

FULLY HUMAN ANTI-MESOTHELIN ANTIBODIES AND IMMUNE EFFECTOR CELLS TARGETING MESOTHELIN

Technical field

The present invention relates to the field of immunotherapy or diagnosis of tumor, and in particular, to fully human anti-mesothelin antibodies and immune effector cells targeting mesothelin.

Background

The role of immune effector cells in the tumor immune response is gaining more and more attention. Adoptive immunotherapy based on immune effector cells has achieved some effects in some tumors, and this immunotherapy method can overcome the defects of antibody treatment, however the therapeutic effects in most tumors are still unsatisfactory [Grupp SA, et al. Adoptive cellular therapy. Curr Top Microbiol Immunol., 2011; 344: 149-72.]. In recent years, it was discovered that the recognition specificity of cytotoxic lymphocytes (CTLs) to target cells depends on T cell receptors (TCRs), scFv of antibodies against tumor cell associated antigens and intracellular signal-activating motifs of T lymphocyte receptor CD3 ζ or Fc ϵ RI γ were fused to a chimeric antigen receptor (CAR), and T lymphocyte was genetically modified by the chimeric antigen receptors on its surface by means of, for example, lentivirus infection. Such CAR T lymphocytes are capable of selectively targeting T lymphocytes to tumor cells and specifically killing the tumor in a non-limiting manner by Major Histocompatibility Complex (MHC). CAR T lymphocyte is a new immunotherapy strategy in the field of tumor immunotherapy. CAR modified NK cells or NKT cells also exhibit antitumor activities in preclinical studies.

When designing CAR-modified immune effector cells, especially T cells, the targeted antigen genes are in fact a crucial choice. Given the complexity of gene expressions in vivo and various uncontrollable factors, selection for suitable genes for a CAR is very difficult. Moreover, for many tumor-specific antigens, it is difficult to find a specific molecule directed against them and suitable for constructing CAR-modified immune effector cells.

Mesothelin is a cell surface glycoprotein, molecular weight of which is 40-kDa. It is highly expressed in a variety of tumors, such as pancreatic cancer, ovarian cancer, and thymus mesothelioma. In normal tissues, it is expressed only on the normal mesothelial cells of the pleura, pericardium and peritoneum. Mesothelin is synthesized as a 71 kDa precursor protein, the mature portion of which is expressed on the cell surface. The precursor protein is

proteolytically cleaved by furin into a 31 kDa shedding part (termed megakaryocyte chimeric factor, or MPF) and a 40 kDa mesothelin fraction). The latter component may remain bound to the cell surface via GPI linkage and may also shed off via the proteolytic enzyme mechanism.

Antibodies against mesothelin or other targeted therapies have been reported. CAR-T has also been reported in clinical studies (Maus MV, Haas AR, Beatty GL, Albelda SM, Levine BL, Liu X, Zhao Y, Kalos M, June CH. T cells expressing chimeric antigen receptors can cause anaphylaxis in humans. *Cancer Immunol Res.* 2013; 1 (1): 26-31; Beatty GL, Haas AR, Maus MV, Torigian DA, Soulen MC, Plesa G, Chew A, Zhao Y, Levine BL, Albelda SM, Kalos M, June CH. Mesothelin-specific chimeric antigen receptor mRNA-engineered T cells induce anti-tumor activity in solid malignancies. *Cancer Immunol Res.* 2014 Feb; 2 (2): 112-20). However, it has also been found that CAR-T constructed with mouse anti-human mesothelin antibody clinically shows side effects, such as anti-mouse antibody and allergy, indicating that mesothelin may be a potential therapeutic target, but the properties of the antibody itself may affect its efficacy and side effects. Therefore, there is still a need in the art to find solutions that can overcome problems caused by antibodies that are not ideal or have toxic side effects.

Summary of the invention

It is an object of the present invention to provide fully human anti-mesothelin antibodies as well as immune effector cells targeting mesothelin.

In the first aspect of the invention, a fully human antibody that specifically binds to mesothelin is provided, which is selected from a group consisting of:

(a) an antibody comprising a heavy chain variable region having CDR1 comprising the amino acid sequence of SEQ ID NO: 54, CDR2 comprising the amino acid sequence of SEQ ID NO: 55, CDR3 comprising the amino acid sequence of SEQ ID NO: 56;

(b) an antibody comprising a light chain variable region having CDR1 comprising the amino acid sequence of SEQ ID NO: 51, CDR2 comprising the amino acid sequence of SEQ ID NO: 52, CDR3 comprising the amino acid sequence of SEQ ID NO: 53;

(c) an antibody comprising a heavy chain variable region of said antibody of (a) and a light chain variable region of said antibody of (b);

(d) an antibody comprising a heavy chain variable region having CDR1 comprising the amino acid sequence of SEQ ID NO: 60, CDR2 comprising the amino acid sequence of SEQ ID NO: 61, CDR3 of the amino acid sequence of ID NO: 62;

(e) an antibody comprising a light chain variable region having CDR1 comprising the

amino acid sequence of SEQ ID NO: 57, CDR2 comprising the amino acid sequence of SEQ ID NO: 58, CDR3 of the amino acid of ID NO: 59;

(f) an antibody comprising a heavy chain variable region of said antibody of (d) and a light chain variable region of the antibody of (e);

(g) an antibody which recognizes the same antigenic determinant as that recognized by the antibody according to any one of (a) to (f).

In a preferred embodiment, the fully human antibody comprises a heavy chain variable region and a light chain variable region, the amino acid sequence of the heavy chain variable region is shown in positions 1 to 123 of SEQ ID NO: 6; and the amino acid sequence of the light chain variable region is shown in positions 139-254 of SEQ ID NO: 6; or

the fully human antibody comprises a heavy chain variable region and a light chain variable region, the amino acid sequence of the heavy chain variable region is shown in positions 1 to 124 of SEQ ID NO: 8; and the amino acid sequence of the light chain variable region is shown in positions 140-247 of SEQ ID NO: 8.

In another preferred embodiment, the fully human antibody that specifically binds to mesothelin may be single chain antibody (scFv), monoclonal antibody, domain antibody, Fab fragment, Fd fragment, Fv fragment, F(ab')₂ fragment and a derivative thereof, or other forms of antibody; preferably single chain antibody.

In another aspect of the invention, a nucleic acid encoding the antibody is provided.

In another aspect of the invention, an expression vector comprising the nucleic acid is provided.

In another aspect of the invention, a host cell is provided, which comprises the expression vector or has the nucleic acid integrated into the genome.

In another aspect of the present invention, use of the antibodies described above is provided for the preparation of a targeted drug, antibody-drug conjugate, or a polyfunctional antibody that specifically targets tumor cells expressing mesothelin; or for the preparation of a reagent for diagnosing a tumor expressing mesothelin; or for the preparation of chimeric antigen receptor-modified immune cells.

In another aspect of the present invention, a chimeric antigen receptor (CAR) of the antibody is provided, and said chimeric antigen receptor comprises sequentially linked: the antibody of the present invention, a transmembrane region and intracellular signal region.

In a preferred embodiment, the intracellular signal region is selected from a group consisting of intracellular signal region sequences of CD3 ζ , Fc ϵ RI γ , CD27, CD28, CD137, CD134, MyD88, CD40 or a combination thereof.

In another preferred embodiment, the transmembrane region comprises a transmembrane region of CD8 or CD28.

In another preferred embodiment, the chimeric antigen receptor comprises the following sequentially linked antibody, transmembrane region and intracellular signal region:

The antibody, CD8 and CD3 ζ ;

The antibody, CD8, CD137 and CD3 ζ ;

The antibody, the transmembrane region of CD28 molecule, the intracellular signal region of CD28 molecule and CD3 ζ ; or

The antibody, the transmembrane region of CD28 molecule, the intracellular signal region of CD28 molecule, CD137 and CD3 ζ .

In another preferred embodiment, the antibody is a single chain antibody or domain antibody.

In another preferred embodiment, the chimeric antigen receptor has:

SEQ ID NO: 41 or the amino acid sequence shown in positions 22-353 thereof;

SEQ ID NO: 42 or the amino acid sequence shown in positions 22-454 thereof;

SEQ ID NO: 43 or the amino acid sequence shown in positions 22-498 thereof;

SEQ ID NO: 44 or the amino acid sequence shown in positions 22-501 thereof;

SEQ ID NO: 45 or the amino acid sequence shown in positions 22-543 thereof;

SEQ ID NO: 46 or the amino acid sequence shown in positions 22-346 thereof;

SEQ ID NO: 47 or the amino acid sequence shown in positions 22-447 thereof;

SEQ ID NO: 48 or the amino acid sequence shown in positions 22-491 thereof;

SEQ ID NO: 49 or the amino acid sequence shown in positions 22-494 thereof; or

SEQ ID NO: 50 or the amino acid sequence shown in positions 22-536 thereof.

In another aspect of the invention, a nucleic acid encoding the chimeric antigen receptor is provided.

In another preferred embodiment, the nucleic acid encoding the chimeric antigen receptor has:

SEQ ID NO: 31 or the nucleotide sequence set forth in positions 473-1468 thereof;

SEQ ID NO: 32 or the nucleotide sequence set forth in positions 473-1771 thereof;

SEQ ID NO: 33 or the nucleotide sequence set forth in positions 473-1903 thereof;

SEQ ID NO: 34 or the nucleotide sequence set forth in positions 473-1912 thereof;

SEQ ID NO: 35 or the nucleotide sequence set forth in positions 473-2038 thereof;

SEQ ID NO: 36 or the nucleotide sequence set forth in positions 473-1447 thereof;

SEQ ID NO: 37 or the nucleotide sequence set forth in positions 473-1750 thereof;

SEQ ID NO: 38 or the nucleotide sequence set forth in positions 473-1882 thereof;

SEQ ID NO: 39 or the nucleotide sequence set forth in positions 473-1891 thereof;

SEQ ID NO: 40 or the nucleotide sequence set forth in positions 473 to 2017 thereof.

In another aspect of the present invention, an expression vector comprising the nucleic acid is provided.

In another preferred embodiment, the expression vector is derived from lentiviral plasmid pWPT (or pWPT-eGFP).

In another aspect of the present invention, a virus comprising said vector is provided.

In another aspect of the invention, use of the chimeric antigen receptor, or the nucleic acid, or the expression vector, or the virus is provided for the preparation of genetically modified immune cells targeting tumor cells expressing mesothelin.

In a preferred embodiment, the mesothelin-expressing tumor includes, but is not limited to pancreatic cancer, ovarian cancer and thymus mesothelioma.

In another aspect of the present invention, a genetically modified immune cell is provided, which is transduced with the nucleic acid, or the expression vector or the virus; or expresses the chimeric antigen receptor on its surface-expressed.

In a preferred embodiment, the immune cell further carries an encoding sequence of an exogenous cytokine; and preferably, the cytokine includes: IL-12, IL-15 or IL-21.

In another preferred embodiment, the immune cell also expresses another chimeric antigen receptor which does not contain CD3 ζ but contains the intracellular signaling domain of CD28, the intracellular signaling domain of CD137, or a combination of both.

In another preferred embodiment, the immune cell further expresses a chemokine receptor; and preferably, the chemokine receptor includes: CCR2.

In another preferred embodiment, the immune cell further expresses siRNA which can reduce expression of PD-1 or a protein which blocks PD-L1.

In another preferred embodiment, the immune cell further expresses a safety switch; and preferably, the safety switch includes iCaspase-9, Truncated EGFR or RQR8.

In another preferred embodiment, the immune cells include T lymphocytes, NK cells or NKT cells.

In another aspect of the invention, use of the genetically modified immune cells is provided for the preparation of a tumor-inhibiting drug, and the tumor is a tumor expressing mesothelin.

In another aspect of the present invention, a multi-functional immunoconjugate is provided, comprising: any one of the above described antibodies; and a functional molecule linked thereto (including covalently linked, conjugated, attached, adsorbed); the functional molecule is selected from a group consisting of a molecule that targets a tumor surface

marker, a tumor-suppressing molecule, a molecule that targets a surface marker of an immune cell, or a detectable label.

In a preferred embodiment, in the multifunctional immunoconjugate, the molecule that targets the tumor surface marker is an antibody or ligand that binds to a tumor surface marker; or the tumor-suppressing molecule is an anti-tumor cytokine or an anti-tumor toxin; and preferably, the cytokines include but are not limited to: IL-12, IL-15, IFN-beta, TNF-alpha.

In another preferred embodiment, in the multi-functional immunoconjugate, the detectable label includes a fluorescent label or a chromogenic label.

In another preferred embodiment, in the multifunctional immunoconjugate, the antibody that binds to a tumor surface marker refers to an antibody that recognizes an antigen other than mesothelin, and the other antigen includes EGFR EGFRvIII, mesothelin, HER2, EphA2, Her3, EpCAM, MUC1, MUC16, CEA, Claudin 18.2, folate receptor, Claudin 6, CD3, WT1, NY-ESO- 1, MAGE 3, ASGPR1 or CDH16.

In another preferred embodiment, in the multifunctional immunoconjugate, the molecule that targets the surface marker of the immune cell is an antibody that binds to T cell surface marker and forms a T-cell-engaging bifunctional antibody with the above described antibody (bispecific T cell engager, BiTE).

In another preferred embodiment, in the multifunctional immunoconjugate, the antibody that binds to T cell surface marker is an anti-CD3 antibody.

In another preferred embodiment, the anti-CD3 antibody is a single chain antibody (scFV), a monoclonal antibody, a Fab fragment, an Fd fragment, an Fv fragment, an F(ab')₂ fragment and a derivative thereof, antibody; preferably single chain antibody.

In another preferred embodiment, the anti-CD3 antibody is humanized, fully human, chimeric or murine antibody.

In another preferred embodiment, the multifunctional immunoconjugate is a fusion polypeptide, and further comprises a linker peptide (linker) between the above described antibody of the invention and the functional molecule linked thereto.

In another preferred embodiment, the linker peptide has the sequence (GlyGlyGlyGlySer)_n, wherein n is an integer from 1 to 5; more preferably, n = 3.

In another preferred embodiment, the multi-functional immunoconjugate is administered in a form of polypeptide or in the manner of gene administration.

In another aspect of the invention, a nucleic acid encoding the multi-functional immunoconjugate is provided.

In another aspect of the present invention, use of the multi-functional immunoconjugate is provided, for the preparation of an antineoplastic agent or an agent

for diagnosis of tumors that express mesothelin; or for the preparation of chimeric antigen receptor modified immune cells; and preferably, the immune cells include T lymphocyte, NK cell or NKT lymphocyte.

In another aspect of the invention, a pharmaceutical composition (including medicament or diagnostic reagent) is provided, comprising:

- the antibody or a nucleic acid encoding the antibody; or
- the immunoconjugate or a nucleic acid encoding the conjugate; or
- the chimeric antigen receptor or a nucleic acid encoding the chimeric antigen receptor; or
- the genetically modified immune cell.

In another aspect of the invention, an antibody is provided, which is capable of competing for binding to mesothelin with the antibody of the invention.

In another aspect of the invention, an antibody is provided, which is capable of binding to mesothelin epitope as shown in SEQ ID NO: 66. In a preferred embodiment, an antibody that binds to mesothelin epitope as shown in SEQ ID NO: 72 is also provided.

Other aspects of the invention will be apparent to a skilled person in the art from the disclosure herein.

Description of drawings

Figure 1. Binding of antibodies P1A6E and P3F2 to hu-mesothelin and control BSA in a single-phage ELISA assay. The values of antibodies P1A6E and P3F2 against human mesothelin and negative control BSA demonstrated that the two selected antibodies could specifically bind to human mesothelin.

Figure 2. Binding of two different single chain antibodies P1A6E and P3F2 to human mesothelin and BSA detected by ELISA.

Figure 3. Electrophoresis of purified SDS-PAGE of anti-human mesothelin antibodies.

Figure 4. SDS-PAGE electrophoresis of the monoclonal antibodies P1A6E and P3F2.

Figure 5. Binding curves of monoclonal antibody P1A6E to different concentrations of human mesothelin in Biacore.

Figure 6. Binding curve of the monoclonal antibody P3F2 to different concentrations of human mesothelin in Biacore.

Figure 7. Assay of specific binding of four single-chain antibodies (P1A6E, P3F2 and control antibodies SS, C10) to PANC-1-MSLN cells as shown by Fluorescence Activated Cell Sorter (FACS).

Figure 8. Assay of specific binding of four monoclonal antibodies (P1A6E, P3F2 and control antibody SS, C10) to PANC-1-MSLN cells as shown by Fluorescence Activated Cell Sorter (FACS).

Figure 9. ELISA showing binding of the antibodies scFv-P1A6E-Fc and scFv-P3F2-Fc to regions R1, R2, R3.

Figure 10. ELISA showing binding of the antibodies scFv-P1A6E-Fc and scFv-P3F2-Fc to regions R1A, R1B, R1C, R1AB, R1BC.

Mode for carrying out the invention

The present inventors investigated many kinds of tumor-specific genes in the early stage and found that a significant proportion of these genes were also expressed in normal cells of some tissues and were relatively difficult to be applied to immune effector cell technology of chimeric antigen receptor modification. Some tumor specific genes exhibit better tumor-specific expression characteristics, however, the CAR-modified immune effector cells based on them have no tumor cell killing activity or low activity, because the target can induce secretion of immune effect cell-inhibiting factors, such as PD-L1 by tumor cells.

After repeated investigation and screening, the present inventors found mesothelin from many candidate molecules as a target for designing CAR. The present inventors have demonstrated that CAR-modified T cells prepared based on antibodies against mesothelin do selectively target mesothelin-positive tumor cells and are highly cytotoxic to tumor cells. The inventors believe that the corresponding CAR-modified immune effector cells, particularly T cells, should be useful for the treatment of human tumors.

Antibodies against mesothelin

Specific antibodies which have good binding properties to mesothelin and are suitable for preparing genetically modified immune effector cells, were screened and obtained in all-human natural antibody libraries by the present inventors, and key CDR regions for them to exert their binding properties were also found by the inventors.

Antibodies of the invention may be intact immunoglobulin molecules or antigen-binding fragments, including but not limited to Fab fragments, Fd fragments, Fv fragments, F(ab')₂ fragments, complementarity determining region (CDR) fragments, single-chain antibody (scFv), domain antibody, bivalent single chain antibody, single chain phage antibody, bispecific diabody, triple chain antibody, quadruple chain antibody.

The antigen-binding properties of an antibody can be described by three specific

regions located in variable regions of the heavy and light chains, termed complementarity determining regions (CDRs), which divide the variable regions into four framework regions (FR), and the amino acid sequences of four FRs are relatively conservative, not directly involved in binding reaction. These CDRs form a loop structure, in which β -folds formed by the FRs are located close to each other in space and the antigen binding site of the antibody is constituted by CDRs on the heavy chain and CDRs on the corresponding light chain. It is possible to determine which amino acids make up FR or CDR regions by comparing the amino acid sequences of the same type of antibody. The CDR regions are sequences of immunologically interesting proteins and the CDR regions of the antibodies of the invention are brand new. The antibody may comprise two, three, four, five, or all six of the CDR regions disclosed herein.

Another aspect of the invention includes functional variants of the antibodies described herein. If the variant is capable of competing with the parental antibody for specific binding to mesothelin 1 and its ability to recognize mesothelin expressed by tumor cells is close to that of the specific antibodies provided in Examples of the present invention. The functional variants may have conservative sequence modifications, including nucleotide and amino acid substitutions, additions and deletions. These modifications can be introduced by standard techniques known in the art, such as directed mutagenesis and random PCR-mediated mutagenesis, and can include both natural and non-natural nucleotides and amino acids. Preferably, modification of the sequence occurs on a region outside the CDR region of the antibody.

The antibodies of the present invention can be applied to prepare various targeted antitumor drugs and drugs for diagnosing tumors, and in particular to prepare immune effector cells targeting mesothelin.

Chimeric antigen receptor and genetically modified immune cell

In the present invention, a chimeric antigen receptor expressed on the surface of an immune effector cell (immune cell) is provided, wherein the chimeric antigen receptor comprises sequentially linked: extracellular binding region, transmembrane region and intracellular signal region, and the extracellular binding region comprises the antibody of the invention. By expressing the chimeric antigen receptor on the surface of immune effector cells, immune effector cells can have a highly specific cytotoxic effect on tumor cells expressing mesothelin.

As used herein, "immune cells" and "immune effector cells" are used interchangeably and include: T lymphocytes, NK cells or NKT cells, and the like.

As a preferred embodiment of the present invention, the antibody contained in the chimeric antigen receptor is a single chain antibody, which is connected to CD8 or the transmembrane region of CD28 through the hinge region of CD8, and the transmembrane region is immediately followed by the intracellular signal region.

The invention also includes nucleic acids encoding the chimeric antigen receptors. The present invention also relates to variants of the above described polynucleotides, which encode a polypeptide, or a fragment, analog and derivative of the polypeptide having the same amino acid sequence as the present invention.

The transmembrane region of the chimeric antigen receptor may be selected from the transmembrane region of a protein such as CD8 or CD28. The human CD8 protein is a heterodimer composed of two chains, $\alpha\beta$ or $\gamma\delta$. In one embodiment of the invention, the transmembrane region is selected from the transmembrane region of CD8 α or CD28. In addition, the CD8 α hinge is a flexible region so that CD8 or CD28 and the transmembrane region as well as the hinge region are used to connect the target recognition domain scFv of the chimeric antigen receptor CAR to the intracellular signal region.

The intracellular signal region may be selected from a group consisting of intracellular signal region of CD3 ζ , Fc ϵ RI γ , CD27, CD28, CD137, CD134, MyD88, CD4 protein, and combinations thereof. The CD3 molecule consists of five subunits, in which CD3 ζ subunit (also known as CD3 zeta, abbreviated as Z) contains 3 ITAM motifs that are important signal transduction regions in TCR-CD3 complex. CD3 δ Z is a truncated CD3 ζ sequence without ITAM motif and is generally constructed in the present invention as a negative control. Fc ϵ RI γ is mainly distributed on the surface of mast cells and basophils, which contains an ITAM motif, which is similar to CD3 ζ in structure, distribution and function. In addition, as mentioned above, CD28, CD137 and CD134 are co-stimulatory signaling molecules. The co-stimulatory effect of their intracellular signaling segments upon binding to the respective ligands results in the continued proliferation of immune effector cells, primarily T lymphocytes, and increase in the level of cytokines such as IL-2 and IFN- γ secreted by immune effector cells, and the survival period and anti-tumor effect of CAR immune effector cells *in vivo* are increased.

The chimeric antigen receptor of the present invention can be sequentially linked as follows:

The antibody of the invention, CD8 and CD3 ζ ;

The antibody of the invention, CD8, CD137 and CD3 ζ ;

The antibody of the invention, the transmembrane region of CD28 molecule, the intracellular signal region of CD28 molecule and CD3 ζ ; or

The antibodies of the invention, the transmembrane region of CD28 molecule, the intracellular signal region of CD28 molecule, CD137 and CD3.

And combinations thereof, wherein CD28a in the relevant chimeric antigen receptor protein represents the transmembrane region of CD28 molecule and CD28b represents the intracellular signal region of CD28 molecule. The various chimeric antigen receptors described above are collectively referred to as scFv (mesothelin)-CAR.

The present invention also provides a vector comprising the above-mentioned nucleic acid encoding a chimeric antigen receptor protein expressed on the surface of an immune effector cell. In a specific embodiment, the vector used in the present invention is a lentiviral plasmid vector pWPT-eGFP. This plasmid belongs to the third generation of self-inactivating lentiviral vector system. The system has three plasmids, packaging plasmid psPAX2 encoding protein Gag / Pol, encoding Rev protein; envelope plasmid PMD2.G encoding VSV-G protein; and empty vector pWPT-eGFP, which can be used for recombinant introduction of a nucleic acid sequence of interest, i.e., a nucleic acid encoding CAR. In the empty vector pWPT-eGFP, the expression of enhanced green fluorescent protein (eGFP) is regulated by elongation factor-1 α (EF-1 α) promoter. While in the recombinant expression vector pWPT-eGFP-F2A-CAR containing the nucleic acid sequence encoding CAR, co-expression of eGFP and CAR is achieved by ribosomal skipping sequence 2A (abbreviated as F2A) from food-and-mouth disease virus (FMDV). It is to be understood that other expression vectors are also useful.

The invention also includes viruses comprising the vectors described above. The viruses of the invention include packaged infectious viruses as well as viruses to be packaged that contain the necessary components for packaging into infectious viruses. Other viruses known in the art that can be used to transduce exogenous genes into immune effector cells and their corresponding plasmid vectors are also useful in the present invention.

The present invention further includes a genetically modified T lymphocyte, which is transduced with a nucleic acid of the present invention or transduced with the above-mentioned recombinant plasmid containing the nucleic acid of the present invention or a viral system containing the plasmid. Conventional nucleic acid transduction methods in the art, including non-viral and viral transduction methods, can be used in the present invention. Non-viral transduction methods include electroporation and transposon methods. Recently,

nucleofector nuclear transfection instrument developed by Amaxa can directly introduce foreign genes into nucleus to achieve highly efficient transduction of target genes. In addition, compared with conventional electroporation, the transduction efficiency of transposon system based on Sleeping Beauty system or PiggyBac transposon was significantly improved. The combination of nucleofector transfection instrument and SB Sleeping Beauty transposon system has been reported [Davies JK., et al. Combining CD19 redirection and alloanergization to generate tumor-specific human T cells for allogeneic cell therapy of B-cell malignancies. *Cancer Res*, 2010, 70(10): OF1-10.], and high transduction efficiency and site-directed integration of target genes can be achieved by this method. In one embodiment of the invention, the transduction method of a T lymphocyte modified by a chimeric antigen receptor gene is a transduction method based on a virus such as a retrovirus or a lentivirus. The method has the advantages of high transduction efficiency and stable expression of exogenous gene, and the time for in vitro culturing T lymphocytes to clinical level can be shorten. The transduced nucleic acid is expressed on the surface of the transgenic T lymphocytes by transcription, translation. In vitro cytotoxicity assay performed on various cultured tumor cells demonstrated that the immune effector cells of the present invention have highly specific tumor cell killing effects (also known as cytotoxicity). Therefore, the nucleic acid encoding a chimeric antigen receptor protein of the present invention, a plasmid comprising the nucleic acid, a virus comprising the plasmid, and a transgenic immune effector cells transfected with the nucleic acid, plasmid or virus described above can be effectively used in tumor immunotherapy.

The immune cells of the present invention may also carry exogenous encoding sequences for cytokines, including but not limited to IL-12, IL-15 or IL-21. These cytokines have immunomodulatory or antitumor activity, enhance the function of effector T cells and activated NK cells, or directly exert anti-tumor effects. Therefore, those skilled in the art will understand that the use of these cytokines will help the immune cells to function better.

In addition to the chimeric antigen receptor described above, the immune cells of the present invention may also express another chimeric antigen receptor, which does not contain CD3 ζ , but contains intracellular signaling domain of CD28 and intracellular signal domain of CD137, or a combination of both.

The immune cells of the present invention may also express chemokine receptors; the chemokine receptors include, but are not limited to, CCR2. A skilled person will understand that the CCR2 chemokine receptor can competitively bind CCR2 in the body and is beneficial for blocking the metastasis of the tumor.

The immune cells of the present invention may also express siRNAs that can reduce

PD-1 expression or PD-L1-blocking proteins. A skilled person will understand that competitive blocking of the interaction between PD-L1 and its receptor PD-1 will facilitate the recovery of anti-tumor T-cell responses, thereby inhibiting tumor growth.

The immune cells of the present invention may also express a safety switch; preferably, the safety switch includes iCaspase-9, Truncated EGFR or RQR8.

Immunoconjugate

In the present invention, a multifunctional immunoconjugate is also provided, comprising the antibodies described herein and further comprising at least one functional molecule of other type. The functional molecule is selected from, but not limited to, a molecule that targets a tumor surface marker, a tumor-suppressing molecule, a molecule that targets a surface marker of an immune cell, or a detectable label. The antibody and the functional molecule may form a conjugate by covalent attachment, coupling, attachment, cross-linking, or the like.

As a preferred mode, the immunoconjugate may comprise an antibody of the invention and at least one molecule that targets a tumor surface marker or a tumor-suppressing molecule. The tumor-suppressing molecule may be anti-tumor cytokines or anti-tumor toxins. Preferably, the cytokines include but are not limited to IL-12, IL-15, IFN-beta, TNF-alpha. The molecules that target tumor surface markers, for example, can act synergistically with the antibodies of the invention to more precisely target tumor cells.

As a preferred mode, the immunoconjugate may comprise an antibody of the present invention and a detectable label. Such detectable labels include, but are not limited to, fluorescent labels, chromogenic labels such as enzymes, prosthetic groups, fluorescent materials, luminescent materials, bioluminescent materials, radioactive materials, positron-emitting metals and non-radioactive paramagnetic metal ion. More than one marker can also be included. The label used to label the antibody for the purpose of detection and / or analysis and / or diagnosis depends on the used particular detection / analysis / diagnosis technique and / or method, eg, immunohistochemical staining (tissue) samples, flow cytometry, and the like. Suitable labels for detection / analysis / diagnosis techniques and / or methods known in the art are well known to those skilled in the art.

As a preferred mode, the immunoconjugate may comprise an antibody of the invention as well as a molecule that targets a surface marker of an immune cell. The molecule that targets surface markers of immune cells can recognize immune cells and carry the antibodies of the invention to the immune cells, so that the antibodies of the invention can target the immune cells to the tumor cells and thus trigger immunocyte for specifically killing tumor.

As a means of chemically generating an immunoconjugate by conjugation, either directly or indirectly (eg, by a linker), the immunoconjugate can be produced as a fusion protein comprising an antibody of the invention and other suitable proteins. The fusion protein can be produced by a method known in the art, for example recombinantly produced by constructing and subsequently expressing the nucleic acid molecule which comprises the nucleotide sequence encoding the antibody in frame with a nucleotide sequence encoding a suitable label.

In another aspect of the invention, a nucleic acid molecule encoding at least one antibody of the invention, a functional variant, or an immunoconjugate thereof is provided. Once obtaining the relevant sequence, the recombination method can be used to obtain the relevant sequence in large quantities. This is usually done by cloning it into a vector, transferring it to a cell, and then isolating the relevant sequence from the proliferating host cells by conventional methods.

The present invention also relates to vectors comprising the appropriate DNA sequences described above as well as appropriate promoters or control sequences. These vectors can be used to transform an appropriate host cell to enable expression of the protein. The host cell may be a prokaryotic cell, such as a bacterial cell; or a lower eukaryotic cell, such as a yeast cell; or a higher eukaryotic cell, such as a mammalian cell.

Pharmaceutical composition

The antibodies, immunoconjugates comprising the antibodies, and genetically modified immune cells of the present invention can be used in the preparation of a pharmaceutical composition or diagnostic reagent. In addition to an effective amount of the antibody, immunological conjugate, or immune cell, the composition may further comprise a pharmaceutically acceptable carrier. The term "pharmaceutically acceptable" means that

when the molecular entities and compositions are properly administered to animals or humans, they do not cause adverse, allergic or other untoward reactions.

Specific examples of some of the substances which may be used as pharmaceutically acceptable carriers or components thereof are sugars, such as lactose, dextrose and sucrose; starches, such as corn starch and potato starch; cellulose and its derivatives, such as carboxymethylcellulose sodium, ethylcellulose and methylcellulose; gum tragacanth; malt; gelatin; talc; solid lubricants such as stearic acid and magnesium stearate; calcium sulfate; vegetable oils, such as peanut oil, cottonseed oil, sesame oil, olive oil, corn oil and cocoa butter; polyhydric alcohols such as propylene glycol, glycerin, sorbitol, mannitol and polyethylene glycol; alginic acid; emulsifiers such as Tween®; wetting agents such as sodium lauryl sulfate; coloring agents; flavoring agents; tablets, stabilizers; antioxidants; preservatives; pyrogen-free water; isotonic saline solutions; and phosphate buffers and the like.

The composition of the present invention can be prepared into various dosage forms as needed, and the dosage to be administered to a patient can be determined by a physician according to factors, such as type, age, body weight, and general disease condition of a patient, mode of administration, and the like. For example, injection or other treatment may be used.

The present invention is further described below with reference to specific embodiments. It should be understood that these examples are only for illustrating the present invention and are not intended to limit the scope of the present invention. Experimental procedures in the following examples where no specific conditions are indicated are generally carried out in accordance with the conditions described in customary conditions such as those compiled by J. Sambrook et al., *Molecular Cloning Experiments Guide*, Third Edition, Science Press, 2002, or according to the manufacturer Suggested conditions.

Example 1. Construction of Cell Lines Stably Expressing Mesothelin

1.1 Construction of plasmid vector

The vector system used in this example belongs to the third generation of self-inactivating lentiviral vector system. The system has three plasmids, packaging plasmid psPAX2 encoding protein Gag / Pol, encoding Rev protein; envelope plasmid PMD2.G encoding VSV-G protein; and recombinant plasmid pWPT-MSLN encoding the extracellular and transmembrane region of the target gene human mesothelin based on empty vector pWPT (purchased from Addgene).

According to GenBank Accession No. NM_005823, the target gene fragment (SEQ ID NO: 1 (nucleotide), 2 (amino acid)) containing signal peptide, Flag tag, extracellular domain and transmembrane region of human mesothelin was synthesized using a gene synthesis method based on bridge-PCR. PCR amplification was performed by primer pairs pWmslnF (SEQ ID NO: 3, GCTTACGCGTCCTAGCGCTACCGGTCGCCACCATGAGGGCCTGGATC) and pWmslnR (SEQ ID NO: 4, CGAGGTCGACCTAGGCCAGGGTGGAGGCTAGGAGCAGTGCCAGGACGG) under the following conditions: pre-denaturation: 94°C for 4 min; denaturation: 94°C for 30 s; annealing: 58°C for 30 s; extension: 68°C for 80 s; 30 cycles. The theoretical size of the obtained fragment was 1113bp. The amplification product was confirmed by agarose electrophoresis and consistent with the theoretical size. MluI and SalI restriction sites were introduced upstream and downstream to the open reading frame. The target gene obtained above was double-digested with MluI and SalI and ligated into the same double-digested pWPT vector to construct a successful lentiviral vector pWPT-MSLN. The constructed vector was identified by MluI and SalI digestion and sequenced correctly, which was ready for lentivirus packaging.

1.2 Plasmid transfecting 293T cells for packaging lentivirus

293T cells (ATCC: CRL-11268) cultured at passage 6 to passage 10 were seeded at a density of 6×10^6 in 10 cm dishes and cultured overnight at 37°C in 5% CO₂ for transfection. The medium was DMEM (Invitrogen) containing 10% fetal bovine serum (Sigma). And the next day, the medium was changed to serum-free DMEM about 2 hours prior to transfection.

Transfection steps were as follows:

1) 5 µg of target gene plasmid pWPT-MSLN was solved into 500 µl of MillQ water with 7.5 µg of packaging plasmid PAX2 and 2.5 µg of envelope plasmid pMD2.G, respectively, and mixed,

2) 62 µL of 2.5 M CaCl₂ (Sigma) was added dropwise and mixed at 1200 rpm / min vortex,

3) Finally, 500 µL of 2 × HBS (280 mM NaCl, 10 mM KCl, 1.5 mM Na₂HPO₄, 12 mM glucose, 50 mM Hepes (Sigma), pH 7.05, and sterilized through 0.22 µM filter) was added dropwise and mixed by shaking at 1200 rpm/min for 10 s,

4) Immediately added to the culture dish, gently shake at 37°C, 5% CO₂, cultured for 4 ~ 6h, replaced with DMEM containing 10% fetal bovine serum.

After 48 or 72 hours of transfection, cell debris was removed by centrifugation and the

virus was collected by filtration through a 0.45 µm filter (Millipore).

1.3 Recombinant lentivirus infecting PANC-1 cells

The collected virus solution was concentrated and titrated, and cells PANC-1 (purchased from the ATCC) plated in 6 cm plate were infected. Three days after infection, cells were harvested, part of mixed clones were taken, and lysed with cell lysis liquid. And then, 40 µg of cell protein was subjected to SDS-PAGE gel electrophoresis followed by immunoblotting and staining with mouse anti-Flag-tag antibody. After washing with PBS, the protein was incubated with horseradish peroxidase-labeled goat anti-mouse antibody, washed and finally developed with ECL reagent. Western blot results showed that a band with a molecular weight of about 38 kDa was detected in PANC-1 cells infected with human mesothelin MSLN (i.e., PANC-1-MSLN), while no corresponding band was detected in uninfected empty cells. Remaining cells were expanded, frozen and stored for later experiments.

Example 2. Preparation of human mesothelin antigen

According to GenBank Accession No. NM_005823, the gene fragment of human mesothelin (positions 88-942 of SEQ ID NO: 1 (nucleotide), positions 30-314 of SEQ ID NO: 12 (amino acid)) were synthesized using a gene synthesis method based on bridge-PCR, and PCR amplification was performed. The amplified product was inserted into plasmid vector pCMV-V5 (the vector has 6 × His tag fused and expressed downstream to the multiple cloning site, purchased from Shanghai Rui Jin Biotechnology Co., Ltd.) by NheI/BglII, and transformed into host strain TOP10. Positive clones were picked out, identified by PCR and confirmed by sequencing to obtain recombinant expression plasmid V5-MSLN.

The above expression plasmids were transfected into well-growing HEK-293F cells and cultured continuously at 37°C, 5% CO₂, 12.5 rpm on a shaker for 7 days and centrifuged at 4000rpm for 10min, the pelletes were removed, the supernatant was collected and filtered through a 0.45 µm membrane filter, the processes sample was purified with HisTrap (from GE) affinity chromatography column to finally obtain purified human mesothelin protein, and the identification results are shown in FIG. 1.

Example 3. Screening of single chain antibody against human mesothelin

3.1 Screening of human mesothelin-specific binding antibodies based on phage display

Using phage display technology, human mesothelin specific antibody was screened from the all-human natural antibodies library. For this purpose, glycerol bacteria (purchased from Shanghai Rui Jin Biotechnology Co., Ltd.) from the natural

library of phage-displayed all-human single-chain antibody were inoculated in 400 ml of $2 \times$ YT/ampicillin medium so that the cell density reached $OD_{600} = 0.1$, and incubated at 37°C and 200 rpm until cell density reached $OD_{600} = 0.5$. Cells were infected with 10^{12} pfu of M13KO7 helper phage (purchased from Invitrogen) and incubated at 30°C and 50 rpm for 30 minutes. After 50 mg/L kanamycin was added and shaking-culture was performed at 37°C and 200 rpm for 30 minutes, the pellet was separated by centrifugation (15 minutes, $1600 \times g$, 4°C) and resuspended in 400 ml of $2 \times$ YT/Penicillin/kanamycin medium and shaken for 16 hours at 37°C and 200 rpm. Finally, the pellet was separated by centrifugation (5000 rpm, 4°C for 20 minutes) and discarded. The supernatant was filtered through a $0.45 \mu\text{m}$ filter and 1/4 volume of 20% (w/v) PEG 8000, 2.5 M NaCl solution was added and incubated in an ice bath for 1 hour to precipitate bacteriophage pellets. The pellet was then precipitated by centrifugation (20 min, $8000 \times g$, 4°C) and the supernatant discarded. The phage were resuspended in 25 ml of prechilled PBS (137 mM NaCl, 2.7 mM KCl, 8 mM Na_2HPO_4 , 2 mM KH_2PO_4) and centrifuged (5 minutes, $20000 \times g$, 4°C). 1/4 volume of 20% (w/v) PEG8000, 2.5 M NaCl solution was added to the supernatant and incubated in an ice bath for 30 minutes to precipitate phage particles again. The pellets were centrifuged (30 min, $20000 \times g$, 4°C) and the phage pellets were resuspended in 2 ml of prechilled PBS again, kept on ice for 30 min and centrifuged (30 min, $17000 \times g$, 4°C). Supernatants were mixed with 4% (w/v) BSA in PBS at 1: 1, placed on a rotary mixer and incubated for 30 minutes at room temperature before being directly used for screening.

Using the above phage antibody library, four rounds of directional screening were performed on biotinylated human mesothelin recombinant protein with the following scheme: The phage antibody library was incubated with biotin-labeled antigen mesothelin at room temperature for 2 hours and then incubated with streptavidin magnetic beads MyOne Cl (from Invitrogen) blocked with 2% (w/v) BSA (bovine serum albumin) at room temperature for 30 minutes. The beads were then washed with PBST (containing 0.1% Tween-20) buffer to remove phages which were not specifically bound or with weak binding capacities. Strongly-binding phages were then eluted from magnetic beads with glycine-HCl (pH 2.2), neutralized with Tris neutralizing solution (pH 9.1), and used to infect *E. coli* ER2738 in the mid-logarithmic growth phase and for the next round of screening. In the four rounds of screening, the beads were used in an amount of 50 μl , 20 μl , 10 μl and 10 μl , and the concentrations of biotin-labeled human mesothelin were 100 nM, 10 nM, 5 nM and 1 nM, respectively, and the time for PBST-washing was 10, 10, 15 and 20, respectively.

3.2 Identification of human mesothelin-specific binding antibodies

96 clones were randomly selected in the clones obtained from the fourth round of screening and their binding capability to human mesothelin was analyzed by single phage ELISA (enzyme-linked immunosorbent assay). For this purpose, each single colony was inoculated in 300 μ l of 2 $\times$ YT/ampicillin medium (containing 2% glucose) in a 96-well deep-well plate and cultured with shaking at 37°C and 250 rpm for 16 hours. 20 μ l of culture was inoculated into 500 μ l of 2 $\times$ YT/ampicillin medium (containing 0.1% glucose) and shaken at 37°C and 250 rpm for 1.5 hours. To prepare the helper phage solution, 75 μ l of M13KO7 (titer of 3×10^{12} pfu/ml) was taken and mixed into 15 ml of 2 $\times$ YT medium and added into a culture plate at 50 μ l/well, and incubated at 37°C and 150 rpm for 30 minutes. And then prepared kanamycin solution (180 μ l of 50 mg/ml kanamycin was taken and added into 15 ml of 2 $\times$ YT medium) was added at 50 μ l/well and incubated with shaking for 16 hours at 37°C and 250 rpm. Finally, cells were precipitated by centrifugation (30 mins, 5000 $\times$ g, 4°C) and the supernatant was transferred to a new 96-well deep-well plate.

For single phage ELISA, 100 ng/well of antigen human mesothelin and negative control protein BSA (100 μ l/well) were used in a 96-well MediSorp ELISA plate (purchased from Nunc) and coated overnight at 4°C. Each well was blocked with PBST containing 2% BSA (w/v). The wells were then washed with PBST for three times and PBST was discarded. Then, each phage solution prepared above was added into each well of the plate at 100 μ l/well. After incubated at 37°C for 2 hours, the plate was washed for three times with PBST. To detect bound phage, anti-M13 antibody peroxidase conjugate (purchased from GE Healthcare) was diluted at 1: 5000 in PBST and 100 μ l was taken and added into each well. After incubated at 37°C for 1 hour, the wells were rinsed for three times with PBST and then rinsed for three times with PBS. Finally, 50 μ l of TMB substrate was pipetted into the wells and developed for 10 minutes at room temperature, followed by addition of 50 μ l of 2M H₂SO₄ per well to quench the color reaction. Extinction values were measured at 450 nm with an enzyme-linked immunosorbent (Bio-Rad). Two different single chain antibodies P1A6E (SEQ ID NO: 5 (nucleotide), 6 (amino acid)) and P3F2 (SEQ ID NO: 7 (nucleotide), 8 (amino acid)) were observed with sequencing analysis, which exhibited significantly stronger binding signal to human mesothelin (hu-mesothelin) in ELISA assay, while not binding to BSA (Figure 2).

SEQ ID NO: 5 (nucleotide)

caggtacagctggaacagtcaggtctaggactggtgaagccctcgagaccctctctcacctgtgccatctccggggacactgtc

tctagcgacagtgtgcttggaaactggatcaggcagtcctccatcgagaggccttgagtggtgggaaggacatactacaggtccaagtgggt
taatgattatgcagtatctgtgaaggtcgaataacatcaactcagacacatccaagaaccagttctccctgcagttgaactctgtgactcccc
aggacacggctgtgtattattgtgaagaagtaatagtactactacgctatggacgtctggggccaaggcacctgggtcaccgtctcgag
tgggtggaggcgggtcaggcggaggtggttctggcggtggcggtatcgaggtgtgctgactcagccgtcttccctctctgcatctctggag
catcagccagttcacctgcaccttgcgagtggtcatcaatgttggtatctacagatatctgggtaccaacagaggccaggagtcctcccc
agattctctgacttacaaatcagactcagataagtaaccagggtctggagtcctcagtcgttcttgatccaaagatgcttcggccaatgc
agggattttactcatctctgggtcctcagtcgaagatgaggctgactattactgcatgattggcacagcggcggtgggtgttcggcgaggagg
accaaggtcaccgtcctaggt

SEQ ID NO: 6 (amino acid)

QVQLEQSGGLGLVKPSQTLSTCAISGDTVSSDSAAWNWRQSPSRGLEWLGRTYYRSK
WFNDYAVSVKGRITNSDTSKNQFSLQLNSVTPEDTAVYYCARSNSYYYAMDVWGQGT
LTVVSSGGGGSGGGSGGGSGQAVLTQPSSLSASPGASASLTCTLRSGINVGIIYRIYQYQRP
GSPPQILLTYKSDSDKYQSGVPSRFSKSDASANAGILLISGLQSEDEADYYCMIWHS GGW
VFGGGTKVTVLG

Wherein the amino acid sequence of the heavy chain variable region is shown in positions 1 to 123 of SEQ ID NO: 6 and the amino acid sequence of the light chain variable region is shown in positions 139 to 254 of SEQ ID NO: 6.

Wherein the amino acid sequence of light chain CDR1 is TLRSGINVGIIYRIY (SEQ ID NO: 51), the amino acid sequence of light chain CDR2 is YKSDSDKYQGS (SEQ ID NO: 52), the amino acid sequence of light chain CDR3 is MIWHS GGWV (SEQ ID NO: 53); the amino acid sequence of heavy chain CDR1 is GDTVSSDSAAWN (SEQ ID NO: 54), the amino acid sequence of heavy chain CDR2 is RTYYRSKWFNDYAVSVKG (SEQ ID NO: 55), and the amino acid sequence of heavy chain CDR3 is SNSYYYAMDV (SEQ ID NO: 56).

SEQ ID NO: 7 (nucleotide)

cagatgcagctagtgcagtcctggggctgaggtgaagaagcctggggcctcagtggaaggtttcctgcaaggcatctggatacacctt
caccagctactatgcactgggtgcgacaggccctggacaagggttgagtggtgggaataatcaaccctagtgggtgtagcacaagct
acgcacagaagttccagggcagagtcaccatgaccaggggacacgtccacgagcacagtcacatggagctgagcagcctgagatctgagg
acacggccgtgtattactgtgcgagtagtcggagtggtgactacgggtgtaaatcatgatgcttttgatatctgggggaaaggaccacgggtca
ccgtctcagtggtggaggcgggtcaggcggaggtggttctggcggtggcggtatcgacatccagttgacccagtcctccatcctcctgtct
gcgtctgtaggagacagagtcaccatcacttgcggggcaagccaggtcattagccgtgctttagcctggtatcaacaaacaccagggaacc
tcctaaactctgatctatgatgcctcaatttgagagtggtgggtcccatcaaggttcagcggcagtggtggtgacagatttactctacca
tcagccgctgcagcctgaagattttgcaacttattactgtcaacagtttaattacccctcactttcggcgaggaggaccaagctggagatc
aaacgt

SEQ ID NO: 8 (amino acid)

QMQLVQSGAEVKKPGASVKVSCKASGYTFTSYMHVWRQAPGQGLEWMGIINPSG
GSTSYAQKFQGRVTMTRDTSTSTVYMELSSLRSEDVAVYYCASSRSGTTVVNHDAFDIWK
GTTVTVSSGGGGSGGGSGGGSDIQLTQSPSSLSASVGDRTITCRASQVISRALAWYQQT
PGKPPKLLIYDASNLQSGVPSRFSKSGSGTDFTLTISRLQPEDFATYYCQFNSYPLTFGGGT
KLEIKR

Wherein, the amino acid sequence of the heavy chain variable region is shown in positions 1 to 124 of SEQ ID NO: 8; the amino acid sequence of the light chain variable region is shown in positions 140-247 of SEQ ID NO: 8.

Wherein the amino acid sequence of light chain CDR1 is RASQVISRALA (SEQ ID

NO: 57), the amino acid sequence of light chain CDR2 is DASNLQS (SEQ ID NO: 58), the amino acid sequence of light chain CDR3 is QQFNSYPLT (SEQ ID NO: 59); the amino acid sequence of heavy chain CDR1 is GYTFTSYMH (SEQ ID NO: 60), the amino acid sequence of heavy chain CDR2 is IINPSGGSTSYAQKFQG (SEQ ID NO: 61) and the amino acid sequence of heavy chain CDR3 is SRSGTTVVNHDAFDI (SEQ ID NO: 62).

Example 4. Preparation of single chain antibody and monoclonal antibody

4.1 Preparation of single chain antibody against human mesothelin

scFv-P1A6E fragment was amplified from the resulting clones using primer pair V5-P1A6E-F (SEQ ID NO: 9) and V5-P1A6E-R (SEQ ID NO: 10); scFv-P3F2 fragment was amplified using primer pair V5-P3F2-F (SEQ ID NO: 11) and V5-P3F2-R (SEQ ID NO: 12), digested by NheI / BamHI restriction enzyme, connected to NheI/BamHI double-digested vector plasmid pCMV-V5-Fc (in the vector, Fc fragment of human antibody IgG1 was fused downstream to multiple cloning sites, hereinafter referred to as V5-Fc, purchased from Shanghai Rui Jin Biotech Co., Ltd.) with T4 DNA ligase, and transformed into host strain TOP10. Clones were picked up, and positive clones were identified by PCR and confirmed by sequencing to obtain eukaryotic expression plasmids, V5-scFv-P1A6E-Fc and V5-scFv-P3F2-Fc, respectively.

SEQ ID NO: 9: ACAGTGCTAGCACAGGTACAGCTGGAACAG;

SEQ ID NO: 10: TTGTCGGATCCACCTAGGACGGTGACC;

SEQ ID NO: 11: ACAGTGCTAGCACAGATGCAGCTAGTGC;

SEQ ID NO: 12: TTGTCGGATCCACGTTTGATCTCCAGC.

The above expression plasmids were transfected into well-growing HEK-293F cells respectively, cultured at 37°C, 5% CO₂, 125rpm on a shaker continuously for 7 days, centrifuged at 4000rpm for 10min. Pelletes were removed, and the supernatant was collected and filtered with 0.45 µm membrane. The processed sample was affinity-purified with protein A (from GE) affinity column to finally obtain the purified antibody-Fc fusion proteins scFv-P1A6E-Fc and scFv-P3F2-Fc. The identification results are shown in FIG. 3.

4.2 Preparation of monoclonal antibody against human mesothelin

In this example, the monoclonal antibody was expressed using a two-plasmid system. The gene of antibody heavy chain variable region shall be constructed into pIH plasmid containing human IgG1 CH gene, and the gene of antibody light chain variable region be constructed into PIK plasmid containing human IgG CL gene (plasmid purchased from Shanghai Rui Jin Biotechnology Co., Ltd.).

VH-P1A6E fragment was amplified from the template plasmid V5-scFv-P1A6E-Fc

using primer pair P1A6E-HF (SEQ ID NO: 13, gcctttcctggtttcctgtctcaggtacagctgg aacagtc) and P1A6E-HR (SEQ ID NO: 14, GATGGGCCCCTTGGTGGAGGCACTCGAGACGGTGACCAG). HF1 fragment was amplified from the template plasmid pIH using primer pair HF1F (SEQ ID NO: 15, ggctaactagagaacccactgc) and HF1R (SEQ ID NO: 16, AGACAGGAAACCAGGAAAGGC); and HF3 fragment was amplified from the template plasmid pIH primers HF3F (SEQ ID NO: 17, gcctccaccaagggcccatc) and HF3R (SEQ ID NO: 18, gacaatcttagcgcagaagtc). The three fragments were mixed at equimolar ratio, and then splicing-PCR was performed. Fragments were recovered by restriction endonuclease NheI / NotI double digestion and connected into NheI/NotI double-digested vector plasmid pIH with T4 DNA ligase and transformed into host strain TOP10. Clones were picked out and the positive clones were identified by PCR and confirmed by sequencing to obtain pIH-P1A6E eukaryotic expression plasmid. pIH-P3F2 eukaryotic expression plasmid was also obtained in the same manner.

To obtain pIK-P1A6E eukaryotic expression plasmid, VL1-P1A6E fragment was obtained from the template plasmid V5-scFv-P1A6E-Fc using the primer pair P1A6E-LF (SEQ ID NO: 19, ctttggttccaggtgcaagatgtcaggctgtgctgactcag) and P1A6E-LR (SEQ ID NO: 20, GAAGACAGATGGTGCAGCCACCGTACCTAGGACGGTGACCTTG); LF1 fragment was amplified from the template plasmid pIK using the primer pair LF1F (SEQ ID NO: 21, ggctaactagagaacccactgc) and LF1R (SEQ ID NO: 22, ACATCTTGCACCTGGAAACCAAAG); LF3 fragment was amplified from the template plasmid pIK using the primer pair LF3F (SEQ ID NO: 23, acggtggctgcaccatctgtcttc) and LF3R (SEQ ID NO: 24, GACAATCTTAGCGCAGAAGTC). The three fragments were mixed in equimolar ratio for splicing PCR. After the fragments were recovered, the fragments were digested with EcoRV / NotI restriction endonucleases and ligated in EcoRI/NotI double-digested vector plasmid pIK with T4 DNA ligase, and transformed into host strain TOP10. Clones were picked out and positive clones were identified by PCR and confirmed by sequencing. pIK-P3F2 eukaryotic expression plasmid was also obtained in the same manner.

Expression plasmids pIH-P1A6E and pIK-P1A6E were equimolarly mixed, pIH-P3F2 and pIK-P3F2 were equimolarly mixed and transfected into well-growing HEK-293F cells respectively. The cells were cultured at 37°C, 5% CO₂, 125rpm on a shaker continuously for 7 days, centrifuged at 4000rpm for 10min. Pelletes were removed, and the supernatant was collected and filtered with 0.45 µm membrane. The processed sample was affinity-purified with protein A (from GE) affinity column to finally obtain the purified antibody P1A6E and P3F2. The identification results are shown in FIG. 4.

Example 5. Affinity of antibody against human mesothelin

To quantitatively analyze the binding of an antibody to human mesothelin, the affinity and kinetic parameters of single-chain antibody and monoclonal antibody of P1A6E and P3F2 were measured by capture method using Biacore T200 system (from GE). An anti-human IgG (Fc) antibody (purchased from GE) was coupled to carboxymethyl dextran surface of sensor chip CM5 through primary amino with NHS / EDC coupling according to the manufacturer's instructions. Measurements were performed in 1 × HBS-EP + working buffer at 25°C, 30 µl/min, and regeneration condition was 3 M MgCl₂, 10 µl/min for 30 seconds. In each round of the testing cycle, the antibody to be tested is firstly captured onto the chip. Analyte (human mesothelin) of a certain concentration flowed over the chip surface. Due to the produced SPR signal, the interaction between human mesothelin and the captured antibody can be detected. The detected signal is defined as resonance unit (RU), which was plotted vs time (second) to obtain the corresponding binding curve and dissociation curve. In different test cycles, concentrations of human mesothelin were 10 nM, 20 nM, 40 nM, 80 nM and 160 nM, respectively. The resulting curves were evaluated using Biacore T200 evaluation software and the affinity KD values were calculated. Figure 5 and Figure 6 show kinetic curves of the monoclonal antibodies P1A6E and P3F2, in a Biacore Affinity Assay, respectively. The binding data for single-chain antibody and monoclonal antibody of P1A6E and P3F2 to human mesothelin are summarized in Table 1.

Table 1. Affinity parameters of single chain antibodies and monoclonal antibodies of P1A6E and P3F2 to human mesothelin

Sample of antibody	ka (1/Ms)	kd (1/s)	KD (M)
P1A6E monoclonal antibody	2.88E+05	1.16E-03	4.04E-09
P3F2 monoclonal antibody	1.10E+05	7.89E-04	7.17E-09
P1A6E single chain antibody	8.25E+04	1.56E-03	1.89E-08
P3F2 single chain antibody	5.77E+04	9.35E-04	1.62E-08

Example 6. Cell-binding properties of antibody to human mesothelin (single-chain antibody and monoclonal antibody)

Each of antibodies scFv-P1A6E-Fc and scFv-P3F2-Fc was analyzed for binding ability to mesothelin at cell surface by Fluorescence Activated Cell Sorter (FACS) (Guava 8HT, supplied by Millipore).

Specific methods are as follows:

1) inoculating PANC-1-MSLN and PANC-1 in logarithmic growth phase into a 6 cm dish respectively at inoculation cell density of about 90%, and incubating overnight at 37°C

in an incubator.

2) digesting cells with 10 mM EDTA, collecting cells through centrifugation at $200\text{ g} \times 5\text{ mins}$, and resuspending cells in 1% phosphate buffered saline (NBS PBS) containing calf serum at 1×10^6 to $1 \times 10^7/\text{mL}$ into a flow-specific tube in an amount of 100 μl per tube.

3) centrifuging at $200\text{g} \times 5\text{min}$, and discarding the supernatant.

4) antibodies P1A6E and P3F2 to be tested were added into the two experimental groups, respectively, adding antibodies ss and C10 (purchased from Shanghai Rui Jin Biotechnology Co., Ltd.) were added into two positive control groups added as positive controls, and another control group is PBS blank control without antibody. The final concentration of each antibody was 20 $\mu\text{g}/\text{ml}$. 100 μl was added to each tube, and incubated in an ice bath for 45 minutes.

5). Adding 2 ml of 1% NBS PBS to each tube and centrifuging at $200\text{ g} \times 5\text{ min}$ for two times.

6) Discarding the supernatant and adding goat anti-human antibody-FITC (Shanghai Karrie Biotech Co., Ltd.) at a dilution of 1: 100 with 100ul being added to each tube, incubating in an ice bath for 45 minutes.

7). Adding 2 ml of 1% NBS PBS into each tube, centrifuging at $200\text{ g} \times 5\text{ min}$ for two times.

8) Discarding the supernatant, resuspending in 300 μl of 1% NBS PBS and detecting by flow cytometry.

9) Analyzing the data using flow cytometry data analysis software Flowjo7.6.

Flow cytometry results showed that four antibodies, P1A6E and P3F2, as well as control antibodies SS and C10, either in single-chain antibody format (Figure 7) or in monoclonal full antibody format (Figure 8, fluorescence peak of PANC-1-MSLN cells was significantly different from that of blank control (PBS) (FIG. 7B, FIG. 8B), while no significant difference from PANC-1 cells (FIG. 7A, FIG. 8A)), can specifically recognize PANC-1-MSLN cells stably expressing human mesothelin, but do not bind to human mesothelin-negative PANC-1 cells, indicating that the four antibodies could specifically recognize human mesothelin. The fluorescence peaks of antibodies P1A6E and P3F2 were significantly stronger than those of control antibodies SS and C10, indicating that the binding efficiencies of P1A6E and P3F2 to PANC-1-MSLN cells are higher than those of SS and C10.

Example 7. Preparation of CAR T containing antibody to human mesothelin

To construct a chimeric antigen receptor, the connection order of the parts of the

chimeric antigen receptor exemplified in the present invention is shown in Table 2.

Table 2

Chimeric antigen receptor	Extracellular binding region - transmembrane region - intracellular signal region 1 - intracellular signal region 2 and the like	Description
P1A6E- δ Z	scFv(MSLN)-CD8-CD3 δ zeta	Negative control
P1A6E-Z	scFv(MSLN)-CD8-CD3 zeta	1 st generation
P1A6E-BBZ	scFv(MSLN)-CD8-CD137-CD3 zeta	2 nd generation
P1A6E-28Z	scFv(MSLN)-CD28a-CD28b-CD3 zeta	2 nd generation
P1A6E-28BBZ	scFv(MSLN)-CD28a-CD28b-CD137-CD3 zeta	3 rd generation
P3F2- δ Z	scFv(MSLN)-CD8-CD3 δ zeta	Negative control
P3F2-Z	scFv(MSLN)-CD8-CD3 zeta	1 st generation
P3F2-BBZ	scFv(MSLN)-CD8-CD137-CD3 zeta	2 nd generation
P3F2-28Z	scFv(MSLN)-CD28a-CD28b-CD3 zeta	2 nd generation
P3F2-28BBZ	scFv(MSLN)-CD28a-CD28b-CD137-CD3 zeta	3 rd generation

Note: CD28a represents the transmembrane region of CD28 molecule and CD28b represents the intracellular signaling region of CD28 molecule.

The lentiviral plasmid vector system used in the present example belongs to lentiviral 4-plasmid system of the third generation, which has 4 plasmids, namely, envelope plasmid pCMV-VSV-G encoding VSV-G protein (from addgene), packaging plasmid pRSV-REV encoding Rev protein (from addgene); pMDLg/pRRE encoding Gal and Pol (from addgene) and the recombinant expression vector encoding the gene of interest CAR based on empty vector pRRLSIN-cPPT.PGK-GFP.WPRE (from addgene). For the promoter in all vectors of CAR gene, elongation factor-1 α (EF-1 α) of the vector disclosed in 201310164725.X was used. Specific construction method is as follows:

(1) Obtaining Promoter Fragment: a fragment with the promoter EF-1 α was amplified by PCR using the vector pWPT-eGFP-F2A-CAR, primers pwp_{xl}F (SEQ ID NO: 25, 5'-gcaggggaaagaatagtaga ca-3') and pWPT-MluIR (SEQ ID NO: 26, 5'-aggccagcggcaggagcaaggcggctactggta aggccatggtggcgaccggtagc-3').

(2) Obtaining fragment of target CAR: P1A6E part and P3F2 part of the target CAR fragment was amplified using the above aobtained V5-scFv- P1A6E-Fc and V5-scFv- P3F2-Fc as templates and using primers P1A6E-F (SEQ ID NO: 27, 5'-ctcctgccgtggccttgctgctccacgccgccaggccgcaggtacagc tgaaca-3') and primer P1A6E-R (SEQ ID NO: 28, 5'-gcggcgctggcgctggtgtacctaggacggtgacc-3'), primer P3F2-F (SEQ ID NO: 29, 5'-ctcctgccgtggccttgctgctccacgccgccaggccgcagatgcagctagt gca-3') and P3F2-R (SEQ ID NO: 30, 5'-gcggcgctggcgctggtgtacgtttgatctccag-3').

(3) The first, second, third generation of consensus sequence and negative control sequence of CAR were obtained by PCR: fragments CD8-CD3 δ zeta(δ Z), CD8-CD3 zeta (Z), CD28a-CD28b-CD3 zeta (28Z) and CD28a-CD28b-CD137-CD3 zeta (28BBZ) sequences

were obtained by using pWPT-eGFP-F2A-GPC3- δ Z, pWPT-eGFP-F2A-GPC3-Z, pWPT-eGFP-F2A-GPC3-28Z and pWPT-eGFP-F2A-GPC3-28BBZ in 201310164725.X as templates and primer HF (SEQ ID NO: 63, 5'-accacgacgccagcgccgcgaccac) and primer pwpxlR (SEQ ID NO: 64, 5'-tagcgtaaaaggagcaacatag), respectively.

(4) fragments of consensus sequence CD8-CD137-CD3 zeta (BBZ) were synthesized using a gene synthesis method based on bridge-PCR with reference to BBZ sequence in US 8,911,993 B2 (COMPOSITIONS FOR TREATMENT OF CANCER).

(5) After the above obtained promoter fragment, target CAR fragments and fragments of consensus sequence CD8-CD3 δ zeta(δ Z), CD8-CD3 zeta(Z), CD8-CD137-CD3 zeta(BBZ), CD28a-CD28b-CD3 zeta(28Z) and CD28a-CD28b-CD137-CD3 zeta(28BBZ) were respectively routinely bridged, primers pwpxlF and pwpxlR were used for amplification to obtain fragments containing the EF-1 α and target gene CAR and respectively referred to as:

P1A6E- δ Z (SEQ ID NO: 31);
P1A6E-Z (SEQ ID NO: 32);
P1A6E-BBZ (SEQ ID NO: 33);
P1A6E-28Z (SEQ ID NO: 34);
P1A6E-28BBZ (SEQ ID NO: 35).
P3F2- δ Z (SEQ ID NO: 36);
P3F2-Z (SEQ ID NO: 37);
P3F2-BBZ (SEQ ID NO: 38);
P3F2-28Z (SEQ ID NO: 39);
P3F2-28BBZ (SEQ ID NO: 40).

(6) The CAR fragment with the promoter and the target gene CAR obtained in the above step was double-digested with ClaI and SalI and ligated into the same digested vector pRRLSIN.cPPT.PGK-GFP.WPRE to construct a lentiviral vector expressing each chimeric antigen receptor. The successfully constructed vector was identified by Mlu and Sal digestion and confirmed by sequencing for lentivirus packaging.

The resulting vectors containing each target CAR are as follows:

pRRLSIN-EF1 α -P1A6E- δ Z;
pRRLSIN-EF1 α -P1A6E-Z;
pRRLSIN-EF1 α -P1A6E-BBZ;
pRRLSIN-EF1 α -P1A6E-28Z;
pRRLSIN-EF1 α -P1A6E-28BBZ;
pRRLSIN-EF1 α -P3F2- δ Z;
pRRLSIN-EF1 α -P3F2-Z;
pRRLSIN-EF1 α -P3F2-BBZ;
pRRLSIN-EF1 α -P3F2-28Z;
pRRLSIN-EF1 α -P3F2-28BB.

Through the above construction, 10 CAR polypeptide sequences can be obtained respectively, which are referred to as:

P1A6E- δ Z (SEQ ID NO: 41);

P1A6E-Z (SEQ ID NO: 42);
P1A6E-BBZ (SEQ ID NO: 43);
P1A6E-28Z (SEQ ID NO: 44);
P1A6E-28BBZ (SEQ ID NO: 45).
P3F2-δZ (SEQ ID NO: 46);
P3F2-Z (SEQ ID NO: 47);
P3F2-BBZ (SEQ ID NO: 48);
P3F2-28Z (SEQ ID NO: 49);
P3F2-28BBZ (SEQ ID NO: 50).

Transfection of 293T by Plasmid for packaging lentivirus

HEK-293T cells (ATCC: CRL-11268) cultured at passage 6 to passage 10 were seeded at a density of 6×10^6 in 10 cm dishes and cultured overnight at 37°C in 5% CO₂ for transfection. The medium was DMEM containing 10% fetal bovine serum.

Transfection steps are as follows:

Preparation of liquid A: dissolving 10 µg of desired gene plasmids pRRLSIN-cPPT.EF1α-CAR (selected from pRRLSIN-EF1α-P1A6E-δZ, pRRLSIN-EF1α-P1A6E-Z, pRRLSIN-EF1α-P1A6E-BBZ, pRRLSIN-EF1α-P1A6E-28Z, pRRLSIN-EF1α-P1A6E-28BBZ, pRRLSIN-EF1α-P3F2-Z, pRRLSIN-EF1α-P3F2-BBZ, pRRLSIN-EF1α-P3F2-28Z, pRRLSIN-EF1α-P3F2-28BBZ) with 7.5 µg of packaging plasmid pMDLg RRE and pRSV-REV and 3 µg of envelope plasmid pCMV-VSV-G into 800 µL of serum-free DMEM medium and mixing well.

Preparation of liquid B: dissolving 60 µg PEI (polyethylenimine 1 µg/µl, purchased from Polysciences) in 800µL serum-free DMEM medium, mixing gently and incubating at room temperature for 5min.

Formation of transfection complex: adding liquid A into liquid B and gently mixing, vortexing or gently mixing immediately after addition, incubating at room temperature for 20min.

Adding 1.6 ml of the transfection complex into HEK-293T cells dropwise, and after 4-5 h, changing to DMEM with 2% FBS for transfected 293T cells.

After 72 h of transfection, the virus was collected by filtration using a 0.45 µm filter and centrifuged at 28,000 rpm using a Beckman Optima L-100XP ultracentrifuge for 2 hours at 4°C. The supernatant was discarded and the resulting pellet was centrifuged at 1/10 ~ 1/50 stock solution of AIM-V medium (purchased from Invitrogen) and resuspend at 100 µL/tube in -80°C for virus titration or infection of T lymphocytes.

Example 8. Infection of CTL cells by Recombinant lentivirus

Human peripheral blood mononuclear cells were obtained from healthy human

peripheral blood by density gradient centrifugation (supplied by Shanghai Blood Center), and CTLs were obtained from peripheral blood mononuclear cells by negative sorting method using CTL magnetic beads (purchased from Stem Cell Technologies). Sorted CTL cells were subjected to flow cytometry to detect the purity of CTL cells. The positive rate of CTL cells $\geq 95\%$ was appropriate for the next step. Cells were added in Quantum 007 lymphocyte medium (purchased from PAA) at a density of about 1×10^6 / mL. Magnetic beads coated with anti-CD3 and CD28 antibodies (Invitrogen) were added in a 1: 1 ratio of cells to magnetic beads, and recombinant human IL-2 (purchased from Shanghai Huaxin Biotechnology Co., Ltd.) at a final concentration of 300U/mL was added for stimulation and culture for 24 h. And then CTL cells were infected with the above recombinant lentivirus at $MOI \approx 5$. The infected cells were passaged every other day at a density of 5×10^5 /mL and recombinant human IL-2 at a final concentration of 300 U / mL was supplemented in the lymphocyte culture medium.

Infected CTL cells were detected by flow cytometry on day 8 of culture for the expression of different chimeric antigen receptors. Firstly, the infected CAR T cells were incubated with biotinylated human mesothelin recombinant protein for 1 h at 37°C, washed in D-PBS twice and then incubated with PE-labeled streptavidin for 40 min at 37°C. After washed with D-PBS for 3 times, the ratio of positive cells was determined by flow cytometry. Uninfected T lymphocytes was used as a negative control, the positive rates of virus-infected T cells expressing different chimeric antigen receptors are shown in Table 3. The positive rate results show that a certain positive rate of CAR⁺T cells can be obtained by lentivirus infection.

Table 3

CTL cells transfected by following CARs	Positive rate of CTL cells transfection
P1A6E - δ Z (negative control)	75%
P1A6E -Z	58%
P1A6E-BBZ	85%
P1A6E-28Z	73%
P1A6E-28BBZ	69%
P3F2 - δ Z (negative control)	71%
P3F2 -Z	68%
P3F2-BBZ	83%
P3F2-28Z	86%
P3F2-28BBZ	77%

CTL cells were infected with viruses that had different chimeric antigen receptors packaged, respectively, and then subcultured at a cell density of 5×10^5 / ml quaque die alterna, counted, and supplemented with IL-2 (final concentration of 300 U / ml). On the 11th day of culture, about 20 ~ 40 times of amplification was obtained, indicating that the CTL

cells expressing different chimeric antigen receptors can be expanded in a certain amount *in vitro*, which ensures subsequent *in vitro* toxicity tests and *in vivo* experiments.

Example 9. *in vitro* toxicity test of T lymphocytes expressing chimeric antigen receptors

In vitro toxicity experiments used the following materials:

Mesothelin-negative pancreatic cancer cell line (PANC-1) and PANC-1 (PANC-1-MSLN) cell line transfected with mesothelin gene as shown in Table 4 were used as target cells and effector cells were CTL cultured for 12 days *in vitro*, which were verified in Example 4 and detected chimeric antigen receptor-expression positive by FACS. Effective target ratios were 3: 1, 1: 1 and 1: 3, respectively. The number of target cells was 10000/well, and effector cells corresponded to different effective target ratio. Each group had 5 replicate wells, average of 5 wells was calculated, and detection time was 18h.

Each experimental group and each control group are listed as follows:

Each experimental group: each target cell + CTL expressing different chimeric antigen receptors;

Control group 1: target cells with maximum LDH release;

Control group 2: target cells with spontaneous LDH release;

Control group 3: effector cells with spontaneous LDH release.

Detection method: CytoTox 96® Non-Radioactive Cytotoxicity Assay (Promega) is used, which is a colorimetric based assay that can replace 51Cr release assay. CytoTox 96® Assay measures lactate dehydrogenase (LDH) quantitatively. LDH is a stable cytosolic enzyme that is released upon lysis of cells and is released in the same way as radioactive 51Cr is released. The supernatant with released LDH medium can be detected by a 30-minute coupled enzyme reaction in which LDH converts a tetrazolium salt (INT) to a red formazan. The amount of red product produced is proportional to the number of lysed cells. Details can be found in instructions of CytoTox 96 non-radioactive cytotoxicity detection kit.

Cytotoxicity is calculated as:

$$\text{Cytotoxicity \%} = [(\text{experiment group} - \text{control group 2} - \text{control group 3}) / (\text{control group 1} - \text{control group 2})] \times 100$$

Specifically, as shown in Table 4, the CARs of anti-mesothelin single chain antibody (P1A6E, P3F2) of the present invention exhibited significant killing activity on mesothelin-positive pancreatic cancer cells, and the second and third generations of anti-mesothelin CAR T cells were slightly more potent than the antitumor activity of the

first generation. There was no significant killing effects in mock group. In addition, all CAR T cells showed no cytotoxic activity on mesothelin-negative PANC-1 pancreatic cancer cells. These results indicate that anti-mesothelin CAR T cells of the invention (including 1st, 2nd, and 3rd generation of CAR T) can selectively target mesothelin-positive pancreatic cancer cells and kill them effectively. In addition, the first, second and third generation of anti-mesothelin CAR T of the present invention exhibited a effector target ratio gradient dependency, that is, the higher the effector target ratio, the stronger the cytotoxic effects.

Table 4. *In vitro* anti-tumor activity of CAR T cells having single chain antibody fused and expressed

CYTOT OXICIT Y (%)	P1A6E -28BBZ			P1A6E -BBZ			P1A6E -28Z			P1A6E -Z			P1A6E -δZ (mock)		
	Different effector target ratio			Different effector target ratio			Different effector target ratio			Different effector target ratio			Different effector target ratio		
	3:1	1:1	1:3	3:1	1:1	1:3	3:1	1:1	1:3	3:1	1:1	1:3	3:1	1:1	1:3
PANC-1 -MSLN	95.3	63.8	32.5	86.5	56.7	25.3	89.4	58.1	23.9	63	33.1	13.7	2.5	1.8	3.6
PANC-1	3.5	4.3	2.2	1.8	2.3	3.4	2.3	3.9	2.8	1.7	2.7	3.5	2.1	2.4	2.8

CYTOT OXICIT Y (%)	P3F2-28BBZ			P3F2 -BBZ			P3F2 -28Z			P3F2 -Z			P3F2-δZ(mock)		
	Different effector target ratio			Different effector target ratio			Different effector target ratio			Different effector target ratio			Different effector target ratio		
	3:1	1:1	1:3	3:1	1:1	1:3	3:1	1:1	1:3	3:1	1:1	1:3	3:1	1:1	1:3
PANC-1 -MSLN	85.6	62.9	30.7	89.3	60.2	31.9	92.	59.3	28.7	58.4	29.9	15.7	3.1	1.5	2.8
PANC-1	2.8	3.1	2.5	4.8	1.8	3.6	4.1	1.7	2.8	3	3.9	2.2	1.8	3.3	3.5

Example 10. Epitope analysis of antibody to human mesothelin

Human mesothelin gene fragment was amplified by PCR from SEQ ID NO: 1 and ligated into eukaryotic expression vector pCMV-V5-muFc containing mouse Fc fragment by NheI/BamHI double-digestion. HEK-293F cells were transiently transfected according to Example 4 and the culture supernatant of cells was processed and affinity-purified through protein G (from GE) affinity column to finally obtain purified human mesothelin fragment-muFc fusion protein, and the binding of antibodies scFv-P1A6E-Fc and scFv-P3F2-Fc was identified through ELISA. The mature human mesothelin is divided into three regions, region R1 (E296-T390, SEQ ID NO: 66), region R2 (S391-Q486, SEQ ID NO: 67), region R3 (N487-G581, SEQ ID NO: 68) according to Genbank Accession No. NP_001170826.1 (SEQ ID NO: 65). ELISA results showed that both of antibodies scFv-P1A6E-Fc and scFv-P3F2-Fc only bind to region 1 (E296-T390). Region 1 was further

divided into 5 small fragments, and fused and expressed with muFc, respectively. Region R1A (296E-337D, SEQ ID NO: 69), Region R1B (328D-369I, SEQ ID NO: 70), Region R1C (360Y- 405T, SEQ ID NO: 71), Region R1AB (296E- 359L, ID NO: 72), R1BC (328D-405T, SEQ ID NO: 73). The results from ELISA are shown in FIG. 9 and FIG. 10, in which the antibodies scFv-P1A6E-Fc and scFv-P3F2-Fc significantly bound to region R1AB while weakly bound to region R1A and not bound to region R1B. Therefore, the binding sites for the antibodies scFv-P1A6E-Fc and scFv-P3F2-Fc should be located around the sites where R1A and R1B overlap. This region contains 10 amino acids "DAALLATQMD", based on which 10 amino acids or 5 amino acids were extended to both ends to form two peptides R1J10: "YKKWELEACVDAALLATQMDRVNAIPFTYE (SEQ ID NO: 74)" and R1J5: "LEACVDAALLATQMDRVNAI (SEQ ID NO: 75)" and fused and expressed with muFc, respectively. ELISA results showed that antibodies scFv-P1A6E-Fc and scFv-P3F2-Fc did not bind to R1J10 or R1J5. Based on the above results, the epitopes of the antibodies scFv-P1A6E-Fc and scFv-P3F2-Fc should be a conformational epitope located in region R1AB (SEQ ID NO: 72).

All references mentioned in the present invention are incorporated herein by reference, as if each reference was individually incorporated by reference. In addition, it should be understood that after reading the above teachings of the present invention, those skilled in the art can make various modifications or changes to the present invention, and these equivalent forms also fall within the scope of the appended claims of the present application.

Claims

1. A fully human antibody that specifically binds to mesothelin, wherein the fully human antibody is selected from a group consisting of:

(a) an antibody comprising a heavy chain variable region having CDR1 comprising the amino acid sequence of SEQ ID NO: 54, CDR2 comprising the amino acid sequence of SEQ ID NO: 55, CDR3 comprising the amino acid sequence of SEQ ID NO: 56; and

a light chain variable region having CDR1 comprising the amino acid sequence of SEQ ID NO: 51, CDR2 comprising the amino acid sequence of SEQ ID NO: 52, CDR3 comprising the amino acid sequence of SEQ ID NO: 53; or

(d) an antibody comprising a heavy chain variable region having CDR1 comprising the amino acid sequence of SEQ ID NO: 60, CDR2 comprising the amino acid sequence of SEQ ID NO: 61, CDR3 of the amino acid sequence of ID NO: 62; and

a light chain variable region having CDR1 comprising the amino acid sequence of SEQ ID NO: 57, CDR2 comprising the amino acid sequence of SEQ ID NO: 58, CDR3 of the amino acid of ID NO: 59.

2. The fully human antibody of claim 1, wherein the fully human antibody comprises a heavy chain variable region and a light chain variable region, the amino acid sequence of the heavy chain variable region is shown in positions 1 to 123 of SEQ ID NO: 6; and the amino acid sequence of the light chain variable region is shown in positions 139-254 of SEQ ID NO: 6; or

the fully human antibody comprises a heavy chain variable region and a light chain variable region, the amino acid sequence of the heavy chain variable region is shown in positions 1 to 124 of SEQ ID NO: 8; and the amino acid sequence of the light chain variable region is shown in positions 140-247 of SEQ ID NO: 8.

3. A nucleic acid encoding the antibody of claim 1 or 2.

4. An expression vector comprising the nucleic acid of claim 3.

5. A host cell, comprising the expression vector of claim 4 or having the nucleic acid of claim 3 integrated into the genome.

6. Use of the antibody of claim 1 or 2 for the preparation of a targeted drug, antibody-drug conjugate, or a polyfunctional antibody that specifically targets tumor cells expressing mesothelin; or

for the preparation of a reagent for diagnosing a tumor expressing mesothelin; or

for the preparation of chimeric antigen receptor-modified immune cells.

7. A chimeric antigen receptor, wherein said chimeric antigen receptor comprises

sequentially linked: the antibody of claim 1 or 2, a transmembrane region and intracellular signal region.

8. The chimeric antigen receptor of claim 7, wherein the intracellular signal region is selected from a group consisting of intracellular signal region sequences of CD3 ζ , Fc ϵ RI γ , CD27, CD28, CD137, CD134, MyD88, CD40 or a combination thereof.

9. The chimeric antigen receptor of claim 7, wherein the transmembrane region comprises a transmembrane region of CD8 or CD28.

10. The chimeric antigen receptor of claim 7, comprising the following sequentially linked antibody, transmembrane region and intracellular signal region:

The antibody of claim 1 or 2, CD8 and CD3 ζ ;

The antibody of claim 1 or 2, CD8, CD137 and CD3 ζ ;

The antibody of claim 1 or 2, the transmembrane region of CD28 molecule, the intracellular signal region of CD28 molecule and CD3 ζ ; or

The antibody of claim 1 or 2, the transmembrane region of CD28 molecule, the intracellular signal region of CD28 molecule, CD137 and CD3 ζ .

11. The chimeric antigen receptor of claim 7, wherein the antibody is a single chain antibody or domain antibody.

12. The chimeric antigen receptor of claim 7, wherein the chimeric antigen receptor has:

SEQ ID NO: 41 or the amino acid sequence shown in positions 22-353 thereof;

SEQ ID NO: 42 or the amino acid sequence shown in positions 22-454 thereof;

SEQ ID NO: 43 or the amino acid sequence shown in positions 22-498 thereof;

SEQ ID NO: 44 or the amino acid sequence shown in positions 22-501 thereof;

SEQ ID NO: 45 or the amino acid sequence shown in positions 22-543 thereof;

SEQ ID NO: 46 or the amino acid sequence shown in positions 22-346 thereof;

SEQ ID NO: 47 or the amino acid sequence shown in positions 22-447 thereof;

SEQ ID NO: 48 or the amino acid sequence shown in positions 22-491 thereof;

SEQ ID NO: 49 or the amino acid sequence shown in positions 22-494 thereof; or

SEQ ID NO: 50 or the amino acid sequence shown in positions 22-536 thereof.

13. A nucleic acid encoding the chimeric antigen receptor of any one of claims 7-12.

14. An expression vector comprising the nucleic acid of claim 13.

15. A virus, wherein the virus comprises the vector of claim 14.

16. Use of the chimeric antigen receptor of any one of claims 7-12, or the nucleic acid of claim 13, or the expression vector of claim 14, or the virus of claim 15 for the preparation of genetically modified immune cells targeting tumor cells expressing mesothelin.

17. The chimeric antigen receptor of claim 16, wherein the mesothelin-expressing tumor includes: pancreatic cancer, ovarian cancer and thymus mesothelioma.

18. A genetically modified immune cell, wherein it is transduced with the nucleic acid of claim 13, or the expression vector of claim 14 or the virus of claim 15; or

expresses the chimeric antigen receptor of any one of claims 7-12 on its cell surface.

19. The immune cell of claim 18, wherein it further carries an encoding sequence of an exogenous cytokine; and preferably, the cytokine includes: IL-12, IL-15 or IL-21.

20. The immune cell of claim 18, wherein the immune cell also expresses another chimeric antigen receptor which does not contain CD3 ζ but contains the intracellular signaling domain of CD28, the intracellular signaling domain of CD137, or a combination of both.

21. The immune cell of claim 18, wherein the immune cell further expresses a chemokine receptor; and preferably, the chemokine receptor includes: CCR2.

22. The immune cell of claim 18, wherein the immune cell further expresses siRNA which can reduce expression of PD-1 or a protein which blocks PD-L1.

23. The immune cell of claim 18, wherein the immune cell further expresses a safety switch; and preferably, the safety switch includes: iCaspase-9, Truncated EGFR or RQR8.

24. The immune cell of claim 18, wherein the immune cell includes: T lymphocyte, NK cell or NKT cell.

25. Use of the genetically modified immune cell of any one of claims 18-24 for the preparation of a tumor-inhibiting drug, and the tumor is a tumor expressing mesothelin.

26. A multi-functional immunoconjugate, wherein the multi-functional immunoconjugate comprises:

The antibody of claim 1 or 2; and

a functional molecule linked thereto; and the functional molecule is selected from a molecule that targets a tumor surface marker, a tumor-suppressing molecule, a molecule that targets a surface marker of an immune cell, or a detectable label.

27. The multi-functional immunoconjugate of claim 26, wherein the molecule that targets the tumor surface marker is an antibody or ligand that binds to a tumor surface marker; or

the tumor-suppressing molecule is an anti-tumor cytokine or an anti-tumor toxin; and preferably, the cytokine includes: IL-12, IL-15, IFN-beta, TNF-alpha.

28. The multi-functional immunoconjugate of claim 26, wherein the detectable label includes a fluorescent label or a chromogenic label.

29. The multi-functional immunoconjugate of claim 27, wherein the antibody that binds

to a tumor surface marker refers to an antibody that recognizes an antigen other than mesothelin, and the other antigen includes EGFR EGFRvIII, mesothelin, HER2, EphA2, Her3, EpCAM, MUC1, MUC16, CEA, Claudin 18.2, folate receptor, Claudin 6, CD3, WT1, NY-ESO- 1, MAGE 3, ASGPR1 or CDH16.

30. The multi-functional immunoconjugate of claim 26, wherein the molecule that targets the surface marker of the immune cell is an antibody that binds to T cell surface marker and forms a T-cell-engaging bifunctional antibody with the antibody of claim 1 or 2.

31. The multi-functional immunoconjugate of claim 30, wherein the antibody that binds to T cell surface marker is an anti-CD3 antibody.

32. The multi-functional immunoconjugate of claim 31, wherein it is a fusion polypeptide, and further comprises a linker peptide between the antibody of claim 1 or 2 and the functional molecule linked thereto.

33. A nucleic acid encoding the multi-functional immunoconjugate of any one of claims 26-32.

34. Use of the multi-functional immunoconjugate of any one of claims 26-32 for the preparation of an antineoplastic agent or an agent for diagnosis of tumors that express mesothelin; or

for the preparation of chimeric antigen receptor modified immune cells; and preferably, the immune cells include T lymphocyte, NK cell or NKT lymphocyte.

35. A pharmaceutical composition, comprising:

the antibody of claim 1 or 2 or a nucleic acid encoding the antibody; or

the immunoconjugate of any one of claims 26-32 or a nucleic acid encoding the conjugate; or

the chimeric antigen receptor of any one of claims 7-12 or a nucleic acid encoding the chimeric antigen receptor; or

the genetically modified immune cell of any one of claims 18-24.