cleavage activity of ZFA36-FokI targeting the ZFA36 reporter. On the other hand, in TALE-HPRT1-ND1 in which the nuclease domain of Platinum

TALEN is replaced with ND1, the cleavage activity of the reporter targeting the HPRT locus-derived sequence was about twice as high as that of TALE-FokI, and the same result as that of the ROSA26 locus-derived sequence was obtained.

From these results, it has been clarified that TALE-ND1 having ND1 as the nuclease domain of Platinum TALEN shows higher cleavage activity than TALE-FokI having the conventional FokI-ND. From the above, it has been suggested that the novel nuclease domains of the present invention are nuclease domains having better cleavage activity than FokI-ND even when in the case of using not only ZFN but also other nucleic acid binding domains.

From the above, it has been demonstrated that the novel nuclease domains of the present invention have the following main characteristics.

(i) ND1 and ND2 of the present invention, especially ND1, have significantly higher cleavage activity than FokI-ND. In addition, since ND1 shows a cleavage activity higher than FokI-ND even in ZF array that recognizes other sequences and in TALE, the effect of increasing cleavage activity by ND1 is universal.

(ii) By modifying the linker between the ZF array and ND, ND1 exhibits about the same cleavage activity as the 6bp spacer even with a 5bp or 7bp spacer, and therefore ND1 has higher flexibility than FokI-ND in dimerization

and can relax the restriction of the target sequence.

(iii) By introducing a DDD-type mutation and an RRR-type mutation into ND1 and ND2, homodimerization can be suppressed as in FokI-ND. Furthermore, by combining ZFL1-DDD and ZFA36-RRR, cleavage with a heterodimer is possible in ND1. Further, since the cleavage activity at that time is about the same as that of the wild-type ND1, it is possible to obtain a nuclease domain having both high specificity and high cleavage activity by using ND1-DDD/RRR.

(iv) When the activity was verified by combining DDD/RRR-type FokI-ND, ND1, and ND2 with each other, it was revealed that the pair of ND1-DDD and ND1-RRR showed the highest activity among all the combinations, demonstrating the superiority of the ND1-DDD/ND1-RRR heterodimer system.

Example 11: Preparation of Protein in Escherichia Coli

(1) Construction of Expression Vectors for ZF-ND1 and ZF-FokI

The XhoI site and SalI site of the pET-MCS plasmid containing a His tag at the N-terminus were cleaved, and a ZF-ND1 fragment was inserted. The ZF-ND1 fragment contains the nuclear localization signal NLS, Zinc-Finger (hereinafter abbreviated as ZF), and the nuclease domain ND1. As ZF, a domain that recognizes two types of sequences was used. One is ZFA36, which recognizes the

12 base pair DNA sequence GAAGATGGT. The other is ZFL1, which recognizes the 12 base pair DNA sequence GAAGGTGAC. Therefore, as plasmids expressing ZF (ZFA36A)-ND1 and ZF (ZFL1)-ND1, pET-ZF (ZFA36A) ND1 and pET-ZF (ZFL1) ND1 were prepared, respectively.

Based on the above plasmids, plasmids in which the nuclease domain of the restriction enzyme FokI (hereinafter abbreviated as FokI) was inserted instead of ND1, pET-ZF (ZFA36A)-FokI, and pET-ZF (ZFL1)-FokI were prepared. The amino acid sequences of ZF (ZFA36A)-ND1, ZF (ZFL1)-ND1, ZF (ZFA36A)-FokI, and ZF (ZFL1)-FokI are set forth in SEQ ID NOs: 119 to 122.

(2) Expression and Purification of ZF-ND1 Protein in Escherichia Coli

The pET plasmid expressing ZF-ND1 or ZF-FokI, and pRARE2 (Stratagene) were transformed into Escherichia coli strain BL21 (DE3) and cultured in LB medium containing kanamycin and chloramphenicol. The transformed Escherichia coli was cultured at 37°C until the OD (absorbance at 600 nm) became 0.6, and then cultured at 18°C for 1 hour. Isopropyl β -D-1-thiogalactopyranoside (IPTG) was added to a final concentration of 0.1 mM to induce protein expression. After further shaking and culturing at 18°C for 17 hours, Escherichia coli was lysed using a lysis buffer (20 mM Tris-HCl, 500 mM NaCl, 10% glycerol, 10 mM imidazole, 1 mM benzyl sulfonyl fluoride,

1 mM dithiothreitol, pH 8.0). Subsequently, the protein was adsorbed on a nickel NTA column, and a washing buffer (20 mM Tris-HCl, 500 mM NaCl, 10% glycerol, 20 mM imidazole, pH 8.0) was used to remove impurities. Elution of the protein was performed using an elution buffer (20 mM Tris-HCl, 500 mM NaCl, 10% glycerol, 500 mM imidazole, pH 8.0). A portion of the eluted protein was dissolved in SDS sample buffer for protein yield analysis. The eluted protein was purified using gel filtration chromatography HiPrep 16/60 Sephacryl S-200 HR (GE healthcare, United States, Illinois) and buffer A (20 mM HEPES, 150 mM NaCl, 10% glycerol, pH 7.4), frozen instantly with liquid nitrogen, and then stored at -80°C. For analysis of protein yield, the imidazole-eluted protein fraction and the final purified protein were dissolved in SDS sample buffer and electrophoresed by SDS-PAGE. During electrophoresis, a known concentration of BSA protein was electrophoresed in another lane, the gel after PAGE was stained with Coomassie, the band of the target protein molecular weight was quantified by ChemiDoc XRS+, and the protein yield was analyzed from the protein molecular weight.

(3) Results

When expressing and purifying ZFN proteins in *Escherichia coli*, there is a problem that the protein yield is low. It is considered the fundamental properties of

ZFN proteins are that they are low in solubility, resulting in aggregation. It was verified how soluble the protein of the novel ND1 was compared to the FokI as the conventional art.

5 [Table 5]

	Protein Yield per 1 L of Escherichia Coli Culture (nmol/culture L)	Increase (Times) in Protein Yield of ND1 When Compared to FokI
ZF(ZFA36A)-ND1 Protein	104.8	11
ZF(ZFA36A)-FokI Protein	9.3	(1)
ZF(ZFL1)-ND1 Protein	67.6	13
ZF(ZFL1)-FokI Protein	5.0	(1)

As shown in Table 5, when ZF-ND1 was expressed in Escherichia coli, it was generally more soluble than ZF-FokI, and the yield per 1 L of Escherichia coli culture was improved. The higher the solubility, the higher the concentration of protein that can be introduced, which therefore is particularly convenient for genome editing using protein.

Example 12: Activity of ZF-ND1 and ZF-FokI in Plant Cells

(1) Construction of Reporter Cells

In order to evaluate the activity of ZF-ND1 or ZF-FokI, reporter cells were constructed that expresses a full-length 2.1 kb GUS (β -glucuronidase) gene when SSA (single-strand annealing) after DNA cleavage is induced.

Specifically, 1.8 kb from the upstream of the GUS gene, the recognition sequence of ZFA36 (GAAGCTGGT), and 0.8 kb from the downstream of the GUS gene were introduced into pCAMBIA 1305.2 (Marker Gene). Regarding 1.8 kb from the upstream of the GUS gene and 0.8 kb from the downstream of the GUS gene, they have 500 bp as a common sequence (overlap region). This vector was transformed via *Agrobacterium* into an *Arabidopsis thaliana* T87 cultured cell line (RIKEN), and the established cell line was designated as T87-GUUS (ZFA36). Since the expression of GUS can be easily visualized and detected using the blue staining reagent X-Gluc, the detection of the GUS protein allows the evaluation of the introduction of ZF-ND1 or ZF-FokI into the nucleus and the SSA-inducing activity.

(2) Introduction by Electroporation Method

The protein prepared in Example 11 was introduced by the electroporation method. The established T87-GUUS (ZFA36) cells were used to attempt to introduce ZF-ND1 and ZF-FokI by electroporation into T87 cells having a cell wall. NEPA21 Type II sold by Neppa Gene was used for electroporation. Electroporation was performed using Opti-MEMI buffer, and the GUS activity was evaluated two days later. As a result, as shown in Fig. 12, when electroporation was performed using Opti-MEMI, a very large number of cells expressed GUS. In the experiment using the ZF-ND1 protein, it was found that the

SSA-inducing activity was about twice as high as that in the case of using the ZF-FokI protein. In the experiment, it has been found that, when introduced not only as a gene expression vector but also as a protein, ZF-ND1 has higher activity than that of ZF-FokI, and that ZF-ND1 has higher activity than ZF-FokI not only in animal cells but also in plant cells.

(3) Introduction by Protein Transduction Method

The protein prepared in Example 11 was used to attempt introduction by the protein transduction method. That is, to T87-GUUS (ZFA36) having a cell wall, ZF (ZFA36A)-ND1 protein or ZF (ZFA36A)-FokI protein having a final concentration of 0.1 to 2 μ M was added, and then, after 1 hour, the mixture was washed with a culture medium and cultured for 3 days. When the protein was added, no biochemical treatment such as protease treatment or physicochemical treatment such as electroporation was performed. Therefore, spontaneous intake of the protein was expected. As a result, as shown in Fig. 13, although it is a small proportion compared to the electroporation method, it has been revealed that the ZF (ZFA36A)-ND1 protein and the ZF (ZFA36A)-FokI protein are taken in by the protein transduction method, allowing genome editing. When the protein transduction method was used, the activity of ZF (ZFA36A)-ND1 was equal to or higher than that of ZF (ZFA36A)-FokI.

[Industrial Applicability]

The novel nuclease domains of the present invention have excellent properties different from the nuclease domain of FokI, and the artificial nucleic acid-cleaving enzyme containing the nuclease domains of the present invention is very useful as a genome editing tool.

[Sequence Listing Free Text]

SEQ ID NO: 9; ND1 substitution forward primer

SEQ ID NO: 10; ND1 substitution reverse primer

SEQ ID NO: 11; ND2 substitution forward primer

SEQ ID NO: 12; ND2 substitution reverse primer

SEQ ID NO: 13; ND3 substitution forward primer

SEQ ID NO: 14; ND3 substitution reverse primer

SEQ ID NO: 15; ND4 substitution forward primer

SEQ ID NO: 16; ND4 substitution reverse primer

SEQ ID NO: 17; forward primer for linker alteration,
ZFN-FokI-GS-F

SEQ ID NO: 18; reverse primer for linker alteration,
ZFN-GS-inverse-R

SEQ ID NO: 19; forward primer for linker alteration,
ZFN-ND1-GS-F

SEQ ID NO: 20; reverse primer for linker alteration,
ZFN-GS-inverse-R

SEQ ID NO: 21; forward primer for linker alteration,
ZFN-ND2-GS-F

SEQ ID NO: 22; reverse primer for linker alteration,

ZFN-GS-inverse-R

SEQ ID NO: 23; forward primer for linker alteration,
ZFN-FokI-RPGEKP-F

SEQ ID NO: 24; reverse primer for linker alteration,
5 ZFN-RPGEKP-R

SEQ ID NO: 25; forward primer for linker alteration,
ZFN-ND1-RPGEKP-F

SEQ ID NO: 26; reverse primer for linker alteration,
ZFN-RPGEKP-R

10 SEQ ID NO: 27; forward primer for linker alteration,
ZFN-ND2-RPGEKP-F

SEQ ID NO: 28; reverse primer for linker alteration,
ZFN-RPGEKP-R

SEQ ID NO: 29; forward primer for linker alteration,
15 ZFN-FokI-TGPGAAARA-F

SEQ ID NO: 30; reverse primer for linker alteration,
ZFN-FokI-TGPGAAARA-R

SEQ ID NO: 31; forward primer for linker alteration,
ZFN-ND1-TGPGAAARA-F

20 SEQ ID NO: 32; reverse primer for linker alteration,
ZFN-FokI-TGPGAAARA-R

SEQ ID NO: 33; forward primer for linker alteration,
ZFN-ND2-TGPGAAARA-F

SEQ ID NO: 34; reverse primer for linker alteration,
25 ZFN-FokI-TGPGAAARA-R

SEQ ID NO: 35; forward primer for Sharkey mutation

introduction in FokI-ND

SEQ ID NO: 36; reverse primer for Sharkey mutation
introduction in FokI-ND

SEQ ID NO: 37; forward primer for Sharkey mutation
5 introduction in ND1

SEQ ID NO: 38; reverse primer for Sharkey mutation
introduction in ND1

SEQ ID NO: 39; forward primer for Sharkey mutation
introduction in ND2

10 SEQ ID NO: 40; reverse primer for Sharkey mutation
introduction in ND2

SEQ ID NO: 41; ZFA substitution forward primer

SEQ ID NO: 42; ZFA substitution reverse primer

SEQ ID NO: 43; forward primer for FokI-DDD mutation
15 introduction

SEQ ID NO: 44; reverse primer for FokI-DDD mutation
introduction

SEQ ID NO: 45; forward primer for ND1-DDD mutation
introduction

20 SEQ ID NO: 46; reverse primer for ND1-DDD mutation
introduction

SEQ ID NO: 47; forward primer for ND2-DDD mutation
introduction

SEQ ID NO: 48; reverse primer for ND2-DDD mutation
25 introduction

SEQ ID NO: 49; forward primer for FokI-RRR vector mutation

introduction

SEQ ID NO: 50; reverse primer for FokI-RRR vector mutation

introduction

SEQ ID NO: 51; forward primer for FokI-RRR insert mutation

5 introduction

SEQ ID NO: 52; reverse primer for FokI-RRR insert mutation

introduction

SEQ ID NO: 53; forward primer for ND1-RRR vector mutation

introduction

10 SEQ ID NO: 54; reverse primer for ND1-RRR vector mutation

introduction

SEQ ID NO: 55; forward primer for ND1-RRR insert mutation

introduction

SEQ ID NO: 56; reverse primer for ND1-RRR insert mutation

15 introduction

SEQ ID NO: 57; forward primer for ND2-RRR vector mutation

introduction

SEQ ID NO: 58; reverse primer for ND2-RRR vector mutation

introduction

20 SEQ ID NO: 59; forward primer for ND2-RRR insert mutation

introduction

SEQ ID NO: 60; reverse primer for ND2-RRR insert mutation

introduction

SEQ ID NO: 61; M13-F primer

25 SEQ ID NO: 62; CHO-K1 ZFA36-ZFA36 target 1st site

SEQ ID NO: 63; CHO-K1 ZFA36-ZFA36 target 2nd site

SEQ ID NO: 64; CHO-K1 ZFA36-ZFA36 target 3rd site

SEQ ID NO: 65; CHO-K1 ZFL1-ZFA36 target 1st site

SEQ ID NO: 66; CHO-K1 ZFL1-ZFA36 target 2nd site

SEQ ID NO: 67; FokI-DDD amino acid sequence

5 SEQ ID NO: 68; FokI-RRR amino acid sequence

SEQ ID NO: 69; ND1-DDD amino acid sequence

SEQ ID NO: 70; ND1-RRR amino acid sequence

SEQ ID NO: 71; ND2-DDD amino acid sequence

SEQ ID NO: 72; ND2-RRR amino acid sequence

10 SEQ ID NO: 73; FokI-S418P/K441E amino acid sequence

SEQ ID NO: 74; ND1-S418P/K441E amino acid sequence

SEQ ID NO: 75; ND2-S441E amino acid sequence

SEQ ID NO: 76; FokI-cleaved CHO-K1 ZFA36-ZFA36 target 1st site

15 SEQ ID NO: 77; FokI-cleaved CHO-K1 ZFA36-ZFA36 target 1st site

SEQ ID NO: 78; FokI-cleaved CHO-K1 ZFA36-ZFA36 target 1st site

SEQ ID NO: 79; ND1-cleaved CHO-K1 ZFA36-ZFA36 target 1st site

20 SEQ ID NO: 80; ND1-cleaved CHO-K1 ZFA36-ZFA36 target 1st site

SEQ ID NO: 81; ND1-cleaved CHO-K1 ZFA36-ZFA36 target 1st site

25 SEQ ID NO: 82; ND1-cleaved CHO-K1 ZFA36-ZFA36 target 1st site

SEQ ID NO: 83; ND1-cleaved CHO-K1 ZFA36-ZFA36 target 1st
site

SEQ ID NO: 84; ND1-cleaved CHO-K1 ZFA36-ZFA36 target 1st
site

5 SEQ ID NO: 85; ND2-cleaved CHO-K1 ZFA36-ZFA36 target 1st
site

SEQ ID NO: 86; ND2-cleaved CHO-K1 ZFA36-ZFA36 target 1st
site

10 SEQ ID NO: 87; ND2-cleaved CHO-K1 ZFA36-ZFA36 target 1st
site

SEQ ID NO: 88; ND2-cleaved CHO-K1 ZFA36-ZFA36 target 1st
site

SEQ ID NO: 89; ND2-cleaved CHO-K1 ZFA36-ZFA36 target 1st
site

15 SEQ ID NO: 90; ND3-cleaved CHO-K1 ZFA36-ZFA36 target 1st
site

SEQ ID NO: 91; ND4-cleaved CHO-K1 ZFA36-ZFA36 target 1st
site

20 SEQ ID NO: 92; FokI-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

SEQ ID NO: 93; FokI-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

SEQ ID NO: 94; FokI-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

25 SEQ ID NO: 95; FokI-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

SEQ ID NO: 96; FokI-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

SEQ ID NO: 97; FokI-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

5 SEQ ID NO: 98; ND1-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

SEQ ID NO: 99; ND1-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

10 SEQ ID NO: 100; ND1-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

SEQ ID NO: 101 ND1-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

SEQ ID NO: 102 ND1-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

15 SEQ ID NO: 103; ND2-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

SEQ ID NO: 104; ND2-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

20 SEQ ID NO: 105; ND2-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

SEQ ID NO: 106; ND2-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

25 SEQ ID NO: 107; ND2-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

SEQ ID NO: 108; ND3-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

SEQ ID NO: 109; ND3-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

SEQ ID NO: 110; ND3-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

5 SEQ ID NO: 111; ND3-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

SEQ ID NO: 112; ND4-cleaved CHO-K1 ZFA36-ZFA36 target 2nd
site

SEQ ID NO: 113; forward primer for vector amplification
10 for ptTALE-ND substitution, ptTALEN-inverse-F

SEQ ID NO: 114; reverse primer for vector amplification
for ptTALE-ND substitution, NC-inverse-R_2

SEQ ID NO: 115; forward primer for insert amplification
for ptTALE-ND substitution, ND1-NC-F_v2

15 SEQ ID NO: 116; reverse primer for insert amplification
for ptTALE-ND substitution, ND1-ptTALEN-R

SEQ ID NO: 117; target sequence on ROSA26 locus in CHO-K1
cell

SEQ ID NO: 118; target sequence on HPRT1 locus in CHO-K1
20 cell

SEQ ID NO: 119; ZF(ZFA36A)-ND1 amino acid sequence

SEQ ID NO: 120; ZF(ZFL1)-ND1 amino acid sequence

SEQ ID NO: 121; ZF(ZFA36A)-FokI amino acid sequence

SEQ ID NO: 122; ZF(ZFL1)-FokI amino acid sequence

25

[CLAIMS]

[Claim 1]

An artificial nucleic acid-cleaving enzyme comprising:

5 a nuclease domain which is a polypeptide containing an amino acid sequence set forth at positions 391 to 585 of SEQ ID NO: 1 or positions 389 to 579 of SEQ ID NO: 3, or a mutant polypeptide thereof; and

a nucleic acid-binding domain,

10 wherein the mutant polypeptide is a polypeptide containing an amino acid sequence having at least 90% sequence identity with the amino acid sequence set forth at positions 391 to 585 of SEQ ID NO: 1 or positions 389 to 579 of SEQ ID NO: 3 and having nuclease activity,
15 and

wherein the nucleic acid-binding domain contains a zinc finger, TALE, CRISPR/Cas, or PPR.

[Claim 2]

20 The artificial nucleic acid-cleaving enzyme according to claim 1, further comprising: a linker located between the nuclease domain and the nucleic acid-binding domain.

[Claim 3]

25 An isolated nucleic acid comprising: a nucleic acid sequence encoding the artificial nucleic acid-cleaving enzyme according to any one of claims 1 or 2.

[Claim 4]

A vector comprising: the nucleic acid according to claim 3, or a transcription product or translation product thereof.

5 [Claim 5]

A method for modifying a target nucleic acid, comprising: introducing into a cell (except for a cell present in a human body, a cell present in a non-human animal body, a human germ cell and a human embryonic cell), the artificial nucleic acid-cleaving enzyme according to any one of claims 1 or 2, the nucleic acid according to claim 3, or the vector according to claim 4.

[Claim 6]

15 The method according to claim 5, wherein the artificial nucleic acid-cleaving enzyme, nucleic acid, or vector is two or more kinds of artificial nucleic acid-cleaving enzymes, a nucleic acid encoding the two or more kinds of artificial nucleic acid-cleaving enzymes, or a vector containing the nucleic acid, a transcription product thereof, or a translation product thereof.

20 [Claim 7]

A kit for modifying a target nucleic acid, comprising: the artificial nucleic acid-cleaving enzyme according to any one of claims 1 or 2, the nucleic acid

according to claim 3, or the vector according to claim 4.

[Claim 8]

5 The kit according to claim 7, wherein the
artificial nucleic acid-cleaving enzyme, nucleic acid,
or vector is two or more kinds of artificial nucleic
acid-cleaving enzymes, a nucleic acid encoding the two
or more kinds of artificial nucleic acid-cleaving
enzymes, or a vector containing the nucleic acid, a
10 transcription product thereof, or a translation product
thereof.