ROR1 Antibody Compositions and Related Methods

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The subject patent application claims the benefit of priority to U.S. Provisional Patent Application Number 62/280,843 (filed January 20, 2016). The full disclosure of the priority application is incorporated herein by reference in its entirety and for all purposes.

BACKGROUND OF THE INVENTION

[0002] Cancer is one of the leading causes of death. It is a class of diseases which is caused by malignant transformation of healthy cells, caused by genetic alterations, like chromosomal translocations, mutations in tumor suppressor genes, transcription factors or growth-factor receptors, leading to the immortalization of the cells. If the immortalization is combined with excessive proliferation the immortalized cells generate tumors with or without metastasis (in case of solid tumors) or leukemias and lymphomas (cancers of the blood). Defective apoptosis, or programmed cell death, can further contribute to malignant transformation of cells leading to cancer.

[0003] A family of membrane associated receptor tyrosine kinases, consisting of the receptor tyrosine kinase orphan receptors-1 and -2 (ROR1 and ROR2) have been described as being specifically associated with particular cancers (Rebagay et al. (2012) *Front Oncol.* 2(34)), while being largely absent in expression on healthy tissue with few exceptions (Balakrishnan et al. (2016) *Clin Cancer Res.* doi: 10.1158/1078-0432). Whether or not ROR expression is functionally associated with tumorigenesis remains unclear. However, due to the very tumor-selective expression of the ROR family members, they represent relevant targets for targeted cancer therapies. Receptor tyrosine kinase orphan receptors-1 (ROR1) is of particular interest as a cancer target, due to its nearly 100% association with chronic lymphocytic leukemia (CLL) (Cui et al. (2016) *Blood* 128(25), p. 2931) and the observation that is also expressed in certain solid tumors, like that of lung and breast (Balakrishnan et al. (2016) *Clin Cancer Res.* doi: 10.1158/1078-0432). Members of the ROR family are type-I transmembrane proteins containing three distinct extracellular domains, an Ig, a Kringle and a Frizzled domain, followed a transmembrane spanning region, and an intracellular portion.

Within the intracellular portion, ROR1 possesses a tyrosine kinase domain, two serine/threonine-rich domains and a proline-rich domain. RORs have been studied in the context of embryonic patterning and neurogenesis through a variety of homologs. These physiologic functions are dichotomous based on the requirement of the kinase domain. A growing literature has established ROR1 as a marker for cancer, such as in chronic lymphocytic leukemia (CLL) for which ROR1 expression is nearly 100% correlated, some acute lymphoblastic leukemias (ALL), mantle cell lymphomas, and some other blood malignancies. In addition, ROR1 is critically involved in progression of a number of solid tumors, such as in neuroblastoma, sarcoma, renal cell carcinoma, breast cancer, lung cancer, colon cancer, head and neck cancer, melanoma, and other cancers. ROR1 has been shown to inhibit apoptosis, potentiate EGFR signaling, induce epithelial-mesenchymal transition (EMT), and contribute to caveolae formation. Importantly, ROR1 is mainly detectable in embryonic tissue and generally absent in adult tissue, making the protein an ideal drug target for cancer therapy. As such, ROR1 has previously been recognized as a target for the development of ROR1 specific antibodies. However, due to the high homology of ROR1 between different mammalian species, which is 100% conserved on the amino acid level between humans and cynomolgus monkeys, 96.7 % homologous between human and mouse, and 96.3 % homologous between human and rabbit, it has been difficult to raise high affinity antibodies against this target by standard technologies, like animal immunizations.

[0004] A few murine and rabbit antibodies have been discussed in the literature. For example, WO 2007/051077 discussed monoclonal antibodies, including humanized antibodies, directed against native ROR1 found on lymphomas including CLL, small lymphocytic lymphoma, marginal B-cell lymphoma and Burkett's lymphoma. Methods for inhibiting growth of a tumor cell using agents, which may be ROR1-binding antibodies that inhibit ROR1 kinase activity, are the subject of WO 2007/146957. WO 2011/054007 discussed a method of treatment or prophylaxis of cancer in which the extracellular domain of ROR1 is expressed by administration of specific ROR1-targeting antibodies.

[0005] Additionally, WO 2010/124188 discussed anti-human ROR1 antibodies, and in particular to monoclonal murine antibody referred to under the name 2A2, while WO 2012/075158 refers to monoclonal rabbit antibodies named R11 and R12. Particular ROR1-targeting antibodies are also mentioned in WO 2016/094873. Both WO 2011/079902 and WO 2012/076066 discussed biological inhibitors of ROR1 capable of inducing cell death

that bind to selected extracellular ROR1 domain sequences. WO 2014/031174 refers to anti-ROR1 antibodies having the same binding specificity as an antibody named 99961. Binding epitopes of anti-ROR1 antibodies are further referred to in WO 2016/187220. WO 2011/159847 discussed particular scFv antibody fragment conjugates that bind ROR1. WO 2014/167022, WO 2016/055592 and WO 2016/055593 discussed bispecific ROR1-targeting antibodies and their uses, while WO 2015/184203 discussed tri-specific binding molecules. Especially newer documents disclosing humanized anti-ROR1 monoclonal antibodies are based on the originally disclosed mouse or rabbit antibodies, like 2A2, R11, R12 or D10.

[0006] Due to the low number of available ROR1 specific monoclonal antibodies, there is a need in the art for better anti-ROR1 antibodies that have higher affinity or other functional properties not possessed by the known antibody clones. There is also a need for additional diagnostic tools for detecting ROR1 expressions in ROR1-related disease conditions by, e.g., Western blotting and/or immunohistochemistry (IHC). The instant invention is directed to addressing these and other needs.

SUMMARY OF THE INVENTION

[0007] In one aspect, the invention provides novel, high-affinity binding domains of rabbit antibodies that specifically bind to the extracellular domain of human receptor tyrosine kinase-like orphan receptor 1 (hROR1) and that have been selected from highly diverse phage-display libraries of non-immunized rabbits using human ROR1 (hROR1) extracellular domains expressed in mammalian cells as a bait. The variable regions of rabbit antibodies have been selected by screening for the binding against the ECD of hROR1 both as recombinant proteins and also based on the binding of hROR1 over-expressed on the surface of mammalian host cells. By this strategy novel antibodies for hROR1 of unprecedented quality and favorable functional properties have been identified. Furthermore, the invention provides chimeric full-length antibodies of the rabbit variable domains fused to the constant region domains of human IgG_1 antibodies. Furthermore the invention provides novel, high-affinity humanized antibodies that were generated by CDR grafting of the rabbit anti-ROR1 antibodies disclosed herein into the framework of variable immunoglobulin heavy and light chains. Such humanized antibodies can be used for the therapy of human diseases due to the high homology of said humanized antibodies to endogenous, fully human antibodies. In a second aspect of the invention site-specifically conjugated antibody drug

conjugates (ADCs) based on the chimeric rabbit-human and humanized anti-human ROR1 (hROR1) antibodies with an ultra-potent anthracycline toxin are provided by the invention. The site-specific conjugation is achieved by enzymatic conjugation using sortase enzyme, essentially as disclosed in WO2014140317, which is incorporated as reference herein. The ultra-potent anthracycline toxin resulting in anti-hROR1 ADCs with unprecedented potency in various *in vitro* and *in vivo* tumor models has been disclosed in WO2016102679, which is incorporated as reference herein.

[0008] Lastly, the invention provides chimeric antigen receptors (CARs) and T cells engineered with these CARs, i.e. so-called CAR-T cells, employing said anti-hROR1 binding domains showing high efficacy *in vitro*.

[0009] Therefore the invention relates to anti-hROR1 antibodies, antibody-based binding proteins, antibody fragments thereof, antibody drug conjugates (ADCs), or CARs having the same binding specificity for hROR1 as that of hROR1 specific antibodies containing an immunoglobulin heavy chain variable region sequence and an immunoglobulin light chain variable region sequence, respectively, shown in (1) SEQ ID NO:1 and SEQ ID NO:14; (2) SEQ ID NO:2 and SEQ ID NO:15; (3) SEQ ID NO:3 and SEQ ID NO:16; (4) SEQ ID NO:4 and SEQ ID NO:17; (5) SEQ ID NO:5 and SEQ ID NO:18; (6) SEQ ID NO:6 and SEQ ID NO:19; (7) SEQ ID NO:7 and SEQ ID NO:20; (8) SEQ ID NO:8 and SEQ ID NO:21; (9) SEQ ID NO:9 and SEQ ID NO:22; (10) SEQ ID NO:10 and SEQ ID NO:23; (11) SEQ ID NO:11 and SEQ ID NO:24; (12) SEQ ID NO:12 and SEQ ID NO:25; (13) SEQ ID NO:13 and SEQ ID NO:26; (14) SEQ ID NO:130 and SEQ ID NO:136; (15) SEQ ID NO:131 and SEQ ID NO:137; (16) SEQ ID NO:132 and SEQ ID NO:138; (17) SEQ ID NO:133 and SEQ ID NO:139; (18) SEQ ID NO:134 and SEQ ID NO:140; or (19) SEQ ID NO:135 and SEQ ID NO:141.

[0010] The invention further relates to anti-hROR1 antibodies, antibody-based binding proteins, antibody fragments thereof, antibody drug conjugates (ADCs), or CARs comprising immunoglobulin heavy chain CDR sequences and immunoglobulin light chain CDR sequences that are at least 90%, or at least 95% or greater than 95%, but less than 100% identical, respectively, to (1) SEQ ID NOs:27-29 and SEQ ID NOs:66-68, (2) SEQ ID NOs:30-32 and SEQ ID NOs:69-71, (3) SEQ ID NOs:33-35 and SEQ ID NOs:72-74, (4) SEQ ID NOs:36-38 and SEQ ID NOs:75-77, (5) SEQ ID NOs:39-41 and SEQ ID NOs:78-80, (6) SEQ ID NOs:42-44 and SEQ ID NOs:81-83, (7) SEQ ID NOs:45-47 and SEQ ID

NOs:84-86, (8) SEQ ID NOs:48-50 and SEQ ID NOs:87-89, (9) SEQ ID NOs:51-53 and SEQ ID NOs:90-92, (10) SEQ ID NOs:54-56 and SEQ ID NOs:93-95, (11) SEQ ID NOs:57-59 and SEQ ID NOs:96-98, (12) SEQ ID NOs:60-62 and SEQ ID NOs:99-101, or (13) SEQ ID NOs:63-65 and SEQ ID NOs:102-104.

[0011] The invention further relates to anti-hROR1 antibodies, antibody-based binding proteins, antibody fragments thereof, antibody drug conjugates (ADCs), or CARs comprising immunoglobulin heavy chain CDR sequences and immunoglobulin light chain CDR sequences that are identical, respectively, to (1) SEQ ID NOs:27-29 and SEQ ID NOs:66-68, (2) SEQ ID NOs:30-32 and SEQ ID NOs:69-71, (3) SEQ ID NOs:33-35 and SEQ ID NOs:72-74, (4) SEQ ID NOs:36-38 and SEQ ID NOs:75-77, (5) SEQ ID NOs:39-41 and SEQ ID NOs:78-80, (6) SEQ ID NOs:42-44 and SEQ ID NOs:81-83, (7) SEQ ID NOs:45-47 and SEQ ID NOs:84-86, (8) SEQ ID NOs:48-50 and SEQ ID NOs:87-89, (9) SEQ ID NOs:51-53 and SEQ ID NOs:90-92, (10) SEQ ID NOs:54-56 and SEQ ID NOs:93-95, (11) SEQ ID NOs:57-59 and SEQ ID NOs:96-98, (12) SEQ ID NOs:60-62 and SEQ ID NOs:99-101, or (13) SEQ ID NOs:63-65 and SEQ ID NOs:102-104.

[0012] The invention further relates to anti-hROR1 antibodies, antibody-based binding proteins, antibody fragments thereof, antibody drug conjugates (ADCs), or CARs comprising either an immunoglobulin heavy chain variable region sequence or an immunoglobulin light chain variable region sequence with at least 90%, or at least 95%, or greater than 95% but less than 100% identity at amino acid level relative to an immunoglobulin heavy chain variable region sequence and an immunoglobulin light chain variable region sequence, respectively, shown in (1) SEQ ID NO:1 and SEQ ID NO:14; (2) SEQ ID NO:2 and SEQ ID NO:15; (3) SEQ ID NO:3 and SEQ ID NO:16; (4) SEQ ID NO:4 and SEQ ID NO:17; (5) SEQ ID NO:5 and SEQ ID NO:18; (6) SEQ ID NO:6 and SEQ ID NO:19; (7) SEQ ID NO:7 and SEQ ID NO:20; (8) SEQ ID NO:8 and SEQ ID NO:21; (9) SEQ ID NO:9 and SEQ ID NO:22; (10) SEQ ID NO:10 and SEQ ID NO:23; (11) SEQ ID NO:11 and SEQ ID NO:24; (12) SEQ ID NO:12 and SEQ ID NO:25; or (13) SEQ ID NO:13 and SEQ ID NO:26.

[0013] The invention further relates to anti-hROR1 antibodies, antibody-based binding proteins, antibody fragments thereof, antibody drug conjugates (ADCs), or CARs comprising an immunoglobulin heavy chain CDR sequence selected from the group consisting of SEQ ID NOs:27-65. The invention further relates to relates to anti-hROR1

antibodies, antibody fragments thereof, antibody drug conjugates (ADCs), or CARs comprising an immunoglobulin light chain CDR sequence selected from the group consisting of SEQ ID NOs:66-104. In some embodiments, the hROR1-specific antibodies, antibody-based binding proteins, or antibody fragments thereof, antibody drug conjugates (ADCs), or CARs contain heavy chain CDR1, CDR2, and CDR3 sequences that are respectively identical to SEQ ID NOs:27-29, SEQ ID NOs:30-32, SEQ ID NOs:33-35, SEQ ID NO:36-38, SEQ ID NOs:39-41, SEQ ID NOs:42-44, SEQ ID NOs:45-47, SEQ ID NOs:48-50, SEQ ID NOs:51-53, SEQ ID NOs:54-56, SEQ ID NOs:57-59, SEQ ID NOs:60-62, or SEQ ID NOs:63-65.

[0014] The invention further relates to anti-hROR1 antibodies, antibody-based binding proteins, antibody fragments thereof, antibody drug conjugates (ADCs), or CARs comprising either an immunoglobulin heavy chain variable region sequence or an immunoglobulin light chain variable region sequence identical to (1) SEQ ID NO:1 and SEQ ID NO:14; (2) SEQ ID NO:2 and SEQ ID NO:15; (3) SEQ ID NO:3 and SEQ ID NO:16; (4) SEQ ID NO:4 and SEQ ID NO:17; (5) SEQ ID NO:5 and SEQ ID NO:18; (6) SEQ ID NO:6 and SEQ ID NO:19; (7) SEQ ID NO:7 and SEQ ID NO:20; (8) SEQ ID NO:8 and SEQ ID NO:21; (9) SEQ ID NO:9 and SEQ ID NO:22; (10) SEQ ID NO:10 and SEQ ID NO:23; (11) SEQ ID NO:11 and SEQ ID NO:24; (12) SEQ ID NO:12 and SEQ ID NO:25; (13) SEQ ID NO:13 and SEQ ID NO:26; (14) SEQ ID NO:130 and SEQ ID NO:136; (15) SEQ ID NO:131 and SEQ ID NO:137; (16) SEQ ID NO:132 and SEQ ID NO:138; (17) SEQ ID NO:133 and SEQ ID NO:139; (18) SEQ ID NO:134 and SEQ ID NO:140; or (19) SEQ ID NO:135 and SEQ ID NO:141

[0015] The invention further relates to anti-hROR1 antibodies, antibody-based binding proteins, antibody fragments thereof, antibody drug conjugates (ADCs), or CARs comprising anti-hROR1 specific antibodies, antibody-based-binding proteins or antibody fragments thereof that comprise an immunoglobulin heavy chain variable region sequence and an immunoglobulin light chain variable region sequence, respectively, identical to (1) SEQ ID NO:1 and SEQ ID NO:14; (2) SEQ ID NO:2 and SEQ ID NO:15; (3) SEQ ID NO:3 and SEQ ID NO:16; (4) SEQ ID NO:4 and SEQ ID NO:17; (5) SEQ ID NO:5 and SEQ ID NO:18; (6) SEQ ID NO:6 and SEQ ID NO:19; (7) SEQ ID NO:7 and SEQ ID NO:20; (8) SEQ ID NO:8 and SEQ ID NO:21; (9) SEQ ID NO:9 and SEQ ID NO:22; (10) SEQ ID NO:10 and SEQ ID NO:23; (11) SEQ ID NO:11 and SEQ ID NO:24; (12) SEQ ID NO:12

and SEQ ID NO:25; (13) SEQ ID NO:13 and SEQ ID NO:26; (14) SEQ ID NO:130 and SEQ ID NO:136; (15) SEQ ID NO:131 and SEQ ID NO:137; (16) SEQ ID NO:132 and SEQ ID NO:138; (17) SEQ ID NO:133 and SEQ ID NO:139; (18) SEQ ID NO:134 and SEQ ID NO:140; or (19) SEQ ID NO:135 and SEQ ID NO:141.

[0016] In some embodiments, anti-hROR1 antibodies, antibody-based binding proteins, antibody fragments thereof, antibody drug conjugates (ADCs), or CARs comprise an immunoglobulin light chain CDR sequence selected from the group consisting of SEQ ID NOs:66-104. Some of these molecules further harbor an immunoglobulin heavy chain CDR sequence selected from the group consisting of SEQ ID NOs:27-65. Some of these molecules harbor immunoglobulin light chain CDR1, CDR2, and CDR3 sequences that are, respectively, identical to SEQ ID NOs:66-68, SEQ ID NOs:69-71, SEQ ID NOs:72-74, SEQ ID NO:75-77, SEQ ID NOs:78-80, SEQ ID NOs:81-83, SEQ ID NOs:84-86, SEQ ID NOs:87-89, SEQ ID NOs:90-92, SEQ ID NOs:93-95, SEQ ID NOs:96-98, SEQ ID NOs:99-101, or SEQ ID NOs:102-104. In some embodiments, the anti-hROR1 antibodies, antibody-based binding proteins, antibody fragments thereof, antibody drug conjugates (ADCs), or CARs comprise immunoglobulin heavy chain CDR1, CDR2 and CDR3 sequences and immunoglobulin light chain CDR1, CDR2 and CDR3 sequences, respectively, shown in (1) SEQ ID NOs:27-29 and SEQ ID NOs:66-68, (2) SEQ ID NOs:30-32 and SEQ ID NOs:69-71, (3) SEQ ID NOs:33-35 and SEQ ID NOs:72-74, (4) SEQ ID NOs:36-38 and SEQ ID NOs:75-77, (5) SEQ ID NOs:39-41 and SEQ ID NOs:78-80, (6) SEQ ID NOs:42-44 and SEQ ID NOs:81-83, (7) SEQ ID NOs:45-47 and SEQ ID NOs:84-86, (8) SEQ ID NOs:48-50 and SEQ ID NOs:87-89, (9) SEQ ID NOs:51-53 and SEQ ID NOs:90-92, (10) SEQ ID NOs:54-56 and SEQ ID NOs:93-95, (11) SEQ ID NOs:57-59 and SEQ ID NOs:96-98, (12) SEQ ID NOs:60-62 and SEQ ID NOs:99-101, or (13) SEQ ID NOs:63-65 and SEQ ID NOs:102-104.

[0017] The invention further relates to hROR1-specific humanized antibodies, antibody-based binding proteins, antibody fragments thereof, antibody drug conjugates (ADCs), or CARs with at least 90%, or at least 95%, or at least 95% but less than 100% homology at amino acid level to immunoglobulin heavy or immunoglobulin light chain provided of: (14) SEQ ID NO:130 and SEQ ID NO:136; (15) SEQ ID NO:131 and SEQ ID NO:137; (16) SEQ ID NO:132 and SEQ ID NO:138; (17) SEQ ID NO:133 and SEQ ID NO:139; (18) SEQ ID NO:134 and SEQ ID NO:140; or (19) SEQ ID NO:135 and SEQ ID NO:141.

[0018] In yet additional embodiments, the hROR1-specific antibodies, antibody-based binding proteins or antibody fragments thereof are either of IgA_1, IgA_2, IgD, IgE, IgG_1, IgG_2, IgG_3 IgG_4, or IgM isotypes, or $F(ab)_2$, Fv, scFv, $IgGACH_2$, $F(ab')_2$, $scFv_2CH_3$, Fab, V_L, V_H, $scFv_4$, $scFv_3$, $scFv_2$, dsFv, Fv, scFv-Fc, $(scFv)_2$ fragments thereof, or non-depleting IgG, diabodies or bivalent antibodies. Some of the molecules are IgGs selected from the group consisting of naturally occurring IgG_1, IgG_2, IgG_3, IgG_4 isotypes, or synthetic IgGs. Some of the molecules are Fab, scFv, or dsFv. In some embodiments, the hROR1-specific antibodies, antibody-based binding proteins or antibody fragments thereof of the invention are conjugated to a synthetic molecule. The synthetic molecule can be, e.g., a label, a cytotoxic agent, a radioisotope, or a liposome. The cytotoxic agent can be, e.g., a small molecule weight toxin, a peptide toxin, or a protein toxin. In some embodiments, the hROR1-specific antibodies, antibody-based binding proteins or antibody fragments thereof are conjugated to a transmembrane region and an intracellular T-cell receptor (TCR) signaling domain to form a chimeric antigen receptor (CAR).

[0019] The invention further relates to antibody drug conjugates (ADCs) comprising a hROR1-specific humanized or chimeric antibody, antibody-based binding protein or antibody fragment with a toxin payload that effects efficient killing of hROR1 specific cells. In said ADCs the toxin payload can be conjugated non-site-specifically to the antibody, antibody-based binding protein or antibody fragment via lysine or cysteine amino acid side chains employing classical chemical linkers with maleimide functionality, or other chemical known in the art that can mediate conjugation to lysine or cysteine amino acid side chains. In said ADCs the small molecular weight payload can also be conjugated site-specifically either by chemical, chemo-enzymatic, or enzymatic conjugations known in the art, like e.g. with bifunctional linkers, linkers allowing Pictet-Spengler chemistry on formyl-glycine forming enzyme modified antibodies, by glycan-remodeled antibodies, or by bacterial transglutaminase or sortase enzymes.

[0020] In some related aspects, the invention provides pharmaceutical compositions or kits that contain a therapeutically effective amount of an anti-hROR1 antibody, antibody-based binding protein, antibody fragment thereof, antibody drug conjugate (ADC) described herein and a pharmaceutically acceptable carrier. Some kits of the invention can additionally contain one or more immunoassay buffers. Also provided in the invention are polynucleotides encoding the variable region of the immunoglobulin heavy chain or

immunoglobulin light chain of the anti-hROR1 antibodies, antibody-based binding proteins, antibody fragments thereof, antibody drug conjugates (ADCs), or CARs disclosed herein, as well as expression vectors harboring such a polynucleotide sequence.

[0021] In another aspect, the invention provides methods for killing or inhibiting the growth of a cell expressing hROR1. The methods involve administering a therapeutically effective amount of anti-hROR1 antibodies, antibody-based binding protein, antibody fragment thereof, antibody drug conjugate (ADC), or CAR of the invention to a subject in need thereof, which enables killing or inhibition of the growth of the cell expressing hROR1 in the subject. Some of these methods are specifically directed to killing or inhibiting tumor cells. In another aspect, the invention provides methods of treating a disease or condition associated with elevated expression of hROR1 in a subject. These methods entail administering a therapeutically effective amount of anti-hROR1 antibodies, antibody-based binding proteins, antibody fragments thereof, ADCs, or CARs of the invention to a subject afflicted with a disease or condition associated with elevated expression of hROR1, which allows treatment of the disease or condition associated with elevated expression of hROR1 in the subject. Some of these therapeutic methods are specifically directed to treating cancer. For example, the methods can be employed to treat subjects suffering from various types of cancer, including, e.g., CLL, ALL, mantle cell lymphoma, neuroblastoma, sarcoma, renal cell carcinoma, breast cancer, lung cancer, colon cancer, head and neck cancer, and melanoma.

[0022] In still another aspect, the invention provides methods of detecting an altered ROR1 level in a subject. Such methods involve (a) obtaining a biological sample from the subject; (b) contacting the sample with anti-hROR1 antibodies, antibody-based binding proteins or antibody fragments thereof of the invention; (c) determining the level of ROR1 in the biological sample; and (d) comparing the level of ROR1 in the biological sample to a control level of ROR1 to thereby determine whether the ROR1 level in the biological sample is altered relative to the control level of ROR1. In some of these methods, an increased ROR1 level in the subject relative to the control level is indicative of a disease or condition associated with elevated expression of ROR1 in the subject. Examples of specific diseases or conditions suitable for the methods include, e.g., CLL, ALL, mantle cell lymphoma, neuroblastoma, sarcoma, renal cell carcinoma, breast cancer, lung cancer, colon cancer, head and neck cancer, or melanoma.

[0023] In another related aspect, the invention provides methods for detecting a ROR1-expressing tumor in a subject. The methods involve (a) administering an hROR1 antibody, antibody-based binding protein or antibody fragment thereof of the invention to a subject that has, is suspected to have, or is at risk of developing a ROR1-expressing tumor; and (b) imaging the subject for a region of altered conjugated label density or concentration, wherein the density or concentration is relative to (i) background in proximal tissue or (ii) the density or concentration previously detected in the same region of the subject, such that the existence of a region of altered conjugated label density or concentration is an indication of the presence of an ROR1-expressing tumor in the subject.

[0024] A further understanding of the nature and advantages of the present invention may be realized by reference to the remaining portions of the specification and claims.

DESCRIPTION OF THE DRAWINGS

[0025] Figure 1 shows the amino acid sequences of variable immunoglobulin heavy and light chains of novel rabbit anti-hROR1 mAbs, as indicated. The amino acid sequence alignment of the rabbit variable domains (V_κ, V_λ, and V_H) is shown with framework regions (FR) and complementarity determining regions (CDR) using Kabat numbering. Shown in the figure are the heavy chain variable domain sequences (SEQ ID NOs:1-13, respectively) and the light chain variable domain sequences (SEQ ID NOs:14-26, respectively) of 13 antibodies designated XBR1-402, ERR1-301, ERR1-306, ERR1-316, ERR1-324, ERR1-403, ERR1-409, ERR1-TOP4, ERR1-TOP15, ERR1-TOP22, ERR1-TOP40, ERR1-TOP43, and ERR1-TOP54. As indicated in the figure clones XBR1-402, ERR1-301, ERR1-306, ERR1-316, ERR1-403, ERR1-409, ERR1-TOP4, ERR1-TOP15, ERR1-TOP22, ERR1-TOP43, and ERR1-TOP54 are variable domains of immunoglobulin λ light chains, while antibodies ERR1-324 and ERR1-TOP40 are variable domains of immunoglobulin κ light chains.

[0026] Figure 2 shows the binding activity of chimeric rabbit/human Fabs to human ROR1 (hROR1) and mouse ROR1 (mROR1) expressed as fusion proteins of the extracellular domain (ECD) of hROR1 and mROR1 to the human Fc domain of a human IgG1 antibody. The binding of each chimeric rabbit/human Fab to hROR1 and mROR1 fused with human IgG1 Fc (hFc-hROR1 and hFc-mROR1) was analyzed by ELISA. hFc-ROR1 or hFc-mROR1 were captured by anti-human IgG1 Fc antibody immobilized on plate

and then incubated with hROR1 specific Fabs comprising a His-tag via detection with mouse anti-His tag. Specificity of the Fabs was confirmed by using fusion proteins of the extracellular domain (ECD) of hROR2 with the human Fc domain of a human IgG1 antibody (hFc-hROR2) as control.

[0027] Figure 3 shows binding activity of chimeric rabbit/human Fabs to native human ROR1 protein expressed on the cell surface of murine preB cell line 63-12 (see Example 1). The binding of each chimeric rabbit/human Fab to the ectopically expressed human ROR1 on mouse pre-B cell (63-12) surface was analyzed by flow cytometry. ERR2-TOP35 is a mAb against hROR2 that served as an isotype-matched control.

[0028] Figure 4 shows epitope mapping studies for chimeric rabbit/human Fabs on six different immobilized IgG1-Fc fusion proteins that comprise different parts of the extracellular domain of human ROR1: hFc-hROR1-Ig (comprising the Immunoglobulin-domain of hROR1), hFc-hROR1-Fr (comprising the Frizzled domain of hROR1), hFc-hROR1-Kr (comprising the Kringle domain of hROR1), hFc-hROR1-Ig-Fr (comprising the Immunoglobulin and Frizzled domains of hROR1), hFc-hROR1-Fr-Ki (comprising the Frizzled and Kringle domains of hROR1) and hFc-hROR1 (comprising the entire extracellular domain (ECD) of hROR1).

[0029] Figure 5 shows epitope binding studies performed by surface plasmon resonance. Shown are SPR sensograms obtained for the binding of different Fabs to hFc-hROR1 captured by anti-human Fcγ antibody immobilized on a CM5 chip. Fabs were injected in different orders to identify independent and overlapping epitopes. Resonance unit (RU, y axis) increases that exceeded the values found for previously injected Fabs indicated independent epitopes because they allow simultaneous binding. For example, the increase found for the binding of Fab R11 exceeded the values found for XBR1-402 alone, indicating that Fab R11 and XBR1-402 can bind simultaneously to human ROR1. By contrast, the epitope of Fab XBR1-402 overlaps with the epitopes of ERR1-301, ERR1-403 and R12 (left graph); the epitope of Fab ERR1-TOP43 overlaps with the epitope of ERR1-306, XBR1-402 and ERR1-TOP40. The x axis depicts the time in seconds (s).

[0030] Figure 6 shows affinity measurements of anti-hROR1 specific Fabs to hROR1 ECD by surface plasmon resonance (SPR). (A) Shown are Biacore X100 sensorgrams obtained for the binding of each Fab to hFc-hROR1 captured by anti-human Fcγ antibody immobilized on CM5 chip after instantaneous background depletion. Fabs were injected at

five different concentrations with the highest concentration indicated in table (B), one of the five concentrations was tested in duplicates. (B) Monovalent affinities of each Fab are shown in the table. The equilibrium dissociation constant (K_d) was calculated from k_{off}/k_{on} (k_{on}, association rate constant; k_{off}, dissociation rate constant).

[0031] Figure 7 shows FACS-based cell staining of hROR1 on various human cancer cell lines with anti-human ROR1 antibody 2A2 as described in Example 9. Cell lines analyzed lines include 697 (human acute lymphocytic leukemia, ALL), Kasumi-2 (human preB acute lymphocytic leukemia), human triple-negative breast cancer cell lines MDA-MB-231, MDA-MB-468 and HS-578T, as well as human breast cancer cell line T47D. Except for the T47D human breast cancer cell line, all of the evaluated cells are positive for hROR1 expression.

[0032] Figure 8 shows the binding activity of selected chimeric rabbit/human IgG1 to endogenous hROR1 expressed on breast cancer cells measured by fluorescence activated cell sorting (FACS). Human breast cancer cell line MDA-MB-231 is known to express hROR1, human breast cancer cell line T47D is known to be negative for hROR1. In contrast, T47D is known to be ROR2 positive, whereas MDA-MB-231 is known to be negative for ROR-2 expression. ERR1-Top54, ERR1-Top43, ERR1-324, XBR1-402 were selected anti-hROR1 specific mAbs, XBR2-401 was a hROR2 specific mAb used as a specificity control (A) The expression of endogenous hROR1 and hROR2 on breast cancer cells was detected by flow cytometry using commercially available goat anti-human ROR1 and goat anti-human ROR2 polyclonal antibodies (R&D Systems), respectively, followed by Alexa Fluor 647-conjugated AffiniPure F(ab')$_2$ donkey anti-goat IgG (H+L) polyclonal antibodies (Jackson ImmunoResearch Laboratories). Control stainings were done with the Alexa Fluor 647-conjugated AffiniPure F(ab')$_2$ donkey anti-goat IgG (H+L) polyclonal antibodies alone. (B) The binding of chimeric rabbit/human IgG1 of selected clones ERR1-Top54, ERR1-Top43, ERR1-324, XBR1-402 (all hROR1 specific) and XBR2-401 (hROR2 specific) to ROR1 expressing human breast cancer cell line MDA-MB-231 and to ROR2 expressing human breast cancer cell line T47D was analyzed by flow cytometry using the chimeric rabbit/human IgG1 as primary antibodies and APC-labeled goat anti-human Fc-specific polyclonal antibodies as secondary antibody.

[0033] Figure 9 shows the binding activity of chimeric rabbit/human IgG1 XBR1-402 and ERR1-TOP43 (both hROR1 specific) to denatured hROR1 in Western-blot experiments.

hROR1 expressed on the cell surface K562 cells or purified protein was denatured and detected by Western blotting. The Western blots contained the following samples as indicated: Lane 1: K562 cells ectopically expressing full length of hROR1. Lane 2: untransfected K62 cells. Lane 3: purified extracellular domain of hROR1. Lane 4: purified extracellular domain of hROR2.

[0034] Figure 10 shows the binding analyzed by ELISA of selected hROR1 specific rabbit-human-Fc chimeric antibodies of selected clones ERR1-301, XBR1-402, ERR1-306, ERR1-324, ERR1-403 and ERR1-Top43 to recombinant, purified hROR1 (panel A) and to recombinant, purified hROR2 as a negative control (panel B).

[0035] Figure 11 shows schematically how site-specifically conjugated ADCs disclosed in this invention have been generated. (A) schematically shows the mechanism of sortase-enzyme mediated antibody conjugation (SMAC-technology) as disclosed in WO2014140317. In order to generate site-specifically conjugated ADCs, recombinant antibodies need to be expressed with the C-terminal pentapeptide motif LPXTG (SEQ ID NO:144), which serve as recognition sites for the sortase enzyme A from Staphylococcus aureus (SrtA). When a glycine modified toxin substrate is incubated with pentapeptide motif LPXTG containing antibody and sortase A enzyme, the sortase A enzyme catalyzes a transpeptidation reaction by which the glycine-modified toxin replaces the C-terminal glycine of the LPXTG motif and is covalently coupled to the threonine of the remaining LPXT (SEQ ID NO:147) sequence. This way C-terminally toxin-conjugated ADCs can be generated with high efficiency. (B) shows the structure of the preferred toxin, a PNU-159682 derivative comprising an ethylene-diamino (EDA) linker connecting a 5x glycine stretch to the carbonyl group at C13 of the anthracycline structure, as disclosed in WO2016102697.

[0036] Figure 12 shows the efficacy for *in vitro* cell killing assays performed on (panel A) immortalized human breast cancer cell line MDA-MB-468 with known hROR1-targeting ADCs (2A2-G5-PNU, R12-G5-PNU) and a novel ADC provided in the invention (ERR1-Top43-G5-PNU), and (panel B) immortalized human breast cancer cell line HS 578T with known hROR1-targeting ADCs (2A2-G5-PNU, R12-G5-PNU) and novel ADCs provided in the invention (XBR1-402-G5-PNU and ERR1-Top43-G5-PNU). CD30 targeting ADC Ac10-G5-PNU was used as an isotype-matched control ADC in both panels.

[0037] Figure 13 shows *in vitro* potency for cell killing of ROR1 positive acute lymphocytic leukemia cell line 697 with four anti-ROR1-PNU ADCs, including ADCs

based on antibody clones 2A2, R11 and R12, and based on anti-ROR1-antibody clone XBR1-402 disclosed herein. All antibodies were expressed as rabbit-human (R11, R12, XBR-402) or murine-human (2A2) chimeric IgG_1. (A) shows the cell killing over a concentration range of ADCs site-specifically conjugated to the toxin payload Gly_5-EDA-PNU (abbreviated G5-PNU) with each of the ADCs. (B) shows the numeric IC_{50} values for cell killing calculated from the curves in (A) for each of the anti-ROR1 ADCs.

[0038] Figure 14 shows *in vitro* cell killing of ROR1 positive ALL cell lines Kasumi-2 (A) and 697 (B) with selected anti-hROR1 ADCs site specifically conjugated to the Gly_5-EDA-PNU toxin payload (abbreviated G5-PNU). The ADCs are based on anti-ROR1 antibody clone 2A2 and R12, and anti-ROR1 clone XBR1-402 as indicated. HER-2 specific trastuzumab, site-specifically conjugated to Gly_5-EDA-PNU toxin payload was used as an isotype matched control ADC. Panels C and D show the expression levels of ROR1 measured on the cell surface of Kasumi-2 and 697 as analyzed by FACS using antibody 2A2 as a primary antibody versus an isotype-matched control antibody.

[0039] Figure 15. (A) shows *in vivo* efficacy of ADCs in a disseminated mouse model of ROR1-positive 697 with EDA-Gly_5-PNU ADCs. Mice (groups of 8 animals) have been transplanted intravenously with 10^6 697 human ALL cells and treated 7 and 14 days later with each 1 mg/kg PNU-ADC based on antibody 2A2 and novel antibody XBR1-402, or as a negative control, with PNU-ADC based on HER2-specific antibody trastuzumab. Percent survival in the groups of mice was plotted over time. (B) shows the plasma concentration of the ADCs measured in the mice that received 1 mg/kg after 12 and 19 days measured by immuno-based ELISA assay using capturing with an anti-human Fcg reagent and detection with either an anti-kappa-light chain detection antibody for the antibody concentration and an anti-PNU detection antibody for the ADC concentration.

[0040] Figure 16. Panel (A) shows *in vitro* cell killing of hROR1 transfected mouse breast cancer cell line EMT6-clone14 (abbreviated EMT6-cl14) with site-specifically conjugated PNU-ADCs based on anti-ROR1 antibody R12 and novel antibody XBR1-402, both expressed as chimeric human IgG1 antibodies. A Trastuzumab-G5-PNU ADC, specific for HER2, was used as an isotype-matched control ADC. (B) As a further control the same cell killing experiment with the same ADCs was also performed on the untransfected (and ROR1-negative) EMT6 parental cells. Panel (C) shows the relative expression of hROR1 in

hROR1 transfected versus untransfected EMT6 cells as detected by FACS with ROR1-specific antibody 2A2.

[0041] Figure 17. *In vitro* cell killing of hROR1 transfected mouse breast cancer cell line EMT6-clone14 (abbreviated EMT6-cl.14) with site-specifically conjugated PNU-ADCs based on anti-ROR1 antibody ms961 and novel antibodies XBR1-402 and ERR1-324, each expressed as chimeric human IgG1 antibodies. A Trastuzumab-G5-PNU ADC, specific for HER2, was used as an isotype-matched control ADC.

[0042] Figure 18 (A) shows results of an *in vivo* efficacy study with an orthotopic mouse breast cancer model using hROR1 transfected EMT6 mouse breast cancer cell line that was implanted into the mammary fat pads of Balb/c wild-type mice. The upper panel shows survival curves of mice treated twice with control ADC trastuzumab-G5-PNU. The middle panel shows survival curves of mice treated with PNU-ADC based on anti-ROR1 antibody R12, and the lower panel shows the survival curves of mice treated with PNU-ADC based on novel anti-ROR1 antibody XBR1-402. Little triangles below the x-axis indicate the two treatments with 1 mg/kg of each respective ADC at day 14 and 21 after transplantation of the tumors. (B) shows the Kaplan-Meier Plot of the three experiments displayed in panel (A).

[0043] Figure 19 shows the *in vitro* stability of the XBR1-402-G5-PNU ADC in NOD SCID mouse serum (panel A) and in human serum (panel B) analyzed by an immune-based ELISA assay detecting either the total antibody (solid line) or the intact ADC (dotted line).

[0044] Figure 20 shows the *in vivo* plasma stability of novel naked anti-ROR1 antibody XBR1-402, as well as of XBR1-402-G5-PNU ADC evaluated in female CD-1 mice. Depicted are plasma stability measured by immune-based ELISA assay of total IgG detected with a human Fc detection reagent as well as of intact ADC detected with a PNU-specific detection reagent.

[0045] Figure 21 shows the analysis of different patient derived tumor lysates for hROR1 protein expression by Western-Blot analysis, including lysates from two control cell lines Kasumi-2 (human ALL cell line) and A549 (human lung cancer cell line). The patient-derived tumor lysates are of the following designation and origin: PXF 1118: pleuramesothelioma, RXF 486: hypernephroma, PXF 541, pleuramesothelioma, SXFS 1407: neurofibrosarcoma, CXF 533: adenocarcinoma.

[0046] Figure 22 shows the efficacy of the site-specifically conjugated PNU-ADC of XBR1-402 anti-ROR1 ADC in different patient derived tumor models (PDX models)

established in female NMRI nude mice implanted with CXF533, RXF 486, PXF 1118, SXFS 1407 and PXF 541 patient-derived tumor material as compared to mice treated with vehicle control.

[0047] Figure 23 shows VH and VL amino acid sequences of humanized antibody clones derived from novel anti-ROR1 antibody XBR1-402. The amino acid sequence alignment of the humanized variable domains (V_λ and V_H) is shown with framework regions (FR) and complementarity determining regions (CDR) using Kabat numbering. Shown in the figure are the heavy chain variable domain sequences (SEQ ID NOs:130-135, respectively) and the light chain variable domain sequences (SEQ ID NOs:136-141, respectively) of 6 antibodies designated HuXBR1-402(3), HuXBR1-402(8), HuXBR1-402(15), HuXBR1-402(17), HuXBR1-402(19), and HuXBR1-402(26).

[0048] Figure 24 provides data of the affinity measurements with novel humanized clones of parental mAb XBR1-402, including k_{on} and k_{off} data as indicated.

[0049] Figure 25 shows (Panel A) the dose-response curves of *in vitro* cell killing assays performed on human 697 ALL cancer cells with hROR1-targeting parental XBR1-402-G5-PNU and with ADCs based on humanized antibodies: huXBR1-402-3-G5-PNU, huXBR1-402-8-G5-PNU, huXBR1-402-15-G5-PNU, huXBR1-402-17-G5-PNU, huXBR1-402-19-G5-PNU and huXBR1-402-26-G5-PNU. A PNU-ADC based on HER2-targeting antibody trastuzumab was used as an isotype control ADC (Tras-G5-PNU). Panel B shows the quantification of the *in vitro* cell killing efficacy (IC_{50}).

[0050] Figure 26 shows a comparison of the *in vitro* activities of ROR1-targeting XBR1-402 CAR-T and R12 CAR-T.

[0051] Figure 27 shows a comparison of the *in vitro* activities of ROR1-targeting XBR1-402 CAR-T with short and long spacer.

[0052] Figure 28 provides an overview of the specificity analysis of chimeric rabbit/human anti-human ROR1 IgG1 XBR1-402 and, as a control, chimeric rabbit/human anti-human ROR2 IgG1 XBR2-401, with the Retrogenix Cell Microarray Platform.

[0053] Figure 29 shows a specificity analysis of chimeric rabbit/human anti-human ROR1 IgG1 XBR1-402 and, as a control, chimeric rabbit/human anti-human ROR2 IgG1 XBR2-401, with the Retrogenix Cell Microarray Platform. Primary binding hits from the large screen involving 4,336 human plasma membrane proteins (see Figure 28) were combined on a single slide and stained with chimeric rabbit/human anti-human ROR1 IgG1 XBR1-402

and, as controls, chimeric rabbit/human anti-human ROR2 IgG1 XBR2-401 and a rituximab biosimilar. ZsGreen1 signals on the left indicate the expression levels of the various human membrane proteins. In addition to their respective antigens (ROR1, ROR2, and CD20), the tested antibodies in IgG1 format also bind to Fcγ receptors FCGR3B (CD16B), FCGR1A (CD64A), and FCGR2A (CD32A) as expected. Staining with the secondary antibody alone detects the human IgG3 heavy chain (IGHG3) as expected.

DETAILED DESCRIPTION

I. Overview

[0054] The invention is predicated in part on the generation by the present inventors of a large naïve chimeric rabbit/human Fab library and selection for binders to human ROR1 via phage display. Receptor tyrosine kinase orphan receptors-1 and -2, ROR1 and ROR2, are the only two family members defining a new receptor tyrosine kinase family, based on the overall structural design and some functional similarities. Both ROR1 and ROR2 proteins are type I-single pass trans-membrane receptors with an extracellular domain (ECD) consisting of an immunoglobulin domain, a cysteine rich frizzled domain and a Kringle domain. These three extracellular domains are followed by a trans-membrane domain connecting the ECD to an intracellular portion of the protein comprising kinase domains (Rabagay et al. (2012) Frontiers Oncol. 2: 1-8). The human ROR1 and ROR2 proteins are 58% homologous between each other, but each of the ROR proteins is highly conserved between species. The most conserved is actually the ROR1 protein, a 937 aa long protein, that is over 98.5% identical between humans and all sequenced non-human primate species, and even 96.7 and 96.3 % homologous between human and mouse and rabbit ROR1, respectively (Borcherding et al. (2014) Protein Cell 5: 496-502). Therefore, it has been a challenge to generate high-quality anti-ROR1 antibodies by mouse or rabbit immunizations, and there are only very few known antibodies with acceptable affinity. See, e.g., WO 2010/124188 (murine monoclonal antibody 2A2), WO 2012/075158 (rabbit antibodies R11 and R12), WO 2012/097313 (mouse monoclonal antibody D10) and WO2014/031174 (humanized versions of mouse mAb 99961, which binds the same epitope as that by mAb D10).

[0055] In order to not repeat generation of anti-ROR1 antibodies by conventional immunization/screening of mice/rabbits that would direct antibodies against epitopes of

greatest divergence between mouse/rabbit ROR1 and human ROR1 (as was the case in the identification of mAbs 2A2, R11, R12, D10 and 99961), the present inventors have generated a very high-complexity naïve rabbit antibody Fab library displayed by phage and screened this library for binding to native mammalian recombinant ECD of ROR1 and to cell-surface expressed human ROR1, in order to select most functional and diverse antibody clones reactive with native human ROR1 protein. This strategy was chosen because the antibody repertoire to be mined is still derived from natural rabbit B lymphocytes and thus selected for immune-system pre-selected antibody heavy and light chains. However, due to the applied screening strategy involving native recombinant and cell-expressed human ROR1, it was the hope that hROR1 specific antibodies would be identified with good developability and functional qualities and that are particularly useful for the therapy of human diseases associated with ROR1 expression, like in particular ROR1-positive cancer.

[0056] As a result of the chosen strategy, a number of novel rabbit high-affinity anti-human ROR1 antibodies have been identified with diverse CDR1, 2 and 3 clonotypes (Figure 1) and with high binding selectivity for human ROR1, but not for its most related "sister molecule", human ROR2 (Figures 2, 3 and 10). Some of the hROR1-specific antibodies showed high affinity (single-digit nM affinities) for the hROR1 target (Figure 6). As detailed herein, thirteen monoclonal antibodies (mAbs) in chimeric rabbit/human Fab format with different heavy and light chain sequences were obtained. These mAbs were tentatively named "XBR1-402", "ERR1-301", "ERR1-306", "ERR1-316", "ERR1-324", "ERR1-403", "ERR1-409", "ERR1-TOP4", "ERR1-TOP15", "ERR1-TOP22", "ERR1-TOP40", "ERR1-TOP43", and "ERR1-TOP54". All thirteen antibodies bind to purified human ROR1 as analyzed by ELISA and to cell surface human ROR1 as analyzed by flow cytometry. Neither binds to ROR2, which is the closest relative of ROR1 and shares 58% amino acid sequence identity with ROR1. Two mAbs ("ERR1-306" and "ERR1-TOP22") bind to both human and mouse ROR1 whereas the remaining eleven mAbs only bind to human ROR1.

[0057] The affinity of all thirteen mAbs was determined by biolayer inferometry and surface plasmon resonance. In addition, several mAbs ("ERR-301", ("ERR-306", "ERR-403", "XBR1-402", "ERR1-324", "ERR1-TOP43", and "ERR1-TOP54") were converted to the chimeric rabbit/human IgG1 format, expressed in mammalian cells, and purified by Protein A affinity chromatography. Particularly, the highest affinity clones XBR1-402 and

ERR1-TOP43 in further evaluation showed highest staining activities by FACS with human ROR1 overexpressing (Figure 3) and naturally hROR1 expressing mammalian cells (Figure 8). The two top-binding clones XBR1-402 and ERR1-TOP43 were also able to detect denatured ROR1 protein by Western-Blotting (Figure 9), allowing the use of these clones for the development of a companion diagnostic for ROR1 expressing cancers.

[0058] In addition, several mAbs were expressed as chimeric rabbit/human IgG1 with C-terminal sortase-recognition tags, allowing site-specific conjugation of payloads to the antibody C-termini by sortase-enzyme mediated antibody conjugation technology (SMAC-technology™) essentially as described in WO2014140317. These anti-hROR1 antibodies have then been site-specifically conjugated to a highly potent anthracycline-based PNU-159682 toxin derivative, Gly_5-EDA-PNU (Figure 11B) in order to generate highly potent antibody drug conjugates (ADCs), essentially as disclosed in WO2016102679 (which is incorporated by reference herein and the text of which is included as an Appendix to this application). These ADCs have functionally been evaluated in various *in vitro* and *in vivo* tumor models against ADCs generated based on known anti-hROR1 antibodies. It was observed that one particular lead clone, called XBR1-402, displayed the highest potency and efficacy in comparison to various known antibodies (e.g. 2A2 (from WO 2010/124188), R11, R12 (both from WO 2012/075158), or ms961 (from WO 2014/031174), which forms the basis of humanized anti-hROR1 mAb cirmtuzumab, currently in clinical trials in CLL as a naked IgG1 mAb.

[0059] Based on the best-in-class properties in terms of functionality on tumor cell killing as an ADC, the lead clone XBR1-402 has then been humanized, which generated several humanized clones with further increased affinity against hROR1, called "huXBR1-402-3", "huXBR1-402-8", "huXBR1-402-15", "huXBR1-402-17", "huXBR1-402-19" and "huXBR1-402-26". These humanized versions of lead clone XBR1-402 have also been evaluated as site-specifically conjugated PNU-ADCs and each of which exhibited further improved tumor cell killing in in vitro hROR1 tumor models.

[0060] To further investigate the therapeutic utility of the ROR1-targeting mAbs, CAR-T cells based on XBR1-402 were engineered using methods previously described for known ROR1-targeting mAbs R11 and R12 (Hudecek, M., Lupo-Stanghellini, M. T., Kosasih, P. L., Sommermeyer, D., Jensen, M. C., Rader, C., and Riddell, S. R. (2013) Receptor affinity and extracellular domain modifications affect tumor recognition by ROR1-specific chimeric

antigen receptor T cells. *Clin. Cancer Res.* 19, 3153-3164). In brief, *ex vivo* expanded healthy donor CD8+ CD62L+ T cells were lentivirally transduced with an EF1α promoter-driven expression cassette containing XBR1-402 in scFv format, followed by a short or long spacer, the transmembrane domain of human CD28, the signaling domain of 4-1BB, the signaling domain of CD3ζ, and a T2A-separated transmembrane EGFR fragment with truncated ligand binding and tyrosine kinase domains. FACS isolation of EGFR+ transduced T cells, revealed robust anti-ROR1 recognition in >90% of CAR-T cells. The activity of the ROR1-targeting XBR1-402 CAR-T with a short spacer was tested against breast cancer cell lines MDA-MB-231 (ROR1+ ROR2−) and T47D (ROR1− ROR2+). In the presence of ROR1+ ROR2− but not ROR1− ROR2+ target cells, XBR1-402 CAR-T rapidly proliferated, massively secreted IFN-γ and IL-2, and potently killed the target cells *in vitro* (Figure 26). Notably, in direct comparison, the XBR1-402 CAR-T was found to be equally or more potent than the clinically investigated R12 CAR-T with the same short spacer and signaling domains.

[0061] Moreover, the inventors hypothesized that an optimal distance between T cell and target cell can be achieved by equipping CAR-T cells targeting membrane-distal epitopes with shorter spacers and vice versa. Based on this hypothesis, XBR1-402 CAR-T, which has an overlapping epitope with R12, is predicted to be more active when equipped with a short compared to a long spacer. Indeed, it was found that, in the presence of ROR1+ ROR2− target cells, XBR1-402 CAR-T with short linker proliferated more rapidly than XBR1-402 CAR-T with long spacer (Figure 27) and also secreted significantly more IFN-γ and IL-2. *In vitro* cytotoxicity, however, was found to be equally potent (Figure 27).

[0062] In accordance with these studies, the present invention provides novel monoclonal rabbit and humanized antibodies and related antibody-based binding proteins and antibody fragments thereof that specifically recognize ROR1, as well as antibody drug conjugates and CARs with specific anti-tumor activity in hROR1 expressing tumor models *in vitro* and *in vivo*. Also provided in the invention are methods of using these antibody agents in therapeutic and diagnostic applications for diseases and conditions associated with abnormal or elevated ROR1 expression, e.g., cancer.

[0063] The antibodies and related compositions of the invention have demonstrated other surprisingly advantageous properties. Functional evaluation of the novel clones as site-specifically conjugated ADCs with a highly potent PNU-anthracycline payload,

employing various *in vitro* and *in vivo* models, revealed that particularly novel clone XBR1-402 performed better than any of the known antibodies. For instance, R11-based ADCs had limited potency already in *in vitro* tumor models (Figure 13). In comparison to antibody clones 99961 (ms961), 2A2 and R12, novel XBR1-402 described herein also consistently performed better in tumor models *in vitro* (Figures 13, 14, 17), which was even more evident in tumor models *in vivo* (Figures 15 & 18). Combined with the favorable properties of the XBR1-402 clone, in terms of its highly specific recognition of ROR1when tested against 4,336 human plasma membrane proteins (Figure 29), and the favorable stability of the ADC in mouse plasma and other sera evaluated (Figures 15B, 19 & 20), XBR1-402-based ADCs appear to have the potential for best-in-class anti-ROR1 targeting products with high potential for ADC therapy.

[0064] Furthermore, humanized versions of anti-ROR1 mAb XBR1-402 unexpectedly showed even higher affinity versus the parental rabbit clone XBR1-402 (Figure 24) because affinities are often being reduced during the process of humanization of non-human antibodies (Margreitter et al. (2016) J. Mol. Recognit. 29: 266-275). The increased affinity also correlated with improved potency of these humanized mAbs when evaluated for anti-tumor activity as ADCs (Figure 25). These data evidence the high potential of the evaluated anti-ROR1 ADC, based on humanized XBR1-402 antibodies for the therapy of human disease. This high potential for an effective tumor therapy of a PNU-ADC based on XBR1-402 and/or humanized XBR1-402 is supported by the high efficacy of the XBR1-402 based ADC in a variety of hROR1 expressing patient derived xenograft models (Figure 22).

[0065] The highly functional anti-hROR1 antibodies and related compositions described herein have displayed exquisite functional properties for use as therapeutic agents in the therapy of human cancers associated with ROR1 expression. These include the various hROR1 antibodies, antibody fragments, antibody-based binding proteins, ADCs or CARs described herein, which have the same or essentially the same binding properties as demonstrated by the specific antibodies exemplified herein (e.g., XBR1-402). Thus, the favorable properties and high therapeutic potential demonstrated by the exemplified antibodies herein can be extended to homologous antibodies, antibody fragments, antibody-based binding proteins, ADCs, CARs that contain some or all of the CDR sequences of the variable heavy and/or light chains disclosed in the invention, or essentially similar CDR sequences of the variable heavy and/or light chains disclosed in the invention. The favorable

properties and/or the high therapeutic potential can also be extended to antibodies, antibody fragments, antibody-based binding proteins, ADCs, CARs that only contain one of the two immunoglobulin chains of the disclosed antibodies (i.e., either heavy or light chain), or one of the two immunoglobulin chains (i.e. either heavy or light chain) that are homologous to the exemplified antibodies.

II. Definitions

[0066] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by those of ordinary skill in the art to which this invention pertains. The following references provide one of skill with a general definition of many of the terms used in this invention: *Academic Press Dictionary of Science and Technology*, Morris (Ed.), Academic Press (1st ed., 1992); *Oxford Dictionary of Biochemistry and Molecular Biology*, Smith et al. (Eds.), Oxford University Press (revised ed., 2000); *Encyclopaedic Dictionary of Chemistry*, Kumar (Ed.), Anmol Publications Pvt. Ltd. (2002); *Dictionary of Microbiology and Molecular Biology*, Singleton et al. (Eds.), John Wiley & Sons (3rd ed., 2002); *Dictionary of Chemistry*, Hunt (Ed.), Routledge (1st ed., 1999); *Dictionary of Pharmaceutical Medicine*, Nahler (Ed.), Springer-Verlag Telos (1994); *Dictionary of Organic Chemistry*, Kumar and Anandand (Eds.), Anmol Publications Pvt. Ltd. (2002); and *A Dictionary of Biology (Oxford Paperback Reference)*, Martin and Hine (Eds.), Oxford University Press (4th ed., 2000). In addition, the following definitions are provided to assist the reader in the practice of the invention.

[0067] The term "antibody" also synonymously called "immunoglobulins" (Ig), or "antigen-binding fragment" refers to polypeptide chain(s) which exhibit a strong monovalent, bivalent or polyvalent binding to a given antigen, epitope or epitopes. Unless otherwise noted, antibodies or antigen-binding fragments used in the invention can have sequences derived from any vertebrate species. They can be generated using any suitable technology, e.g., hybridoma technology, ribosome display, phage display, gene shuffling libraries, semi-synthetic or fully synthetic libraries or combinations thereof. Unless otherwise noted, the term "antibody" as used in the present invention includes intact antibodies, antigen-binding polypeptide fragments and other designer antibodies that are described below or well known in the art (see, e.g., Serafini, J Nucl. Med. 34:533-6, 1993).

[0068] An intact "antibody" typically comprises at least two heavy (H) chains (about 50-70 kD) and two light (L) chains (about 25 kD) inter-connected by disulfide bonds. The recognized immunoglobulin genes encoding antibody chains include the kappa, lambda, alpha, gamma, delta, epsilon, and mu constant region genes, as well as the myriad immunoglobulin variable region genes. Light chains are classified as either kappa or lambda. Heavy chains are classified as gamma, mu, alpha, delta, or epsilon, which in turn define the immunoglobulin classes, IgG, IgM, IgA, IgD and IgE, respectively.

[0069] Each heavy chain of an antibody is comprised of a heavy chain variable region (V_H) and a heavy chain constant region. The heavy chain constant region of most IgG isotypes (subclasses) is comprised of three domains, C_{H1}, C_{H2} and C_{H3}, some IgG isotypes, like IgM or IgE comprise a fourth constant region domain, C_{H4} Each light chain is comprised of a light chain variable region (V_L) and a light chain constant region. The light chain constant region is comprised of one domain, C_L. The variable regions of the heavy and light chains contain a binding domain that interacts with an antigen. The constant regions of the antibodies may mediate the binding of the immunoglobulin to host tissues or factors, including various cells of the immune system and the first component (Clq) of the classical complement system.

[0070] The V_H and V_L regions of an antibody can be further subdivided into regions of hypervariability, also termed complementarity determining regions (CDRs), which are interspersed with the more conserved framework regions (FRs). Each V_H and V_L is composed of three CDRs and four FRs, arranged from amino-terminus to carboxyl-terminus in the following order: FR1, CDR1, FR2, CDR2, FR3, CDR3, FR4. The locations of CDR and FR regions and a numbering system have been defined by, e.g., Kabat *et al., Sequences of Proteins of Immunological Interest*, U.S. Department of Health and Human Services, U.S. Government Printing Office (1987 and 1991).

[0071] An "antibody-based binding protein", as used herein, may represent any protein that contains at least one antibody-derived V_H, V_L, or C_H immunoglobulin domain in the context of other non-immunoglobulin, or non-antibody derived components. Such antibody-based proteins include, but are not limited to (i) F_c-fusion proteins of binding proteins, including receptors or receptor components with all or parts of the immunoglobulin C_H domains, (ii) binding proteins, in which V_H and or V_L domains are coupled to alternative molecular scaffolds, or (iii) molecules, in which immunoglobulin V_H, and/or V_L, and/or C_H

domains are combined and/or assembled in a fashion not normally found in naturally occurring antibodies or antibody fragments.

[0072] "Binding affinity" is generally expressed in terms of equilibrium association or dissociation constants (K_A or K_D, respectively), which are in turn reciprocal ratios of dissociation and association rate constants (k_{off} and k_{on}, respectively). Thus, equivalent affinities may correspond to different rate constants, so long as the ratio of the rate constants remains the same. The binding affinity of an antibody is usually be expressed as the K_D of a monovalent fragment (e.g. a F_{ab} fragment) of the antibody, with K_D values in the single-digit nanomolar range or below (subnanomolar or picomolar) being considered as very high and of therapeutic and diagnostic relevance.

[0073] As used herein, the term "binding specificity" refers to the selective affinity of one molecule for another such as the binding of antibodies to antigens (or an epitope or antigenic determinant thereof), receptors to ligands, and enzymes to substrates. Thus, all monoclonal antibodies that bind to a particular antigenic determinant of an entity (e.g., a specific epitope of ROR1 or ROR2) are deemed to have the same binding specificity for that entity.

[0074] The term "Antibody Drug Conjugate", or "ADC" refers to an antibody to which a therapeutically active substance or an active pharmaceutical ingredient (API) has been covalently coupled, such that the therapeutically active substance or an active pharmaceutical ingredient (API) can be targeted to the binding target of the antibody to exhibit its pharmacologic function. The therapeutically active substance or an active pharmaceutical ingredient can be a cellular toxin that is able to effect killing of the cells targeted by the ADCs, preferably malignant or cancer cells. The covalent attachment of a therapeutically active substance, an active pharmaceutical ingredient or a cellular toxin can be performed in a non-site specific manner using standard chemical linkers that couple payloads to lysine or cysteine residues, or, preferably the conjugation is performed in a site-specific manner, that allows full control of conjugation site and drug to antibody ratio (DAR) of the ADC to be generated.

[0075] The term "conservatively modified variant" applies to both amino acid and nucleic acid sequences. With respect to particular nucleic acid sequences, conservatively modified variants refers to those nucleic acids which encode identical or essentially identical amino acid sequences, or where the nucleic acid does not encode an amino acid sequence, to

essentially identical sequences. Because of the degeneracy of the genetic code, a large number of functionally identical nucleic acids encode any given protein. For instance, the codons GCA, GCC, GCG and GCU all encode the amino acid alanine. Thus, at every position where an alanine is specified by a codon, the codon can be altered to any of the corresponding codons described without altering the encoded polypeptide. Such nucleic acid variations are "silent variations," which are one species of conservatively modified variations. Every nucleic acid sequence herein which encodes a polypeptide also describes every possible silent variation of the nucleic acid. One of skill will recognize that each codon in a nucleic acid (except AUG, which is ordinarily the only codon for methionine, and TGG, which is ordinarily the only codon for tryptophan) can be modified to yield a functionally identical molecule. Accordingly, each silent variation of a nucleic acid that encodes a polypeptide is implicit in each described sequence.

[0076] For polypeptide sequences, "conservatively modified variants" refer to a variant which has conservative amino acid substitutions, amino acid residues replaced with other amino acid residue having a side chain with a similar charge. Families of amino acid residues having side chains with similar charges have been defined in the art. These families include amino acids with basic side chains (e.g., lysine, arginine, histidine), acidic side chains (e.g., aspartic acid, glutamic acid), uncharged polar side chains (e.g., glycine, asparagine, glutamine, serine, threonine, tyrosine, cysteine), nonpolar side chains (e.g., alanine, valine, leucine, isoleucine, proline, phenylalanine, methionine, tryptophan), beta-branched side chains (e.g., threonine, valine, isoleucine) and aromatic side chains (e.g., tyrosine, phenylalanine, tryptophan, histidine).

[0077] The term "contacting" has its normal meaning and refers to combining two or more agents (e.g., polypeptides or phage), combining agents and cells, or combining two populations of different cells. Contacting can occur *in vitro*, e.g., mixing an antibody and a cell or mixing a population of antibodies with a population of cells in a test tube or growth medium. Contacting can also occur in a cell or *in situ*, e.g., contacting two polypeptides in a cell by co-expression in the cell of recombinant polynucleotides encoding the two polypeptides, or in a cell lysate. Contacting can also occur *in vivo* inside a subject, e.g., by administering an agent to a subject for delivery the agent to a target cell.

[0078] A "humanized antibody" is an antibody or antibody fragment, antigen-binding fragment, or antibody-based binding protein comprising antibody V_H or V_L domains with a

homology to human V_H or V_L antibody framework sequences having a T20 score of greater than 80, as defined by defined by Gao et al. (2013) BMC Biotechnol. 13, pp. 55.

[0079] The terms "identical" or percent "identity," in the context of two or more nucleic acids or polypeptide sequences, refer to two or more sequences or subsequences that are the same. Two sequences are "substantially identical" if two sequences have a specified percentage of amino acid residues or nucleotides that are the same (*i.e.*, 60% identity, optionally 65%, 70%, 75%, 80%, 85%, 90%, 95%, or 99% identity over a specified region, or, when not specified, over the entire sequence), when compared and aligned for maximum correspondence over a comparison window, or designated region as measured using one of the following sequence comparison algorithms or by manual alignment and visual inspection. Optionally, the identity exists over a region that is at least about 50 nucleotides (or 10 amino acids) in length, or more preferably over a region that is 100 to 500 or 1000 or more nucleotides (or 20, 50, 200 or more amino acids) in length.

[0080] Methods of alignment of sequences for comparison are well known in the art. Optimal alignment of sequences for comparison can be conducted, *e.g.*, by the local homology algorithm of Smith and Waterman, Adv. Appl. Math. 2:482c, 1970; by the homology alignment algorithm of Needleman and Wunsch, J. Mol. Biol. 48:443, 1970; by the search for similarity method of Pearson and Lipman, Proc. Nat'l. Acad. Sci. USA 85:2444, 1988; by computerized implementations of these algorithms (GAP, BESTFIT, FASTA, and TFASTA in the Wisconsin Genetics Software Package, Genetics Computer Group, Madison, WI); or by manual alignment and visual inspection (see, e.g., Brent et al., *Current Protocols in Molecular Biology*, John Wiley & Sons, Inc. (ringbou ed., 2003)). Two examples of algorithms that are suitable for determining percent sequence identity and sequence similarity are the BLAST and BLAST 2.0 algorithms, which are described in Altschul et al., Nuc. Acids Res. 25:3389-3402, 1977; and Altschul et al., J. Mol. Biol. 215:403-410, 1990, respectively.

[0081] The term "subject" refers to human and non-human animals (especially non-human mammals). The term "subject" is used herein, for example, in connection with therapeutic and diagnostic methods, to refer to human or animal subjects. Animal subjects include, but are not limited to, animal models, such as, mammalian models of conditions or disorders associated with elevated ROR1 expression such as CLL, ALL, mantle cell lymphoma, neuroblastoma, sarcoma, renal cell carcinoma, breast cancer, lung cancer, colon

cancer, head and neck cancer, melanoma, and other cancers. Other specific examples of non-human subjects include, e.g., cows, horses, sheep, pigs, cats, dogs, mice, rats, rabbits, guinea pigs, monkeys.

[0082] Artificial T cell receptors (also known as chimeric T cell receptors, chimeric immunoreceptors, chimeric antigen receptors (CARs) or T-bodies) are engineered receptors, which graft an arbitrary specificity onto an immune effector cell. Typically, these receptors are used to graft the specificity of a monoclonal antibody onto a T cell; with transfer of their coding sequence facilitated by retroviral or lentiviral vectors or by transposons. CAR-engineered T cells (also abbreviated CAR-T cells) are genetically engineered T cells armed with chimeric receptors whose extracellular recognition unit is comprised of an antibody-derived recognition domain and whose intracellular region is derived from one or more lymphocyte stimulating moieties. The structure of the prototypic CAR is modular, designed to accommodate various functional domains and thereby to enable choice of specificity and controlled activation of T cells. The preferred antibody-derived recognition unit is a single chain variable fragment (scFv) that combines the specificity and binding residues of both the heavy and light chain variable regions of a monoclonal antibody. The most common lymphocyte activation moieties include a T-cell costimulatory (e.g. CD28) domain in tandem with a T-cell triggering (e.g. CD3zeta) moiety. By arming effector lymphocytes (such as T cells and natural killer cells) with such chimeric receptors, the engineered cell is re-directed with a pre-defined specificity to any desired target antigen, in a non-HLA restricted manner. CAR constructs are introduced *ex vivo* into T cells from peripheral lymphocytes of a given patient using retroviral or lentiviral vectors or transposons. Following infusion of the resulting CAR-engineered T cells back into the patient, they traffic, reach their target site, and upon interaction with their target cell or tissue, they undergo activation and perform their predefined effector function. Therapeutic targets for the CAR approach include cancer and HIV-infected cells, or autoimmune effector cells.

[0083] The terms "treat," "treating," "treatment," and "therapeutically effective" used herein do not necessarily imply 100% or complete treatment. Rather, there are varying degrees of treatment recognized by one of ordinary skill in the art as having a potential benefit or therapeutic effect. In this respect, the inventive method can provide any amount of any level of treatment. Furthermore, the treatment provided by the inventive method can include the treatment of one or more conditions or symptoms of the disease being treated.

[0084] A "vector" is a replicon, such as plasmid, phage or cosmid, to which another polynucleotide segment may be attached so as to bring about the replication of the attached segment. Vectors capable of directing the expression of genes encoding for one or more polypeptides are referred to as "expression vectors".

III. Antibodies, antibody-based binding proteins, antibody fragments thereof, antibody drug conjugates (ADCs), or CARs specifically binding to ROR1 and related derivative compounds

[0085] In one aspect, the invention provides novel antibodies, antibody-based binding proteins, antibody fragments thereof, ADCs or CARs that specifically bind to human ROR1 with the same binding specificity as that of anti-ROR1 antibody exemplified herein (Figure 1 and 23). Antibodies of the invention include intact antibodies (e.g., IgG1 antibodies exemplified herein), antibody fragments or antigen-binding fragments (e.g., Fab fragments exemplified herein), antibody-based binding proteins, ADCs and CARs which contain the antigen-binding portions of an intact antibody that retain capacity to bind the cognate antigen, ROR1. Examples of such antibody fragments include (i) a Fab fragment, a monovalent fragment consisting of the V_L, V_H, C_L and C_{H1} domains; (ii) a $F(ab')_2$ fragment, a bivalent fragment comprising two Fab fragments linked by a disulfide bridge at the hinge region; (iii) a Fd fragment consisting of the V_H and C_{H1} domains; (iv) a Fv fragment consisting of the V_L and V_H domains of a single arm of an intact antibody; (v) disulfide stabilized Fvs (dsFvs) which have an interchain disulfide bond engineered between structurally conserved framework regions; (vi) a single domain antibody (dAb) which consists of a V_H or V_L domain (see, e.g., Ward et al., Nature 341:544-546, 1989); and (vii) an isolated complementarity determining region (CDR) as a linear or cyclic peptide. Examples of antibody-based binding proteins are polypeptides in which the binding domains of the antibodies are combined with other polypeptides or polypeptide domains, e.g. alternative molecular scaffolds, Fc-regions, other functional or binding domains of other polypeptides or antibodies resulting in molecules with addition binding properties, e.g. bi- or multispecific proteins or antibodies. Such polypeptides can create an arrangement of binding or functional domains normally not found in naturally occurring antibodies or antibody fragments.

[0086] Antibodies of the invention also encompass antibody fragments (or "antigen-binding fragments"), like single chain antibodies. The term "single chain antibody" refers to a polypeptide comprising a V_H domain and a V_L domain in polypeptide linkage, generally linked via a spacer peptide, and which may comprise additional domains or amino acid sequences at the amino- and/or carboxyl-termini. For example, a single-chain antibody may comprise a tether segment for linking to the encoding polynucleotide. As an example, a single chain variable region fragment (scFv) is a single-chain antibody. Compared to the V_L and V_H domains of the Fv fragment which are coded for by separate genes, a scFv has the two domains joined (e.g., via recombinant methods) by a synthetic linker. This enables them to be made as a single protein chain in which the V_L and V_H regions pair to form monovalent molecules.

[0087] Antibodies of the present invention also encompass single domain antigen-binding units, which have a camelid scaffold. Animals in the camelid family include camels, llamas, and alpacas. Camelids produce functional antibodies devoid of light chains. The heavy chain variable (V_H) domain folds autonomously and functions independently as an antigen-binding unit. Its binding surface involves only three CDRs as compared to the six CDRs in classical antigen-binding molecules (Fabs) or single chain variable fragments (scFvs). Camelid antibodies are capable of attaining binding affinities comparable to those of conventional antibodies.

[0088] The various antibodies, antibody-based binding proteins, and antibody fragments thereof described herein can be produced by enzymatic or chemical modification of the intact antibodies, or synthesized *de novo* using recombinant DNA methodologies, or identified using phage display libraries. Methods for generating these antibodies, antibody-based binding proteins, and antibody fragments thereof are all well known in the art. For example, single chain antibodies can be identified using phage display libraries or ribosome display libraries, gene shuffled libraries (see, e.g., McCafferty et al., Nature 348:552-554, 1990; and U.S. Pat. No. 4,946,778). In particular, scFv antibodies can be obtained using methods described in, e.g., Bird et al., Science 242:423-426, 1988; and Huston et al., Proc. Natl. Acad. Sci. USA 85:5879-5883, 1988. Fv antibody fragments can be generated as described in Skerra and Plückthun, Science 240:1038-41, 1988. Disulfide-stabilized Fv fragments (dsFvs) can be made using methods described in, e.g., Reiter et al., Int. J. Cancer 67:113-23, 1996. Similarly, single domain antibodies (dAbs) can be produced by a variety

of methods described in, e.g., Ward et al., Nature 341:544-546, 1989; and Cai and Garen, Proc. Natl. Acad. Sci. USA 93:6280-85, 1996. Camelid single domain antibodies can be produced using methods well known in the art, e.g., Dumoulin et al., Nat. Struct. Biol. 11:500–515, 2002; Ghahroudi et al., FEBS Letters 414:521–526, 1997; and Bond et al., J. Mol. Biol. 332:643-55, 2003. Other types of antigen-binding fragments (e.g., Fab, $F(ab')_2$ or Fd fragments) can also be readily produced with routinely practiced immunology methods. See, e.g., Harlow & Lane, *Using Antibodies, A Laboratory Manual*, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York, 1998.

[0089] Antibodies of the invention further include humanized antibodies with higher homology at amino acid level of the humanized antibody V_H or V_L domains to human antibody V_H or V_L domains than rodent V_H or V_L domains, preferably with a T20 score of greater than 80 as defined by Gao et al. (2013) BMC Biotechnol. 13, pp. 55.

[0090] In some embodiments, the antibodies, antibody fragments, antibody-based binding proteins, ADCs or CARs of the invention have heavy chain CDR1, CDR2 and CDR3 sequences and light chain CDR1, CDR2 and CDR3 sequences that are substantially identical to that of the antibodies shown in Figure 1 or Figure 23. The light chain and heavy chain CDR sequences of the exemplified antibodies are all indicated in the figure. In some of these embodiments, the antibodies, antibody fragments, antibody-based binding proteins, ADCs or CARs have (1) heavy chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:27-29, respectively; and light chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:66-68, respectively; (2) heavy chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:30-32, respectively; and light chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:69-71, respectively; (3) heavy chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:33-35, respectively; and light chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:72-74, respectively; (4) heavy chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:36-38, respectively; and light chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:75-77, respectively; (5) heavy chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:39-41, respectively; and light chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:78-80, respectively; (6) heavy chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:42-44, respectively; and light chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:81-83,

respectively; (7) heavy chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:45-47, respectively; and light chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:84-86, respectively; (8) heavy chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:48-50, respectively; and light chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:87-89, respectively; (9) heavy chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:51-53, respectively; and light chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:90-92, respectively; (10) heavy chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:54-56, respectively; and light chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:93-95, respectively; (11) heavy chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:57-59, respectively; and light chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:96-98, respectively; (12) heavy chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:60-62, respectively; and light chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:99-101, respectively; or (13) heavy chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:63-65, respectively; and light chain CDR1-3 sequences that are substantially identical to SEQ ID NOs:102-104, respectively.

[0091] In some embodiments the antibodies, antibody fragments, antibody-based binding proteins, ADCs or CARs of the invention comprise the heavy chain CDR1-CDR3 and light chain CDR1-CDR3 sequences are identical to the sequences shown in (1) SEQ ID NOs:27-29 and SEQ ID NOs:66-68 (antibody XBR1-402), (2) SEQ ID NOs:30-32 and SEQ ID NOs:69-71 (antibody ERR1-301), (3) SEQ ID NOs:33-35 and SEQ ID NOs:72-74 (antibody ERR1-306), (4) SEQ ID NOs:36-38 and SEQ ID NOs:75-77 (antibody ERR1-316), (5) SEQ ID NOs:39-41 and SEQ ID NOs:78-80 (antibody ERR1-324), (6) SEQ ID NOs:42-44 and SEQ ID NOs:81-83 (antibody ERR1-403), (7) SEQ ID NOs:45-47 and SEQ ID NOs:84-86 (antibody ERR1-409), (8) SEQ ID NOs:48-50 and SEQ ID NOs:87-89 (antibody ERR1-TOP4), (9) SEQ ID NOs:51-53 and SEQ ID NOs:90-92 (antibody ERR1-TOP15), (10) SEQ ID NOs:54-56 and SEQ ID NOs:93-95 (antibody ERR1-TOP22), (11) SEQ ID NOs:57-59 and SEQ ID NOs:96-98 (antibody ERR1-TOP40), (12) SEQ ID NOs:60-62 and SEQ ID NOs:99-101 (antibody ERR1-TOP43), or (13) SEQ ID NOs:63-65 and SEQ ID NOs:102-104 (antibody ERR1-TOP54).

[0092] In other embodiments, the antibodies, antibody fragments, antibody-based binding proteins, ADCs or CARs of the invention that specifically bind to human ROR1 contain (a) a light chain variable domain having a sequence that is substantially identical to any one of SEQ ID NOs:14-26 or 136-141, (b) a heavy chain variable domain having a sequence that is substantially identical to any one of SEQ ID NOs:1-13 or 130-135, or (c) both a light chain of (a) and a heavy chain of (b). In some embodiments, the antibody comprises both a light chain of (a) and a heavy chain of (b). In some embodiments, the antibodies, antibody fragments, antibody-based binding proteins, ADCs or CARs of the invention contains (a) a light chain variable domain having at least 90% identity to any one of SEQ ID NOs:14-26 or 136-141, (b) a heavy chain variable domain having at least 90% sequence identity to any one of SEQ ID NOs:1-13 or 130-135, or (c) both a light chain of (a) and a heavy chain of (b). In some embodiments, the percentage identity can be at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, or at least 99%, or even 100%. In some embodiments, the light chain variable domain has at least 95% identity to any one of SEQ ID NOs:14-26 or 136-141. In some embodiments, the light chain variable domain has 100% identity to any one of SEQ ID NOs:14-26 or 136-141. In some embodiments, the antibody, antibody fragments, antibody-based binding proteins, ADCs or CARs contains a heavy chain variable domain having at least 90% identity to any one of SEQ ID NOs:1-13 or 130-135. In other embodiments, the percentage identity can be at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, or at least 99%, or even 100%. In some embodiments, the heavy chain variable domain has at least 95% identity to any one of SEQ ID NOs:1-13 or 130-135. In some embodiments, the heavy chain variable domain has 100% identity to any one of SEQ ID NOs:1-13 or 130-135.

[0093] In some embodiments, the antibodies, antibody fragments, antibody-based binding proteins, ADCs or CARs of the invention can comprise any heavy chain as described herein (e.g., heavy chains shown in Figures 1 and 23) in combination with any suitable light chain, such as those exemplified herein. Likewise, the antibody can comprise any of the light chains as described above (e.g., light chains shown in Figures 1 and 23) in combination with any suitable heavy chain, such as those exemplified herein. For example, in preferred embodiments, the antibody comprises a light chain having at least 90% identity to SEQ ID NO:14 and a heavy chain having at least 90% identity to SEQ ID NO:1 (antibody

XBR1-402), a light chain having at least 90% identity to SEQ ID NO:18 and a heavy chain having at least 90% identity to SEQ ID NO:5 (antibody ERR1-324), a light chain having at least 90% identity to SEQ ID NO:25 and a heavy chain having at least 90% identity to SEQ ID NO:12 (antibody ERR1-TOP43), or a light chain having at least 90% identity to SEQ ID NO:26 and a heavy chain having at least 90% identity to SEQ ID NO:13 (antibody ERR1-TOP54). In some embodiments, the antibody can comprise the light chain and heavy chain sequences respectively shown in (1) SEQ ID NO:14 and SEQ ID NO:1, (2) SEQ ID NO:18 and SEQ ID NO:5, (3) SEQ ID NO:25 and SEQ ID NO:12, or (4) SEQ ID NO:26 and SEQ ID NO:13. In the various embodiments, percent (%) identity of peptide sequences can be calculated, for example, as 100 x [(identical positions)/min(TGA, TGB)], where TGA and TGB are the sum of the number of residues and internal gap positions in peptide sequences A and B in the alignment that minimizes TGA and TGB. See, e.g., Russell et al, J. Mol. Biol., 244: 332-350 (1994).

[0094] The antibody of the invention can be any antibody including a full length antibody, an antibody fragment, an antibody-based binding protein that specifically recognizes or binds to the extracellular domain of human ROR1. For example, the antibody, antibody fragment or antibody-based binding protein can be polyclonal, monoclonal, recombinant, chimeric, or humanized. Furthermore, the antibody can be of any isotype including without limitation IgA, IgD, IgE, IgG, or IgM. Thus, for example, the antibody can be any IgA such as IgA1 or IgA2, or any IgG such as IgG1, IgG2, IgG3, IgG4, or synthetic IgG. The antibody can also be any antibody fragment or antibody-based binding protein having specificity for the extracellular domain of human ROR1, such as F(ab)2, Fv, scFv, IgGACH2, F(ab')2, scFv2CH3, Fab, VL, VH, scFv4, scFv3, scFv2, dsFv, Fv, scFv-Fc, (scFv)2, a diabody, a bivalent, a bispecific, or a multispecific antibody. The antibody can be any modified or synthetic antibody, including, but not limited to, non-depleting IgG antibodies, CARs, or other Fc or Fab variants of antibodies.

[0095] In addition to a heavy chain as described above, the antibody, antibody-based binding proteins or antibody fragments thereof of the invention can further comprise a light chain selected from a Fab library using sequential naive chain shuffling. Likewise, in addition to a light chain as described above, the antibody of the invention can further comprise a heavy chain selected from a Fab library using sequential naive chain shuffling.

In some embodiments, the invention provides antibodies, antibody-based binding proteins or antibody fragments thereof that are conservatively modified variants of the anti-ROR1 antibodies exemplified herein. Typically, the variable regions of these variants have an amino acid sequence that is identical to one of these exemplified sequences except for conservative substitutions at one or more amino acid residues. In some embodiments, the antibody, antibody fragments, antibody-based binding proteins, ADCs or CARs of the invention specifically binds to human ROR1 and contains at least one CDR having a sequence selected from the group consisting of SEQ ID NOs:27-104. The invention also provides an isolated antibody with specificity for ROR1 containing one or more variants of the foregoing CDR sequences or substantially identically CDR sequences. The variant CDR sequences in these antibodies can include 1, 2, or 3 substitutions, insertions, deletions, or combinations thereof in a sequence selected from the group consisting of SEQ ID NOs:27-104. For example, a recombinant chimeric or humanized antibody (or fragment thereof) can include one, two, three, four, five, or six of the foregoing CDR sequences. In some embodiments, however, the recombinant chimeric or humanized antibody (or fragment thereof) includes three CDR sequences of the same light or heavy chain, e.g., light chain CDRS shown in SEQ ID NOs:66-68, SEQ ID NOs:78-80, SEQ ID NOs:99-101, or SEQ ID NOs:102-104; and heavy chain CDRs shown in SEQ ID NOs:27-29, SEQ ID NOs:39-41, SEQ ID NOs:60-62, or SEQ ID NOs:63-65. In some embodiments, the recombinant chimeric or humanized antibody (or fragment thereof) includes six CDR sequences of the same antibody, e.g., (a) SEQ ID NOs:66-68 and SEQ ID NOs:27-29 (antibody XBR1-402); (b) SEQ ID NOs:78-80 and SEQ ID NOs:39-41(antibody ERR1-324); (c) SEQ ID NOs:99-101 and SEQ ID NOs:60-62 (antibody ERR1-TOP43), or (d) SEQ ID NOs:102-104 and SEQ ID NOs:63-65 (antibody ERR1-TOP54).

[0096] In some embodiments, the invention provides antibodies, antibody-based binding proteins or antibody fragments thereof with avidity for ROR1 of about 10 μM or less, 5 μM or less, 2 μM or less, 1 μM or less, 500 nM or less, 400 nM or less, 300 nM or less, or 200 nM or less. In some embodiments, the antibodies, antibody fragments, antibody-based binding proteins, ADCs or CARs bind to ROR1 with an avidity of about 100 nM or less, about 75 nM or less, about 50 nM or less, about 25 nM or less, about 10 nM or less, or about 5 nM or less. In some embodiments, the antibodies, antibody fragments, antibody-based binding proteins, ADCs or CARs bind to ROR1 with an avidity of about 1 nM or less, about

800 pM or less, about 700 pM or less, about 600 pM or less, about 500 pM or less, about 400 pM or less, about 300 pM or less, about 200 pM or less, or about 100 pM or less. Avidity can be measured using art-known techniques, such as ELISA, biolayer inferometry, or surface plasmon resonance.

[0097] The antibody, antibody-based binding protein or antibody fragment thereof of the invention can be produced by any suitable technique, for example, using any suitable eukaryotic or non-eukaryotic expression system. In certain embodiments, the antibody is produced using a mammalian expression system. Some specific techniques for generating the antibodies antibody-based binding proteins or antibody fragments thereof of the invention are exemplified herein. In some embodiments, the antibodies, antibody-based binding proteins or antibody fragments thereof of the invention can be produced using a suitable non-eukaryotic expression system such as a bacterial expression system. Bacterial expression systems can be used to produce fragments such as a F(ab)2, Fv, scFv, IgGACH2, F(ab')2, scFv2CH3, Fab, VL, VH, scFv4, scFv3, scFv2, dsFv, Fv, scFv-Fc, (scFv)2, and diabodies. Techniques for altering DNA coding sequences to produce such fragments are known in the art.

[0098] The antibodies, antibody-based binding proteins or antibody fragments thereof of the invention can be conjugated to a synthetic molecule using any type of suitable conjugation. Recombinant engineering and incorporated selenocysteine (e.g., as described in U.S. Patent 8,916,159 issued on December 23, 2014) can be used to conjugate a synthetic molecule. Other methods of conjugation can include covalent coupling to native or engineered lysine side-chain amines or cysteine side-chain thiols. See, e.g., Wu et al., Nat. Biotechnol, 23: 1 137-1 146 (2005).

[0099] In a preferred embodiment, the antibodies, antibody-based binding proteins or antibody fragments thereof of the invention conjugated to a synthetic molecule (called "ADC" for antibody drug conjugate with the synthetic molecule being a toxin) are obtained by means of site-specific sortase-enzyme mediated antibody conjugation. As disclosed in WO2014140317, sortases (also called sortase transpeptidases) form a group of prokaryotic enzymes that modify surface proteins by recognizing and cleaving a specific peptide motif called "sortase recognition tag" or "sortase tag". Usually, a given sortase enzyme recognizes one or more sortase recognition tags. Sortase enzymes can be naturally occurring, or may have undergone genetic engineering (Dorr et al., *PNAS* 2014; 111, 13343-8).

[00100] In a preferred embodiment, the conjugate is obtained by means of site-specific sortase-enzyme mediated conjugation of (a) an antibody, antibody-based binding protein or antibody fragment thereof as described herein carrying one or more sortase recognition tags, and (b) one or more synthetic molecules carrying a glycine or oligoglycine tag, $Gly_{(n)}$.

[00101] Preferably, the sortase recognition tag is fused or conjugated to the C-terminus of at least one subdomain of the antibody. Said sortase recognition tag is preferably selected from the group consisting of LPXSG (SEQ ID NO:142), LPXAG (SEQ ID NO:143), LPXTG (SEQ ID NO:144), LAXTG (SEQ ID NO:145), and NPQTG (SEQ ID NO:146).

[00102] Preferably, the oligoglycine tag, $Gly_{(n)}$, has a length of 1 to 21 glycine residues with n being any number from 1 to 21), preferably with a length of 3 to 5 amino acids (n from 3 to 5, i.e. $Gly_{(3)}$, $Gly_{(4)}$, or $Gly_{(5)}$).

[00103] The synthetic molecule can be any molecule such as one targeting a tumor. In some embodiments, the synthetic molecule for conjugation to the antibody is a protein (e.g., an antibody) or an RNA or DNA aptamer.

[00104] In one embodiment, the antibodies, antibody-based binding proteins or antibody fragments thereof of the invention conjugated to a synthetic molecule have the general formula $A - (L - P)_n$, in which: A is an antibody, antibody-based binding protein or antibody fragment thereof as described herein, L is one or more linkers, P is one or more payloads selected from the group consisting of a label and a cytotoxic or cytostatic agent, and in which n is an integer between ≥ 1 and ≤ 10.

[00105] In this embodiment, the linker preferably comprises, or consists of, at least one selected from the group consisting of: an oligopeptide linker (including cleavable and non-cleavable oligopeptide linkers), a hydrazine linker, a thiourea linker, a self-immolative linker, a succinimidyl trans-4-(maleimidylmethyl)cyclohexane-1-carboxylate (SMCC) linker, a maleimide linker, a disulfide linker, a thioether linker, and/or a maleimide linker.

[00106] The skilled person understands that further linkers may be suitable. Such linkers may be non-cleavable or may be cleaved by changes in pH, redox potential or specific intracellular enzymes. Cleavable oligopeptide linkers include protease- or matrix metalloprotease-cleavable linkers. It is understood that the linker may comprise combinations of the above. For example, the linker may be a valine-citruline PAB linker.

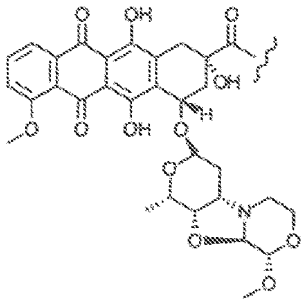
[00107] In a preferred embodiment, the linker comprises an oligopeptide with a sequence that contains the penta-peptide motif LPXSG (SEQ ID NO:142), LPXAG (SEQ ID

NO:143), LPXTG (SEQ ID NO:144), LAXTG (SEQ ID NO:145), or NPQTG (SEQ ID NO:146) with X being any amino acid, followed by an oligo-glycine stretch, $Gly_{(n)}$, with n being an integer between ≥ 1 and ≤ 21. In a preferred embodiment, the linker is conjugated to the C-terminus of at least one subdomain of the antibody, antibody-based binding proteins or antibody fragments thereof.

[00108] In various embodiments, suitable synthetic molecules ("payloads") for conjugation to the antibody include, e.g., therapeutic agents such as cytotoxic, cytostatic, or antiangiogenic agents, radioisotopes, and liposomes. A cytotoxic agent can be a plant, fungal, or bacterial molecule. In some embodiments, the cytotoxic agent for conjugation to the antibody of the invention is a small molecular weight toxin (MW< 2'000 Dalton, preferably MW < 1'000 Dalton), a peptide toxin, or a protein toxin. Many specific examples of these toxins are well known in the art. See, e.g., Dyba et al., Curr. Pharm. Des. 10:2311-34, 2004; Kuyucak et al., Future Med. Chem. 6:1645-58, 2014; Beraud et al., Inflamm. Allergy Drug Targets. 10:322-42, 2011; and Middlebrook et al., Microbiol. Rev. 48:199-221, 1984. In some embodiments, a therapeutic agent is conjugated to the antibody. For example, the therapeutic agent can be a maytansinoid (e.g., maytansinol or DM1 maytansinoid), a taxane, a calicheamicin, a cemadotin, a monomethylauristatin (e.g., monomethylauristatin E or monomethylauristatin F), a pyrrolobenzodiazepine (PBD) or, preferably an anthracycline, more preferably a derivative of the highly potent anthracycline PNU-159682. Particularly preferred derivatives of the highly potent anthracycline PNU-159682 are disclosed in WO2016102679 (which is incorporated by reference herein). Therapeutic agents also include vincristine and prednisone. In various embodiments, the therapeutic agent that may be employed in the invention can be an antimetabolite (e.g., an antifolate such as methotrexate, a fluoropyrimidine such as 5- fluorouracil, cytosine arabinoside, or an analogue of purine or adenosine); an intercalating agent (for example, an anthracycline such as doxorubicin, nemorubicine, or preferably a derivative of PNU-159682), daunomycin, epirabicin, idarubicin, mitomycin-C, dactinomycin, or mithramycin, or other intercalating agents such as pyrrolobenzodiazepine; a DNA-reactive agent such as calicheamicins, tiancimycins, and other enediynes; a platinum derivative (e.g., cisplatin or carboplatin); an alkylating agent (e.g., nitrogen mustard, melphalan, chlorambucil, busulphan, cyclophosphamide, ifosfamide nitrosoureas or thiotepa); an RNA polymerase inhibitor such as α-amanitin; an antimitotic agent (e.g., a vinca alkaloid such as vincristine, or a taxoid such

as paclitaxel or docetaxel); a topoisomerase inhibitor (for example, etoposide, teniposide, amsacrine, topotecan); a cell cycle inhibitor (for example, a flavopyridol); or a microbtubule agent (e.g., an epothilone, a tubulysine, a pre-tubulysine, discodermolide analog, or eleutherobin analog). A therapeutic agent can be a proteasome inhibitor or a topoisomerase inhibitor such as bortezomib, amsacrine, etoposide, etoposide phosphate, teniposide, or doxorubicin. Therapeutic radioisotopes include iodine (^{131}I), yttrium (^{90}Y), lutetium (^{177}Lu), actinium (^{225}Ac), praseodymium, astatine (At), rhenium (Re), bismuth (Bi or Bi), and rhodium (Rh). Antiangiogenic agents include linomide, bevacuzimab, angiostatin, and razoxane.

[00109] In a preferred embodiment, the synthetic toxin molecule is selected from PNU-159682 as described in Quintieri et al. (2005) and derivatives thereof (see formula (i) below), maytansine, monomethyl auristatin MMAE, and monomethyl auristatin MMAF. In a preferred embodiment, the toxin, joined to the linker at its wavy line, is of formula **(i)**, as described in WO 2016102679 (which is incorporated by reference herein):



formula (i)

[00110] In the embodiment where the synthetic molecule is of formula (i), it is preferred that the linker comprise an alkyldiamino group of the form NH_2-$(CH_2)_m$-NH_2, where $m \geq 1$ and ≤ 11, preferably m=2, such that one amino group is directly linked at the wavy line of formula (i) to form an amide bond. It is moreover preferred that the second amino group is linked to an oligopeptide linker, which is more preferably an oligoglycine $Gly_{(n)}$, with n being ≥ 1 and ≤ 21. The most preferred payload is shown in Fig. 11 (B).

[00111] In some embodiments, the synthetic molecule can be conjugated to any antibody, antibody-based binding protein, or antibody-fragment. In some embodiments, the synthetic molecule can be a label. Labels can be useful in diagnostic applications and can include, for example, contrast agents. A contrast agent can be a radioisotope label such as iodine (^{131}I or ^{125}I), indium (^{111}In), technetium (^{99}Tc), phosphorus (^{32}P), carbon (^{14}C), tritium (^{3}H), other radioisotope (e.g., a radioactive ion), or a therapeutic radioisotope such as one of the therapeutic radioisotopes listed above. Additionally, contrast agents can include radiopaque materials, magnetic resonance imaging (MRI) agents, ultrasound imaging agents, and any other contrast agents suitable for detection by a device that images an animal body. A synthetic molecule can also be a fluorescent label, a biologically active enzyme label, a luminescent label, or a chromophore label.

[00112] In some other embodiments, the synthetic molecule can be a liposome, as described in Bendas, BioDrugs, 15: 215-224, 2001. In such embodiments, the antibody can be conjugated to a colloidal particle, e.g., a liposome, and used for controlled delivery of an agent to diseased cells. In preparing an antibody conjugated to a liposome, e.g., an immunoliposome, an agent such as a chemotherapeutic or other drug can be entrapped in the liposome for delivery to a target cell. In some embodiments, the antibodies, antibody-based binding proteins or antibody fragments thereof of the invention can also have specificity for one or more antigens in addition to ROR1. For example, the antibody of the invention can be engineered (e.g., as a bivalent diabody or a conjugated Fab dimer or trimer) to have specificity for ROR1 and another tumor antigen, e.g., an antigen associated with neuroblastoma, renal cell carcinoma, breast cancer, gastric cancer, prostate cancer, colon cancer (e.g., colon adenocarcinoma), or breast cancer (e.g., breast adenocarcinoma). The antibody can be engineered to have specificity for ROR1 and an antigen that promotes activation or targeting of cytotoxic effector cells.

IV. Polynucleotides, vectors and host cells for producing ROR1 antibodies

[00113] The invention provides substantially purified polynucleotides (DNA or RNA) that are identical or complementary to sequences encoding polypeptides comprising segments or domains of the antibody, antibody-based binding protein or antibody fragment thereof chains described herein. In some embodiments, the polynucleotides of the invention encode the heavy chain or light chain domains sequences shown in Figures 1 and 23. When

expressed from appropriate expression vectors, polypeptides encoded by these polynucleotides are capable of exhibiting ROR1 antigen binding capacity. Also provided in the invention are polynucleotides which encode at least one CDR region and usually all three CDR regions from the heavy or light chain of the antibodies described herein. Some other polynucleotides encode all or substantially all of the variable region sequence of the heavy chain and/or the light chain of the exemplified antibodies. For example, some of these polynucleotides encode the amino acid sequence of the heavy chain variable region shown in any one SEQ ID NOs:1-13 or 130-135, and/or the amino acid sequence of the light chain variable region shown in any one SEQ ID NOs:14-26 or 136-141. Because of the degeneracy of the code, a variety of nucleic acid sequences will encode each of the immunoglobulin amino acid sequences.

[00114] The polynucleotides of the invention can encode only the variable region sequences of the exemplified antibodies. They can also encode both a variable region and a constant region of the antibody. Some of polynucleotide sequences of the invention nucleic acids encode a mature heavy chain variable region sequence that is substantially identical (e.g., at least 80%, 90%, 95% or 99%) to the mature heavy chain variable region sequence shown in any one SEQ ID NOs:1-13 or 130-135. Some other polynucleotide sequences encode a mature light chain variable region sequence that is substantially identical (e.g., at least 80%, 90%, 95% or 99%) to the mature light chain variable region sequence shown in any one SEQ ID NOs:14-26 or 136-141. Some of the polynucleotide sequences encode a polypeptide that comprises variable regions of the heavy chain or the light chain of one of the exemplified antibodies. Some other polynucleotides encode two polypeptide segments that respectively are substantially identical to the variable regions of the heavy chain or the light chain of one of the exemplified antibodies.

[00115] The polynucleotide sequences can be produced by *de novo* solid-phase DNA synthesis or by PCR mutagenesis of an existing sequence (e.g., sequences as described in the Examples below) encoding an exemplified functional antibody. Direct chemical synthesis of nucleic acids can be accomplished by methods known in the art, such as the phosphotriester method of Narang et al., Meth. Enzymol. 68:90, 1979; the phosphodiester method of Brown et al., Meth. Enzymol. 68:109, 1979; the diethylphosphoramidite method of Beaucage et al., Tetra. Lett., 22:1859, 1981; and the solid support method of U.S. Patent No. 4,458,066. Introducing mutations to a polynucleotide sequence by PCR can be performed as described

in, e.g., *PCR Technology: Principles and Applications for DNA Amplification*, H.A. Erlich (Ed.), Freeman Press, NY, NY, 1992; *PCR Protocols: A Guide to Methods and Applications*, Innis *et al.* (Ed.), Academic Press, San Diego, CA, 1990; Mattila et al., Nucleic Acids Res. 19:967, 1991; and Eckert *et al.*, PCR Methods and Applications 1:17, 1991.

[00116] Also provided in the invention are expression vectors and host cells for producing the functional antibodies described herein. Specific examples of plasmid and transposon based vectors for expressing the antibodies are described in the Examples below. Various other expression vectors can also be employed to express the polynucleotides encoding the functional antibody chains or binding fragments. Both viral-based and nonviral expression vectors can be used to produce the antibodies in a mammalian host cell. Nonviral vectors and systems include plasmids, episomal vectors, typically with an expression cassette for expressing a protein or RNA, and human artificial chromosomes (see, e.g., Harrington et al., Nat. Genet. 15:345, 1997). For example, nonviral vectors useful for expression of the antibody polynucleotides and polypeptides in mammalian (e.g., human) cells include pCEP4, pREP4, pThioHis A, B & C, pcDNA3.1/His, pEBVHis A, B & C (Invitrogen, San Diego, CA), MPSV vectors, and numerous other vectors known in the art for expressing other proteins. Other useful nonviral vectors include vectors that comprise expression cassettes that can be mobilized with Sleeping Beauty, PiggyBack and other transposon systems. Useful viral vectors include vectors based on lentiviruses or other retroviruses, adenoviruses, adeno-associated viruses, herpes viruses, vectors based on SV40, papilloma virus, HBP Epstein Barr virus, vaccinia virus vectors and Semliki Forest virus (SFV). See, Brent et al., supra; Smith, Annu. Rev. Microbiol. 49:807, 1995; and Rosenfeld et al., Cell 68:143, 1992.

[00117] The choice of expression vector depends on the intended host cells in which the vector is to be expressed. Typically, the expression vectors contain a promoter and other regulatory sequences (e.g., enhancers) that are operably linked to the polynucleotides encoding a functional antibody chain or fragment. In some embodiments, an inducible promoter is employed to prevent expression of inserted sequences except under inducing conditions. Inducible promoters include, e.g., arabinose, lacZ, metallothionein promoter or a heat shock promoter. Cultures of transformed organisms can be expanded under non-inducing conditions without biasing the population for coding sequences whose expression products are better tolerated by the host cells. In addition to promoters, other regulatory

elements may also be required or desired for efficient expression of a functional antibody chain or fragment. These elements typically include an ATG initiation codon and adjacent ribosome binding site (Kozak consensus sequence) or other sequences. In addition, the efficiency of expression may be enhanced by the inclusion of enhancers appropriate to the cell system in use (see, e.g., Scharf et al., Results Probl. Cell Differ. 20:125, 1994; and Bittner et al., Meth. Enzymol., 153:516, 1987). For example, the SV40 enhancer or CMV enhancer may be used to increase expression in mammalian host cells.

[00118] The expression vectors may also provide a secretion signal sequence position to form a fusion protein with polypeptides encoded by inserted functional antibody sequences. More often, the inserted functional antibody sequences are linked to a signal sequences before inclusion in the vector. Vectors to be used to receive sequences encoding the functional antibody light and heavy chain variable domains sometimes also encode constant regions or parts thereof. Such vectors allow expression of the variable regions as fusion proteins with the constant regions thereby leading to production of intact antibodies or fragments thereof. Typically, such constant regions are human, and preferably of human IgG1 antibodies.

[00119] The host cells for harboring and expressing the functional antibody chains can be either prokaryotic or eukaryotic. In some preferred embodiments, mammalian host cells are used to express and to produce the antibody polypeptides of the present invention. For example, they can be either a hybridoma cell line expressing endogenous immunoglobulin genes or a mammalian cell line harboring an exogenous expression vector. These include any normal mortal or normal or abnormal immortal animal or human cell. In addition to the cell lines exemplified herein, a number of other suitable host cell lines capable of secreting intact immunoglobulins are also known in the art. These include, e.g., the CHO cell lines, various HEK 293 cell lines, various Cos cell lines, HeLa cells, myeloma cell lines, transformed B-cells and hybridomas. The use of mammalian tissue cell culture to express polypeptides is discussed generally in, e.g., Winnacker, *From Genes to Clones*, VCH Publishers, N.Y., N.Y., 1987. Expression vectors for mammalian host cells can include expression control sequences, such as an origin of replication, a promoter, and an enhancer, and necessary processing information sites, such as ribosome binding sites, RNA splice sites, polyadenylation sites, and transcriptional terminator sequences. These expression vectors usually contain promoters derived from mammalian genes or from mammalian viruses.

Suitable promoters may be constitutive, cell type-specific, stage-specific, and/or modulatable or regulatable. Useful promoters include, but are not limited to, EF1α and human UbC promoters exemplified herein, the metallothionein promoter, the constitutive adenovirus major late promoter, the dexamethasone-inducible MMTV promoter, the SV40 promoter, the MRP pol III promoter, the constitutive MPSV promoter, the tetracycline-inducible CMV promoter (such as the human immediate-early CMV promoter), the constitutive CMV promoter, and promoter-enhancer combinations known in the art.

[00120] Methods for introducing expression vectors containing the polynucleotide sequences of interest vary depending on the type of cellular host. For example, calcium chloride transformation is commonly utilized for prokaryotic cells, whereas calcium phosphate treatment or electroporation may be used for other cellular hosts (see generally Sambrook et al., supra). Other methods include, e.g., electroporation, calcium phosphate treatment, liposome-mediated transformation, injection and microinjection, ballistic methods, virosomes, immunoliposomes, polycation:nucleic acid conjugates, naked DNA, artificial virions, fusion to the herpes virus structural protein VP22 (Elliot and O'Hare, Cell 88:223, 1997), agent-enhanced uptake of DNA, and *ex vivo* transduction. For long-term, high-yield production of recombinant proteins, stable expression will often be desired. For example, cell lines which stably express the antibody chains or binding fragments can be prepared using expression vectors of the invention which contain viral origins of replication or endogenous expression elements and a selectable marker gene. Following introduction of the vector, cells may be allowed to grow for 1-2 days in an enriched media before they are switched to selective media. The purpose of the selectable marker is to confer resistance to selection, and its presence allows growth of cells which successfully express the introduced sequences in selective media. Resistant, stably transfected cells can be proliferated using tissue culture techniques appropriate for the cell type.

[00121] The invention further provides eukaryotic or non-eukaryotic cells (e.g., T lymphocytes) that have been recombinantly engineered to produce the antibodies, antibody-based binding proteins or antibody fragments thereof of the invention. The eukaryotic or non-eukaryotic cells can be used as an expression system to produce the antibody of the invention. In some embodiments, the invention provides ROR1 targeted immune cells that are engineered to recombinantly express an ROR1 specific antibody of the invention. For example, the invention provides a T cell engineered to express an antibody of the invention

(e.g., an scFv, scFv-Fc, or (scFv)2), which is linked to a synthetic molecule containing one or more of the following domains: a spacer or hinge region (e.g., a CD28 sequence or a IgG4 hinge-Fc sequence), a transmembrane region (e.g., a transmembrane canonical domain), and an intracellular T-cell receptor (TCR) signaling domain, thereby forming a chimeric antigen receptor (CAR) or T-body. Intracellular TCR signaling domains that can be included in a CAR (or T-body) include, but are not limited to, CD3ζ, FcR-γ, and Syk-PT signaling domains as well as the CD28, 4-1BB, and CD134 co-signaling domains. Methods for constructing T-cells expressing a CAR (or T-body) are known in the art. See, e.g., Marcu-Malina et al., Expert Opinion on Biological Therapy, Vol. 9, No. 5 (posted online on April 16, 2009).

V. Therapeutic and diagnostic applications

[00122] The ROR1 antibodies, antibody-based binding proteins, antibody fragments thereof, ADCs and CARs disclosed herein can be used in various therapeutic and diagnostic applications. ROR1 is expressed and implicated in the development of various tumors. See, e.g., Rebagay et al., Front Oncol. 2, 34, 2012; and Shabani et al., Expert Opin. Ther. Targets 19, 941-955, 2015. For example, ROR1 is expressed on the tumor cell surface in CLL, ALL, mantle cell lymphoma, neuroblastoma, sarcoma, renal cell carcinoma, breast cancer, lung cancer, colon cancer, head and neck cancer, melanoma, and other cancers. Importantly, ROR1 is expressed in embryogenesis but largely shut down after birth. Very few adult healthy tissues and cells express ROR1. Consistently, anti-ROR1 CAR-engineered T cells were found to be safe and active in nonhuman primates, validating ROR1 as a therapeutic target in cancer (Berger (2015) *Cancer Immunol Res.* 3(2), page 2016). Thus, mAbs to ROR1 have high therapeutic and diagnostic utility in cancer.

[00123] In some embodiments, the invention provides methods for inhibiting cells that express ROR1 (ROR1 cells) by contacting the cells with an antibody, antibody-based binding protein, antibody fragment thereof, ADC or CAR of the invention. The antibody, antibody-based binding protein or antibody fragment thereof can be a naked (unconjugated) molecule or an antibody, antibody-based binding protein, antibody fragment thereof conjugated to a synthetic molecule, e.g., a cytotoxic, cytostatic, or antiangiogenic agent, a radioisotope, or even to a liposome. Preferably, cells are contacted with an ADC comprising a conjugated cytotoxic molecule. The method can be used to inhibit ROR1 cells *in vitro* or in

a subject (i.e., *in vivo*). The contacted ROR1 cells can be in, for example, a cell culture or animal model of a disorder associated with elevated levels of ROR1. The methods are useful, for example, to measure and/or rank (relative to another antibody) the antibody's inhibitory activity for a specific ROR1 cell type. Inhibiting ROR1 cells can include blocking or reducing the activity or growth of ROR1 cells. Inhibiting can also include the killing of ROR1 cells. While the methods are not bound by or limited to any particular mechanism of action, inhibitory activity can be mediated by blocking ROR1- mediated signaling or by blocking the signaling of an ROR1 associated receptor. Inhibitory activity can also be mediated by recruitment of immune system effectors that attack ROR1 cells, e.g., by activating constituents of the antibody-dependent cell-mediated cytotoxicity (ADCC) or complement systems.

[00124] In some related embodiments, the invention provides methods for treating a subject that has, is suspected to have, or is at risk of developing a disorder associated with expression of ROR1. Generally, the methods include administering a therapeutically effective amount of an isolated antibody, antibody-based binding protein, antibody fragment thereof, ADC or CAR of the invention to the subject. The antibody can be any anti-ROR1 antibody, anti-ROR1 antibody fragment, anti-ROR1 antibody-based binding protein of the invention as described herein. Thus, the antibody can be chimeric, humanized, synthetic, F(ab)2, Fv, scFv, IgGACH2, F(ab')2, scFv2CH3, Fab, VL, VH, scFv4, scFv3, scFv2, dsFv, Fv, or (scFv)2. In some embodiments, the method includes administering an IgG, an scFv, a dsFv, a F(ab')2, a diabody, or a bivalent antibody. The administered antibody, antibody-based binding protein, antibody fragment thereof can be conjugated to a synthetic molecule described above, e.g., a cytotoxic, cytostatic, or antiangiogenic agent, a therapeutic radioisotope, or a liposome. An exemplary cytotoxic agent is Pseudomonas exotoxin A (PE38). Disorders that can be treated include CLL, ALL, mantle cell lymphoma, neuroblastoma, sarcoma, renal cell carcinoma, breast cancer, lung cancer, colon cancer, head and neck cancer, melanoma, and other disorders with elevated ROR1 expression.

[00125] In some embodiments, the invention provides methods for treating a subject that has, is suspected to have, or is at risk of developing a disorder associated with elevated levels of ROR1 by adoptive transfer of the genetically engineered T-cells described herein, which express an antibody or antigen-binding fragment of the invention as a chimeric antigen receptor (CAR) that selectively binds ROR1. Recombinant technology can be used

to introduce CAR-encoding genetic material into any suitable T-cells, e.g., central memory T-cells from the subject to be treated. The T cells carrying the genetic material can be expanded (e.g., in the presence of cytokines). The genetically engineered T-cells are transferred, typically by infusion, to the patient. The transferred T-cells of the invention can then mount an immune response against ROR1 expressing cells in the subject. The adoptive transfer method can be used, for example, to treat subjects that have or are suspected to have any of the cancers associated with ROR1, including CLL, ALL, mantle cell lymphoma, neuroblastoma, sarcoma, renal cell carcinoma, breast cancer, lung cancer, colon cancer, head and neck cancer, melanoma, and other cancers. In some embodiments, the foregoing methods of treatment can further include co-administering a second therapeutic agent for treating the disorder associated with elevated ROR1. For example, when the disorder to be treated involves an ROR1-expressing cancer, the method can further include co-administration of a cytotoxic, cystostatic, or antiangiogenic or immune-stimulatory agent (e.g. immune-checkpoint inhibitor antibodies, for instance, but not limited to, those binding to PD1, PDL1, CTLA4, OX40, TIM3, GITR, LAG3 and the like) suitable for treating the cancer. If the cancer is a B-cell malignancy, the method can further include, for example, co-administration of rituximab, alemtuzumab, ofatumumab, ocrelizumab, or a CHOP chemotherapeutic regimen.

[00126] In some other embodiments, the invention provides method for detecting in a biological sample an altered level of ROR1 (e.g., cell surface ROR1), for example, relative to a control, either by FACS, immunohistochemistry (IHC) or Western Blotting. Generally, the method includes contacting a biological sample with an antibody, antibody-based binding protein, antibody fragment thereof of the invention and determining the amount of antibody that selectively binds to material (e.g., cells) in the sample to thereby determine the level of ROR1 in the biological sample. A biological sample can be from a cell culture or from a test subject, e.g., a plasma or a tissue sample from a subject that has, is suspected to have, or is at risk of developing a disease or condition associated with elevated ROR1 in a subject. A control level desirably corresponds to the ROR1 level detected using the same antibody in a corresponding sample(s) from one or more control cultures or disease-free subjects. Methods of using the antibody of the invention to determine ROR1 levels can include any immunoassay such as immuno- (Western) blotting, enzyme-linked

immunosorbent assay (ELISA), Immunohistochemistry (IHC) and flow cytometry, e.g., fluorescence-activated cell sorting (FACS) analysis.

[00127] The methods of detection can be used to screen for the presence of a disorder associated with elevated ROR1. The methods include obtaining a sample from a test subject in need of screening, e.g., a subject that has, is suspected to have, or is at risk of developing a disorder associated with elevated ROR1. The level of ROR1 (e.g., the amount or concentration) in the sample is measured using an antibody, antibody-based binding protein, antibody fragment thereof of the invention, and the level in the sample is compared to a control level of ROR1. The control level represents, for example, the mean level (e.g., the amount or concentration) in sample(s) from one or, preferably, multiple control group subjects that do not have a disorder associated with elevated ROR1. Alternatively, the control level can correspond to the level or mean level of ROR1 in one or more samples taken from the test subject at one or more prior times, such as when the test subject did not have or did not exhibit, a condition associated with elevated ROR1. A significantly higher level of ROR1 in the biological sample relative to the control level is indicative of a disorder associated with elevated ROR1 in the subject. In subjects such as humans, where cell surface ROR1 expression is largely restricted to embryonic development, a control level of ROR1 can be zero or none. Thus, in some embodiments of the method of the detection provided by the invention, any significant and detectable amount of ROR1 in a biological sample can be indicative of a disorder associated with elevated ROR1 in the subject.

[00128] Additionally, the methods of detection can be used to monitor the progress of a disorder associated with elevated ROR1. The method includes obtaining a sample from a subject in need of screening, e.g., a subject having been diagnosed or suspected to have a disorder associated with elevated ROR1. The level of ROR1 in the sample is measured using an antibody, antibody-based binding protein, antibody fragment thereof of the invention, and the level in the sample is compared to a control level corresponding to the level or mean level of ROR1 in one or more samples taken from the test subject at one or more prior times. Levels of ROR1 that are significantly elevated or decreased relative to control indicate that the subject's disorder is deteriorating or improving, respectively. The foregoing methods of detection can be used to screen for the presence or to monitor the progress of disorders including, for example, CLL, ALL, mantle cell lymphoma,

neuroblastoma, sarcoma, renal cell carcinoma, breast cancer, lung cancer, colon cancer, head and neck cancer, melanoma, and other cancers.

[00129] In some embodiments, the invention provides methods for screening a subject for an altered level of ROR1. Generally, the methods entail administering to the subject an antibody, antibody-based binding protein, antibody fragment thereof of the invention that is conjugated to a label (e.g., a contrast agent), imaging the subject in a manner suitable for detecting the label, and determining whether a region in the subject has an altered density or concentration of label as compared to the background level of label in proximal tissue. Alternatively, the methods include determining whether there is an altered density or concentration of label in a region as compared to the density or concentration of label previously detected in the same region of the subject. Methods of imaging a subject can include x-ray imaging, x-ray computed tomography (CT) imaging (e.g., CT angiography (CTA) imaging), magnetic resonance (MR) imaging, magnetic resonance angiography (MRA), nuclear medicine, ultrasound (US) imaging, optical imaging, elastography, infrared imaging, microwave imaging, and the like, as appropriate for detecting the label conjugated to the antibody. In a preferred embodiment, the subject has, is suspected to have, or is at risk of developing an ROR1-expressing tumor, such as CLL, ALL, mantle cell lymphoma, neuroblastoma, sarcoma, renal cell carcinoma, breast cancer, lung cancer, colon cancer, head and neck cancer, melanoma, and other cancers, and the method is used to screen for or detect the presence of the tumor. In another embodiment, the method can be used to monitor the size or density of a ROR1-expressing tumor over time, e.g., during a course of treatment.

VI. Pharmaceutical compositions and combinations

[00130] In another aspect, the invention provides pharmaceutical compositions that contain an antibody, an antibody fragment, an antibody-based binding protein, or an ADC as described herein and a pharmaceutically acceptable carrier. Pharmaceutical compositions can be prepared from any of the antibodies described herein. Exemplary compositions include one or more of a chimeric antibody having SEQ ID NO:14 (light chain) and/or SEQ ID NO:1 (heavy chain), a chimeric antibody having SEQ ID NO:18 (light chain) and/or SEQ ID NO:5 (heavy chain), a chimeric antibody having SEQ ID NO:25 (light chain) and/or SEQ ID NO:12 (heavy chain), and a chimeric antibody having SEQ ID NO:26 (light chain) and/or SEQ ID NO:13 (heavy chain). Other antibodies, antibody fragments, antibody-based

binding proteins, or ADCs suitable for the pharmaceutical compositions of the invention include those having a light chain sequence as shown in SEQ ID NOs:14-26 or 136-141, and/or a heavy chain sequence as shown in SEQ ID NOs:1-13 or 130-135. Other exemplary compositions of the invention can contain a humanized antibody having one, two, three, four, five, or six CDRs selected from the group consisting of SEQ ID NOs:27-104, like the ones exemplified in SEQ ID NOs: 130-141 In some embodiments the antibody includes three CDR sequences of the same exemplified light or heavy chains shown in Figure 1. These include the heavy chain CDR1, CDR2 and CDR3 sequences and light chain CDR1, CDR2 and CDR3 sequences respectively shown in (1) SEQ ID NOs:27-29 and SEQ ID NOs:66-68 (antibody XBR1-402), (2) SEQ ID NOs:30-32 and SEQ ID NOs:69-71 (antibody ERR1-301), (3) SEQ ID NOs:33-35 and SEQ ID NOs:72-74 (antibody ERR1-306), (4) SEQ ID NOs:36-38 and SEQ ID NOs:75-77 (antibody ERR1-316), (5) SEQ ID NOs:39-41 and SEQ ID NOs:78-80 (antibody ERR1-324), (6) SEQ ID NOs:42-44 and SEQ ID NOs:81-83 (antibody ERR1-403), (7) SEQ ID NOs:45-47 and SEQ ID NOs:84-86 (antibody ERR1-409), (8) SEQ ID NOs:48-50 and SEQ ID NOs:87-89 (antibody ERR1-TOP4), (9) SEQ ID NOs:51-53 and SEQ ID NOs:90-92 (antibody ERR1-TOP15), (10) SEQ ID NOs:54-56 and SEQ ID NOs:93-95 (antibody ERR1-TOP22), (11) SEQ ID NOs:57-59 and SEQ ID NOs:96-98 (antibody ERR1-TOP40), (12) SEQ ID NOs:60-62 and SEQ ID NOs:99-101 (antibody ERR1-TOP43), or (13) SEQ ID NOs:63-65 and SEQ ID NOs:102-104 (antibody ERR1-TOP54). In some embodiments, the pharmaceutical composition includes an antibody having six CDR sequences of the same antibody exemplified in Figure 1, e.g., (a) SEQ ID NOs:66-68 and SEQ ID NOs:27-29 (antibody XBR1-402); (b) SEQ ID NOs:78-80 and SEQ ID NOs:39-41(antibody ERR1-324); (c) SEQ ID NOs:99-101 and SEQ ID NOs:60-62 (antibody ERR1-TOP43), or (d) SEQ ID NOs:102-104 and SEQ ID NOs:63-65 (antibody ERR1-TOP54). Still another exemplary pharmaceutical composition includes a dsFv fragment, which can include one or more modifications to the amino acid sequence as appropriate and understood by one of ordinary skill in the art.

[00131] In some embodiments, the compositions of the invention contain a carrier for the antibody, the antibody fragment, the antibody-based binding protein or the ADC, desirably a pharmaceutically acceptable carrier. The pharmaceutically acceptable carrier can be any suitable pharmaceutically acceptable carrier. It can be one or more compatible solid or liquid fillers, diluents, other excipients, or encapsulating substances which are suitable for

administration into a human or veterinary patient (e.g., a physiologically acceptable carrier or a pharmacologically acceptable carrier). The term "carrier" denotes an organic or inorganic ingredient, natural or synthetic, with which the active ingredient is combined to facilitate the use of the active ingredient, e.g., the administration of the active ingredient to a subject. The pharmaceutically acceptable carrier can be co-mingled with one or more of the active components, e.g., a hybrid molecule, and with each other, when more than one pharmaceutically acceptable carrier is present in the composition, in a manner so as not to substantially impair the desired pharmaceutical efficacy. Pharmaceutically acceptable materials typically are capable of administration to a subject, e.g., a patient, without the production of significant undesirable physiological effects such as nausea, dizziness, rash, or gastric upset. It is, for example, desirable for a composition comprising a pharmaceutically acceptable carrier not to be immunogenic when administered to a human patient for therapeutic purposes.

[00132] Pharmaceutical compositions of the invention can additionally contain suitable buffering agents, including, for example, acetic acid in a salt, citric acid in a salt, boric acid in a salt, and phosphoric acid in a salt. The compositions can also optionally contain suitable preservatives, such as benzalkonium chloride, chlorobutanol, parabens, and thimerosal. Pharmaceutical compositions of the invention can be presented in unit dosage form and can be prepared by any suitable method, many of which are well known in the art of pharmacy. Such methods include the step of bringing the antibody of the invention into association with a carrier that constitutes one or more accessory ingredients. In general, the composition is prepared by uniformly and intimately bringing the active agent into association with a liquid carrier, a finely divided solid carrier, or both, and then, if necessary, shaping the product.

[00133] A composition suitable for parenteral administration conveniently comprises a sterile aqueous preparation of the inventive composition, which preferably is isotonic with the blood of the recipient. This aqueous preparation can be formulated according to known methods using suitable dispersing or wetting agents and suspending agents. The sterile injectable preparation also can be a sterile injectable solution or suspension in a non-toxic parenterally-acceptable diluent or solvent, for example, as a solution in 1,3-butane diol. Among the acceptable vehicles and solvents that can be employed are water, Ringer's solution, and isotonic sodium chloride solution. In addition, sterile, fixed oils are conventionally employed as a solvent or suspending medium. For this purpose any bland

fixed oil can be employed, such as synthetic mono-or di-glycerides. In addition, fatty acids such as oleic acid can be used in the preparation of injectables. Carrier formulations suitable for oral, subcutaneous, intravenous, intramuscular, etc. administrations can be found in Remington's Pharmaceutical Sciences, Mack Publishing Co., Easton, PA.

[00134] Preparation of pharmaceutical compositions of the invention and their various routes of administration can be carried out in accordance with methods well known in the art. See, e.g., Remington: *The Science and Practice of Pharmacy*, Mack Publishing Co., 20th ed., 2000; and *Sustained and Controlled Release Drug Delivery Systems*, J.R. Robinson, ed., Marcel Dekker, Inc., New York, 1978. The delivery systems useful in the context of the invention include time-released, delayed release, and sustained release delivery systems such that the delivery of the inventive composition occurs prior to, and with sufficient time to cause, sensitization of the site to be treated. The inventive composition can be used in conjunction with other therapeutic agents or therapies. Such systems can avoid repeated administrations of the inventive composition, thereby increasing convenience to the subject and the physician, and may be particularly suitable for certain compositions of the invention.

[00135] Many types of release delivery systems are available and known to those of ordinary skill in the art. Suitable release delivery systems include polymer base systems such as poly(lactide-glycolide), copolyoxalates, polycaprolactones, polyesteramides, polyorthoesters, polyhydroxybutyric acid, and polyanhydrides. Microcapsules of the foregoing polymers containing drugs are described in, for example, U.S. Patent 5,075,109. Delivery systems also include non-polymer systems that are lipids including sterols such as cholesterol, cholesterol esters, and fatty acids or neutral fats such as mono-di-and triglycerides; hydrogel release systems; sylastic systems; peptide based systems; wax coatings; compressed tablets using conventional binders and excipients; partially fused implants; and the like. Specific examples include, but are not limited to: (a) erosional systems in which the active composition is contained in a form within a matrix such as those described in U.S. Patents 4,452,775, 4,667,014, 4,748,034, and 5,239,660 and (b) diffusional systems in which an active component permeates at a controlled rate from a polymer such as described in U.S. Patents 3,832,253 and 3,854,480. In addition, pump-based hardware delivery systems can be used, some of which are adapted for implantation.

[00136] The invention also provides kits suitable for carrying out the methods of the invention. Typically, the kits contain two or more components required for performing the

therapeutic or diagnostic methods of the invention. Kit components include, but are not limited to, one or more antibodies, antibody-based binding proteins, antibody fragments thereof, or ADC of the invention, appropriate reagents, and/or equipment. In some embodiments, the kits can contain an antibody, antibody-based binding protein, antibody fragment thereof of the invention and an immunoassay buffer suitable for detecting ROR1 (e.g. by ELISA, flow cytometry, magnetic sorting, or FACS). The kit may also contain one or more microtiter plates, standards, assay diluents, wash buffers, adhesive plate covers, magnetic beads, magnets, and/or instructions for carrying out a method of the invention using the kit. The kit scan include an antibody, antibody-based binding proteins, antibody fragments thereof of the invention bound to a substrate (e.g., a multi-well plate or a chip), which is suitably packaged and useful to detect ROR1. In some embodiments, the kits include an antibody, antibody-based binding proteins, antibody fragments thereof of the invention that is conjugated to a label, such as, a fluorescent label, a biologically active enzyme label, a luminescent label, or a chromophore label. The kits can further include reagents for visualizing the conjugated antibody, antibody-based binding proteins, antibody fragments thereof, e.g., a substrate for the enzyme. In some embodiments, the kits include an antibody, antibody-based binding proteins, antibody fragments thereof of the invention that is conjugated to a contrast agent and, optionally, one or more reagents or pieces of equipment useful for imaging the antibody in a subject.

[00137] Generally the antibody, antibody-based binding proteins, antibody fragments thereof of the invention in a kit is suitably packaged, e.g., in a vial, pouch, ampoule, and/or any container appropriate for a therapeutic or detection method. Kit components can be provided as concentrates (including lyophilized compositions), which may be further diluted prior to use, or they can be provided at the concentration of use. For use of the antibody of the invention in vivo, single dosages may be provided in sterilized containers having the desired amount and concentration of components.

EXAMPLES

[00138] The following examples are provided to further illustrate the invention but not to limit its scope. Other variants of the invention will be readily apparent to one of ordinary skill in the art and are encompassed by the appended claims.

Example 1. Cell lines

[00139] *Cell lines:* MDA-MB-231, MDA-MB-469, 697, Kasumi-2, T47D, HS578T, 63-12 and 63-12/hROR1 and 63-12/hROR2 transfectants, K562 and K562/hROR1 transfectants, EMT-6 and EMT-6/ROR1 transfectants were cultured in DMEM (Invitrogen; Carlsbad, CA) supplemented with 10% (v/v) heat inactivated FBS (Thermo Scientific; Logan, UT), 100 U/mL penicillin, and 100 mg/mL streptomycin (Invitrogen). HEK 293F cells were purchased from Invitrogen and maintained in FreeStyle Medium supplemented with 1% (v/v) heat inactivated FBS (Thermo Scientific) to support adherent culture or without FBS for suspension culture, 100 U/mL penicillin, and 100 mg/mL streptomycin (Invitrogen).

[00140] *Cloning of full-length hROR1 and hROR1 mammalian expression vectors:* Transposable vector backbones (pPB-Puro) were assembled from modular parts with flanking restriction sites that were synthesized or derived from sequence-verified commercially available vectors, and are described in detail in Patent WO2014013026A1. These original transposable vector backbones were modified by exchanging IRES-driven expression of the Puromycin resistance gene in the original vector with separate, phosphoglycerate kinase promoter (PGK) driven expression. This was done by replacing the IRES sequence with an SV40-pA sequence located 3' of the multiple cloning site, followed by introduction of the PGK-promoter sequence 5' of the Puromycin resistance gene. Full-length ROR1/2 open reading frames were synthesized by total gene synthesis (Genscript, Piscataway) with flanking restriction sites (5'NotI/3'BstBI) and were then cloned into the multiple cloning site of the transposable vectors using the respective restriction enzymes.

[00141] *Cell line engineering for ectopic expression of hROR1 or hROR2 in the 63-12 murine A-MuLV-transformed preB cell line:* The mouse Abelson murine pre-B cell line 63-12 (Shinkai et al. (1992) Cell 68:855-67) were cultured in culture media (17.7g/L Gibco® IMDM (Life Technologies, 42200-030), 3.024 g/L $NaHCO_3$ (Sigma-Aldrich, p.a., >99.7%), 10 mL/L 100x non-essential amino acids (Life Technologies, 11140035), 5 mg/L insulin (Sigma-Aldrich, I-5500), 3 mL/L of 10% primatone RL/UF in H_2O (Sheffield Bioscience), and 1 mL/L of 50 mM 2-mercaptoethanol (Sigma-Aldrich, M-3148) in H_2O), supplemented with 2% (v/v) FCS, 100 IU/mL Pen/Strep/Fungizone (Amimed, 4-02F00-H), 200 mM L-glutamine (Amimed, 5-10K00-H) and 50 µM 2-mercaptoethanol (Amresco, 0482) at 37°C and 7.5% CO_2. Cells were engineered to overexpress hROR1 and hROR2 by transposition as follows: cells were centrifuged (6 min, 1200 rpm, 4°C) and resuspended in RPMI-1640

media ($5x10^6$ cells/mL). 400 µL of cell suspension was then added to 400 µL of RPMI containing 10 µg of transposable vector pPB-PGK-Puro-ROR1 (directing co-expression of full-length ROR1 (NP_005003.2) and the puromycin-resistance gene), or 10 µg of transposable vector pPB-PGK-Puro-ROR2 (directing co-expression of full-length ROR2 (NP_004551.2) and the puromycin-resistance gene), along with 10 µg of transposase-containing vector pCDNA3.1_hy_mPB. DNA/63-12 cell mixtures were transferred to electroporation cuvettes (0.4 cm-gap, 165-2088, BioRad, Cressier, Switzerland) and electroporated using the Biorad Gene Pulser II with capacitance extender at 300V and 950 µF. Then, cells were incubated for 5-10 min at room temperature. Following the incubation, cells were centrifuged at 1200 rpm for 6 min (4°C), washed once and subsequently resuspended in aqueous culture media (17.7g/L Gibco® IMDM (Life Technologies, 42200-030), 3.024 g/L $NaHCO_3$ (Sigma-Aldrich, p.a., >99.7%), 10 mL/L 100x non-essential amino acids (Life Technologies, 11140035), 5 mg/L insulin (Sigma-Aldrich, I-5500), 3 mL/L of 10% primatone RL/UF in H_2O (Sheffield Bioscience), and 1 mL/L of 50 mM 2-mercaptoethanol (Sigma-Aldrich, M-3148) in H_2O), supplemented with 2% (v/v) FCS, 100 IU/mL Pen/Strep/Fungizone (Amimed, 4-02F00-H), 200 mM L-glutamine (Amimed, 5-10K00-H) and 50 µM 2-mercaptoethanol (Amresco, 0482). After two days incubation at 37°C in a humidified incubator at 5% CO_2 atmosphere, cell pools stably expressing hROR1 or hROR2 were selected by adding 2 µg/mL puromycin (Sigma-Aldrich, P8833).

[00142] After 4 to 5 days, hROR1 or hROR2 expression on engineered cells were confirmed by flow cytometry. Briefly, following trypzinization, 10^6 cells were centrifuged in FACS tubes; obtained pellets were resuspended in buffer (PBS with 2% (v/v) FCS). In the case of hROR1-engineered cells, cells were then incubated with 2A2 (mAb066 antibody targeting ROR1, final concentration 2 µg/mL) for 30 min at 4°C, followed by centrifugation and washing. Cells were resuspended as previously and incubated with anti-human IgG antibody (Fc gamma-specific) PE (eBioscience, Vienna, Austria, 12-4998-82), at a 1:100 dilution, in the dark (30 min, 4°C), washed once in buffer and kept on ice until FACS sorting. For hROR2-engineered 63-12 cells, the same protocol was followed but using EPR3779 (Abcam antibody targeting ROR2; 1:100 dilution) as primary antibody and allophycocyanin-conjugated AffiniPure F(ab')2 goat anti-rabbit IgG (H+L) (Jackson Immunoresearch, 111-136-144) as secondary antibody.

[00143] In the case of hROR1-engineered 63-12 cells, cells were single cell sorted into 96-well flat-bottom plates containing 200 µL of supplemented culture media per well using a FACS Aria II. Plates were incubated at 37°C and clones were expanded to 6-well plates before analysis. Target expression was confirmed by flow cytometry using a FACSCalibur instrument (BD Biosciences) and FlowJo analytical software (Tree Star, Ashland, OR).

[00144] *Cell line engineering for ectopic expression of hROR1 in the EMT-6 murine breast cancer cell line:* Murine EMT-6 breast cancer cells (kind gift from Prof. Dr. med. Alfred Zippelius, University Hospital of Basel, Switzerland) were cultured in DMEM complete (Dulbecco's Modified Eagle Medium (DMEM) High Glucose (4.5 g/l) with L-Glutamine with 10% (v/v) Fetal Calf Serum (FCS), 100 IU/mL of Pen-Strep-Fungizone and 2 mM L-glutamine (all Bioconcept, Allschwil, Switzerland)) at 37°C and 5% CO_2. Cells were engineered to overexpress ROR1 by transposition as follows: cells were centrifuged (6 min, 1200 rpm, 4°C) and resuspended in RPMI-1640 media ($5x10^6$ cells/mL). 400 µL of this cell suspension was then added to 400 µL of RPMI containing 13.3 µg of transposable vector pPB-PGK-Puro-ROR1, directing co-expression of full-length ROR1 (NP_005003.2) and the puromycin-resistance gene, and 6.6 µg of transposase-containing vector pCDNA3.1_hy_mPB. DNA/EMT-6 cell mixture was transferred to electroporation cuvettes (0.4 cm-gap, 165-2088, BioRad, Cressier, Switzerland) and electroporated using the Biorad Gene Pulser II with capacitance extender at 300V and 950 µF. Then, cells were incubated for 5-10 min at room-temperature. Following the incubation, cells were centrifuged at 1200 rpm for 6 min, washed once and subsequently resuspended in DMEM complete prior to incubation at 37°C in a humidified incubator at 5% CO_2 atmosphere. One day after electroporation, cell pools stably expressing human ROR1 were selected by adding 3 µg/mL puromycin (Sigma-Aldrich, P8833).

[00145] ROR1 expression on selected EMT-6-ROR1 cells was confirmed by flow cytometry. Briefly, following trypsinization, 10^6 cells were centrifuged in FACS tubes; obtained pellets were resuspended in buffer (PBS with 2% (v/v) FCS). Cells were then incubated with 2A2 (mAb066); 30 min, 4°C, final concentration 2 µg/mL), followed by centrifugation and washing. Cells were then resuspended as previously and incubated with anti-human IgG antibody (Fc gamma-specific) PE (eBioscience, Vienna, Austria, 12-4998-82) with a 1:250 dilution in the dark (30 min, 4°C), washed once in buffer and kept on ice until FACS sorting.

[00146] Using a FACS Aria II, cells were single cell sorted into a 96-well flat-bottom plate containing 200 µL of DMEM complete per well. This plate was incubated at 37°C and clones were expanded to 6-well plates before analysis of ROR1-expression by flow cytometry as outlined above, using a FACSCalibur instrument (BD Biosciences) and FlowJo analytical software (Tree Star, Ashland, OR) for analysis.

[00147] Figure 16C shows the FACS analysis data of clone 14 (high ROR1-expressing) and WT (ROR1 negative) EMT-6, detected with anti-ROR1 antibody 2A2 (mAb066).

Example 2. Generation of high-complexity rabbit Fab library and reagents for screening

[00148] *Construction, expression, and purification of recombinant human ROR1 proteins:* Construction, expression, purification and biotinylation of hFc fusion proteins containing different domains of human ROR1 or mouse ROR1 were described (Yang et al., PloS One 6:e21018, 2011). For hROR1-AVI-6XHIS fusion protein, the extracellular domain of human ROR1 (24-403) was PCR amplified with primers pCEP4-hROR1-F and pCEP4-hROR1-Avi tag-R (note that the AVI tag was introduced to the C terminus of ROR1 by primer pCEP4-hROR1-Avi tag-R), followed by extension PCR with primers pCEP4-signal-F-KpnI and pCEP4-6HIS-R-XhoI to add a signal peptide and 6XHIS tag to the N and C terminus separately before cloning into pCEP4 via *KpnI/XhoI*. This construct was then transiently transfected into HEK 293F cells (Invitrogen) using 293fectin (Invitrogen), and the protein was purified by Immobilized Metal Ion Affinity Chromatography using a 1-mL HisTrap column (GE Healthcare) as described in Kwong and Rader, Curr Protoc Protein Sci Chapter 6:Unit 6 10, 2009. The quality and quantity of purified hROR1-AVI-6XHIS was analyzed by SDS-PAGE and A_{280} absorbance, respectively. Subsequently, the fusion protein was biotinylated by BirA enzyme kit from Avidity (Aurora, Colorado) following the protocol. Briefly, 2 mg ROR1-AVI-6XHIS at 40 µM in 10 mM Tris-HCl (pH 8) was biotinylated in the presence of biotin using 10 µg BirA after incubation for 30 min at 37°C, followed by purification again using a 1-mL HisTrap column (GE Healthcare) as described above. pCEP4-hROR1-F: 5'-atcctgtttctcgtagctgctgcaactggagcacactccgcccgggggcgccgccgcccag-3' (SEQ ID NO:105); pCEP4-hROR1- Avi-tag-R: 5'-ccactcgatcttctgggcctcgaagatgtcgttcaggccctccatcttgttcttctcctt-3' (SEQ ID NO:106); pCEP4-signal-F-KpnI: 5' gctgggtaccggcgcgccaccatggactggacttggagaatcctgtttctcgtagctgct-3' (SEQ ID

NO:107); pCEP4-6HIS-R-XhoI: 5'-
gccggcctcgagtcagtgatggtgatggtggtgctcgtgccactcgatcttctgggcctc-3' (SEQ ID NO:108).

[00149] *Construction, expression, and purification of recombinant human ROR1 (hROR1-His) and human ROR2 (hROR2-His) proteins:* hROR1-His was PCR-amplified with primers SP-hROR1_F (5'
gctgggtaccggcgcgccaccatggactggacttggagaatcctgtttctcgtagctgctgcaactggagcacactccgcccgggg
cgccgccgcccag 3') (SEQ ID NO:109) and hROR1-His_R (5'
cggcctcgagtcagtgatggtgatggtggtgctccatcttgttcttctcctt 3') (SEQ ID NO:110) using pCEP4-hFc-hROR1 (Yang et al., PloS One 6:e21018, 2011) as template, while hROR2-His was PCR-amplified with primers SP-hROR2_F
(gctgggtaccggcgcgccaccatggactggacttggagaatcctgtttctcgtagctgctgcaactggagcacactccgaagtgga
ggttctggatccg) (SEQ ID NO:111) and hROR2-His_R
(cggcctcgagtcagtgatggtgatggtggtgccccatcttgctgctgtctcg) (SEQ ID NO:112) using pCEP4-hFc-hROR2 as template. Then they are cloned into pCEP4 (Invitrogen) separately via *Kpn*I/*Xho*I. These constructs were then separately and transiently transfected into HEK 293F cells (Invitrogen) using 293fectin (Invitrogen), and the corresponding proteins were purified by Immobilized Metal Ion Affinity Chromatography using a 1-mL HisTrap column (GE Healthcare) as described in Kwong and Rader, Curr Protoc Protein Sci Chapter 6:Unit 6 10, 2009. The quality and quantity of purified hROR1-His and hROR2-His were analyzed by SDS-PAGE and A_{280} absorbance, respectively.

[00150] *Generation and selection of naïve chimeric rabbit/human Fab libraries:* All rabbit handling was carried out by veterinary personnel at Pocono Rabbit Farm & Laboratory (Canadensis, PA) or R & R Research (Stanwood, WA). A total of nine rabbits (ages 3-4 months) were used. Five of these rabbits were of the New Zealand White (NZW) strain, with three obtained from Pocono Rabbit Farm & Laboratory (Canadensis, PA) and two obtained from R & R Research (Stanwood, WA). Four b9 wild-type rabbits were derived from a separate R & R Research colony that originated from a pedigreed colony developed and characterized at the National Institute of Allergy and Infectious Diseases (NIAID) (McCartney-Francis et al., Proc. Natl. Acad. Sci. U S A 81:1794-1798, 1984; and Popkov et al., J. Mol. Biol. 325:325-335, 2003. Spleen and bone marrow from each rabbit were collected and processed for total RNA preparation and RT-PCR amplification of rabbit V_K, V_λ, and V_H encoding sequences using established protocols (Rader, Methods Mol Biol

525:101-128, xiv, 2009. Rabbit (rb) V_κ/human (hu) C_κ/rbV_H and rbV_λ/huC_λ/rbV_H segments, respectively, were assembled in one fusion step based on 3-fragment overlap extension PCR. Note that the V_L derived from b9 rabbits were also assembled with V_H from NZW rabbits. The Fab-encoding fragments were digested with *Sfi*I and ligated with *Sfi*I-treated phage display vector pC3C (Hofer et al., J Immunol Meth 318:75-87, 2007) at 16°C for 24 h. Subsequently, 15 µg purified pC3C-rbV_κ/hC_κ/rbV_H ligated products were transformed into *E. coli* strain SR320 (a kind gift from Dr. Sachdev S. Sidhu, University of Toronto, Toronto, Ontario, Canada) by 30 separate electroporations (each using 0.5 µg DNA in 50 µl electrocompetent cells) and yielded 7.5 x 10^9 independent transformants for library κ. For library λ, 4.8 x 10^9 independent transformants were obtained using the same procedure. Using VCSM13 helper phage (Stratagene; La Jolla, CA), the phagemid libraries were converted to phage libraries and stored at -80°C. Phage library κ and library λ were re-amplified using XL1-Blue (Stratagene) or ER2738 (Lucigen) and mixed equally before four rounds of panning against biotinylated hFc-hROR1 or hROR1-AVI-6HIS. During the panning, 5 µg/mL antigen was pre-incubated with streptavidin coated magnetic beads (Dynabeads MyOne Streptavidin C1; Invitrogen) at 37°C for 30 min and then binders from the phage library were captured in the presence of 1 mg/mL unspecific polyclonal human IgG (Thermo Scientific) when hFc-ROR1 was used. Starting from the third round of panning, the input phage was negatively depleted by incubation with empty beads before selection against antigen-loaded beads. Following selection, supernatants of IPTG-induced bacterial clones were analyzed by ELISA and by flow cytometry. Repeated clones were identified by DNA fingerprinting with *Alu*I, and the V_L and V_H sequences of unique clones were determined by DNA sequencing (Figure 1).

Example 3. Expression and purification of chimeric rabbit/human Fab and full-length IgG1 antibodies

[00151] *Construction, expression, and purification of chimeric rabbit/human Fab and IgG1:* MAb XBR1-402 in chimeric rabbit/human Fab format was cloned into *E. coli* expression plasmid pC3C-His and expressed and purified as described in Kwong and Rader, Curr Protoc Protein Sci Chapter 6:Unit 6 10, 2009. For the expression of mAb XBR1-402 in chimeric rabbit/human IgG1 format, the previously described vector PIGG-R11 was used (Yang et al., PloS One 6:e21018, 2011). The V_H encoding sequence of Fab XBR1-402 was

PCR amplified using primers 4-2_VH_F and 4-2_VH_R, and cloned via *ApaI/SacI* into PIGG-R11. Then the light chain encoding sequence of XBR1-402 was PCR amplified using primers 4-2_λ_F and LEAD-B, and cloned via *HindIII/XbaI* into PIGG-R11 with the corresponding heavy chain encoding sequence. Note that an internal *ApaI* site in FR4 of V_H encoding sequences of Fab XBR1-402 was removed by silent mutation in primer 4-2_VH_R. In addition, we changed a TAG stop codon, which was suppressed during selection in *E. coli* strain XL1-Blue, to CAG (glutamine) encoding the first amino acid of native V_H (Figure 1) with primer 4-2_VH_F. The resulting PIGG-XBR1-402 plasmid was transiently transfected into HEK 293F cells (Invitrogen) using 293fectin (Invitrogen), and the protein purified with a 1-mL recombinant Protein A HiTrap column (GE Healthcare, Piscataway, NJ) as described (Yang et al., PloS One 6:e21018, 2011; and Yang and Rader, Methods Mol Biol 901:209-232, 2012). The quality and quantity of purified IgG1 were analyzed by SDS-PAGE and A_{280} absorbance, respectively.

[00152] All the other mAbs in chimeric rabbit/human Fab format were cloned into *E. coli* expression plasmid pET11a and expressed and purified as described (Yang et al., PloS One 6:e21018, 2011). For the expression of mAbs ERR1-324, ERR1-TOP43 and ERR1-TOP54 in chimeric rabbit/human IgG1 format, pCEP4 (Invitrogen) was used to clone the heavy chain and light chain separately. For heavy chain, a gBlock containing a heavy-chain signal peptide encoding sequence, V_H of ERR2-302 (a mAb to hROR2) and CH1 (1-49) of human IgG1 was synthesized by IDT (San Jose, CA) and amplified with primers KpnI/AscI-Signal and CH1-internal/overlap-R, and fused to CH1 (50-88)-CH2-CH3 amplified from PIGG with primers CH1-internal/overlap-F and HC-CH3-R-XhoI by overlap extension PCR with primers KpnI/AscI-Signal and HC-CH3-R-XhoI, and then cloned into pCEP4 by *AscI/XhoI*. Note that a *EheI* site was introduced into CH1 at Ala^{12} by synonymous mutation when the gBlock was synthesized. Consequently, this construct served as vector to clone the heavy chains of other mAbs by replacing the V_H using *AscI/EheI*: V_H of ERR1-324, ERR1-TOP43 and ERR1-TOP54 were amplified with forward primer ERR1-324 HC-F, ERR1-TOP43 HC-F and ERR1-TOP54 HC-F and reverse primer VH-CH1-R-EheI separately, followed by extension PCR to add the signal peptide with primer KpnI/AscI-Signal and VH-CH1-R-EheI. Then each V_H was inserted into the vector by *AscI/EheI*. For light chain cloning, while lambda light chains of ERR1-TOP43 and ERR1-TOP54 were amplified with primers ERR1-TOP43 LC-F and ERR1-TOP54 LC-F separately combined with LC-R-XhoI, kappa light

chains of ERR1-324 was amplified with primers ERR1-324 KC-F and KC-R-XhoI. Then, a signal peptide encoding sequence was added by extension PCR with forward primer KpnI/AscI-Signal and reverse primer LC-R-XhoI or KC-R-XhoI. Subsequently, each light chain PCR products was cloned into pCEP4 by *Asc*I/*Xho*I. The resulting constructs containing heavy chain or light chain for each IgG were co-transfected transiently into HEK 293F cells (Invitrogen) using 293fectin (Invitrogen), and the corresponding proteins were purified with a 1-mL recombinant Protein A HiTrap column (GE Healthcare, Piscataway, NJ) as described (Yang et al., PloS One 6:e21018, 2011; and Yang and Rader, Methods Mol Biol 901:209-232, 2012). The quality and quantity of purified IgG1 was analyzed by SDS-PAGE and A_{280} absorbance, respectively.

Table 1. Primer sequences for cloning antibody sequences

Primer	Sequence	SEQ ID NO:
4-2_VH_F	GAGGAGGAGCTCACTCTCAGGAGCAGCAGAAGGAGTCCGGG	113
4-2_VH_R	CGATGGGCCCTTGGTGGAGGCTGAAGAGACGGTGACGAGGGTCCCTGGCCCCCAGAGGTC	114
4-2_λ_F	GAGAAGCTTGTTGCTCTGGATCTCTGGTGCCTACGGGTCCTATGAGCTGACACAGCTGCC	115
LEAD-B	GGCCATGGCTGGTTGGGCAGC	116
KpnI/AscI-Signal	GGTACCGGCGCGCCACCATGGACTGGACTTGGAGAATCCTGTTTCTCGTAGCTGCTGCAA	117
CH1-internal/overlap-R	GCCGCTGGTCAGGGCTCCTG	118
CH1-internal/overlap-F	CAGGAGCCCTGACCAGCGGC	119
HC-CH3-R-XhoI	GGCCTCGAGTCATTTACCCGGAGACAGGGA	120
ERR1-324 HC-F	TTTCTCGTAGCTGCTGCAACTGGAGCACACTCCCAGTCGGCTGGAGGAGTCCGGG	121
ERR1-TOP43 HC-F	TTTCTCGTAGCTGCTGCAACTGGAGCACACTCCCAGTCGTTGGAGGAGTCCGGG	122
ERR1-TOP54 HC-F	Same as ERR1-TOP43 HC-F	123
VH-CH1-R-EheI	GGAGGGCGCCAGGGGGAAGACCGATGGGCCCTTGGT	124
ERR1-TOP43 LC-F	TTTCTCGTAGCTGCTGCAACTGGAGCACACTCCTCCTATGAGCTGACACAGCTG	125
ERR1-	Same as ERR1-TOP43 LC-F	126

TOP54 LC-F		
ERR1-324 KC-F	TTTCTCGTAGCTGCTGCAACTGGAGCACACTCC GAGCTCGTGCTGACCCAGACT	127
LC-R-XhoI	GGCCTCGAGTTATGAACATTCTGTAGGGGC	128
KC-R-XhoI.	GGCCTCGAGTTAACACTCTCCCCTGTTGAA	129

Example 4. Examination of antibody binding activities

[00153] *ELISA:* For ELISA (Figure 2), each well of a 96-well Costar 3690 plate (Corning, Corning, NY) was coated with 100 ng anti-human IgG1 Fc in 25 μL coating buffer (0.1 M Na_2CO_3, 0.1 M $NaHCO_3$, pH 9.6) for 1 h at 37°C. After blocking with 150 μL 3% (w/v) BSA/TBS for 1 h at 37°C, hFc-hROR1 or hFc-mROR1 was captured following incubation at 100 ng / 50 μL for 1 h at 37°C. Then 100 ng / 50 μL of Fab was applied in each well at 37°C. 2h later, 50 μL of a 1:1000 dilution of a mouse anti-His tag mAb conjugated to horse radish peroxidase (HRP) (R&D Systems, Minneapolis, MN) in 1% (w/v) BSA/TBS was used to detect the Fab. To determine the epitopes (Figure 4), hFc fusion proteins containing different domains of hROR1 were coated directly, followed by incubation with Fab before detection by mouse anti-His tag mAb conjugated to HRP. Washing with PBS was repeated and colorimetric detection was performed using 2,2'- azino-bis (3-ethylbenzthiazoline)-6-sulfonic acid (Roche) as substrate according to the manufacturer's directions. The absorbance was measured at 405 nm using a SpectraMax M5 microplate reader (Molecular Devices; Sunnyvale, CA) and SoftMax Pro software (Molecular Devices).

[00154] *Flow cytometry:* Cells were stained using standard flow cytometry methodology. Briefly, for purified anti-ROR1 Fab (Figure 3), 0.1~1 x 10^6 cells were stained with 1000 ng / 100 μL of Fab on ice for 1 h. After washing twice with ice-cold flow cytometry buffer (PBS containing 1% (v/v) BSA, 0.1% sodium azide and 1 mM EDTA), the cells were incubated with a 1:1000 dilution of a mouse anti-His tag mAb conjugated to Alexa Fluor 488 (Qiagen) in 100 μL flow cytometry buffer on ice for 30 min. For purified anti-ROR1 IgG1 (Figure 8), 0.1~1 x 10^6 cells were blocked by 4% goat serum for 15 min at room temperature and then incubated with 100 ng / 100 μL of IgG on ice for 1 h. After washing twice with ice-cold flow cytometry buffer, cells were stained with a 1:500 dilution of goat anti-human IgG, Fcγ pAbs conjugated to APC (Jackson ImmunoResearch) in 100 μL flow cytometry buffer on ice for 30 min. For commercial goat anti human ROR1 polyclonal antibody (Figure 8), 0.1~1 x 10^6 cells were stained with 200 ng / 100 μL of Ab on ice for 1 h. After washing twice with ice-cold flow cytometry buffer (PBS containing 1% (v/v) BSA, 0.1% sodium azide and 1 mM

EDTA), the cells were incubated with a 1:1000 dilution of a Alexa Fluor 647-conjugated AffiniPure F(ab')$_2$ donkey anti goat IgG (H+L) in 100 µL flow cytometry buffer on ice for 30 min. Finally, 4',6-diamidino-2-phenylindole (DAPI) was added to a final concentration of 100 ng / mL to exclude dead cells from the analysis. Cells were analyzed using a FACSCalibur instrument (BD Biosciences) and FlowJo analytical software (Tree Star, Ashland, OR).

[00155] *Surface plasmon resonance:* Surface plasmon resonance for the measurement of the affinities of all Fabs to hFc-hROR1 and for epitope mapping studies were performed on a Biacore X100 instrument using Biacore reagents and software (GE Healthcare, Piscataway, NJ). Anti-Human IgG (Fc) antibody was immobilized on a CM5 sensor chip following the instruction of Human Antibody Capture Kit (GE Healthcare, Piscataway, NJ). Then, hFc-hROR1 fusion proteins were captured at certain density (indicated in Figure 5 and Figure 6). The sensor chip included an empty flow cell for instantaneous background depletion. All binding assays used 1x HBS-EP+ running buffer (10 mM HEPES, 150 mM NaCl, 3 mM EDTA (pH 7.4), and 0.05% (v/v) Surfactant P20) and a flow rate of 30 mL/min. For affinity measurements, all Fabs were injected at five different concentrations (dilution factor was 2), and the lowest concentration was tested in duplicates (the highest concentrations for each Fab are indicated in Figure 6B). The sensor chip was regenerated with 3 $MgCl_2$ from the Human Antibody Capture Kit without any loss of binding capacity. Calculation of association (k_{on}) and dissociation (k_{off}) rate constants was based on a 1:1 Langmuir binding model. The equilibrium dissociation constant (K_d) was calculated from k_{off} / k_{on}. For epitope mapping studies, each Fab was prepared at 500 nM alone in 1x HBS-EP+ running buffer and then injected in order as indicated in Figure 5.

[00156] *Western blotting:* Cells or proteins were lysed by 1x sample buffer (containing 1% β-mercaptoethanol) and boiled before running on NuPAGE Novex 4-12% Bis-Tris gels (Invitrogen). After membrane transferring and blocking by 5% milk, 2 µg / mL chimeric rabbit/human IgG1 of XBR1-402 or ERR1-TOP43 was applied to detect the denatured proteins, followed by incubation with 1/1000 anti-human Fcγ conjugated to HRP before developing using ECL Prime Western Blotting Detection Reagent (GE Healthcare) (Figure 9).

Example 5 Expression of purified, recombinant strep-tagged human ROR1 and human twin strep-tagged human ROR2

[00157] StrepII-tagged human ROR1-extracellular domain was produced as follows: the nucleotide sequence encoding the extracellular domain of human ROR1 (NP_005003.2) was N-terminally fused to a signal sequence (MNFGLRLIFLVLTLKGVQC) and C-terminally fused with a sequence encoding a strepII-tag (GWSHPQFEK). The entire nucleotide sequences with flanking 5'NotI and 3'HindIII sites were produced by total gene synthesis (GenScript, Piscataway, USA), assembled in the proprietary mammalian expression vector pEvi5 by Evitria AG (Schlieren, Switzerland) and verified by DNA sequencing.

[00158] Expression of the proteins was performed in suspension-adapted CHO K1 cells by Evitria AG (Schlieren, Switzerland). Supernatants from pools of transfected CHO K1 cells were harvested by centrifugation and sterile filtered (0.2 µm) before FPLC-based affinity purification using StrepTactin columns (IBA GmbH, Goettingen, Germany).

[00159] Recombinant human twin strep-tagged ROR2 (NP_004551.2) was expressed and purified in-house according to the following protocol: the EBNA expression vector pCB14b-ROR2-ECD-TwinStrep, directing expression of ROR2 extracellular domain (ECD), C-terminally tagged with a TwinStep tag, was transfected into HEK293T using Lipofectamine® LTX with PLUS™ Reagent (Thermo Fisher Scientific, 15388100). Following a 1-day incubation (37°C, 5% CO_2, growth media: Dulbecco's Modified Eagle Medium (DMEM) High Glucose (4.5 g/l) with L-Glutamine with 10% (v/v) Fetal Calf Serum (FCS), 100 IU/mL of Pen-Strep-Fungizone and 2 mM L-glutamine (all Bioconcept)), cells were expanded under selection conditions (2 µg/mL of puromycin (Sigma-Aldrich, P8833-25 mg stock at 2 mg/mL)). Cells were split and further expanded (37°C, 5% CO_2); once confluency was reached, tissue culture dishes were coated with 20 µg/ml poly-L-Lysine (Sigma-Aldrich, P1524) for 2 hrs at 37°C and washed twice with PBS. Then, cells were trypsinized, washed with PBS and split 1:3 onto poly-L-lysine-coated plates. Again after reaching confluency, cells were washed with PBS followed by with media replacement using production media (DMEM/F-12, Gibco/Thermo Fisher Scientific, 31330-03) supplemented with 1 µg/mL puromycin (Sigma-Aldrich, P8833), 100 IU/mL of Pen-Strep-Fungizone (Bioconcept, 4-02F00-H), 161 µg/mL of N-acetyl-L-cysteine (Sigma-Aldrich, A8199) and 10 µg/mL of L-glutathione reduced (Sigma-Aldrich, G6529). Supernatant, harvested bi-weekly and filtered (0.22 µm) to remove cells, was stored at 4°C until purification. For

purification, filtered supernatant was loaded onto a Streptactin® Superflow® high capacity cartridge (IBA, Göttingen, Germany, 2-1238-001) column; purification and elution was performed according to the manufacturer's protocol on an AEKTA pure (GE Healthcare). Fractions were analyzed for protein purity and integrity by SDS-PAGE. Protein-containing fractions were mixed and subjected to buffer exchange using Amicon filtration units (Millipore, Schaffhausen, Switzerland) to reach a dilution of ≥1:100 in PBS, and then sterile filtered using a low retention filter (0.20 µm, Carl Roth, Karlsruhe, Germany, PA49.1).

Example 6. Expression of purified, recombinant humanized anti-human ROR1 and isotype control antibodies

[00160] *Expression vectors:* Antibody variable region coding regions were produced by total gene synthesis (GenScript) using MNFGLRLIFLVLTLKGVQC as leader sequence, and were assembled with human IgH-γ 1 and IgL-κ or IgL-λ constant regions, as applicable, in the expression vector pCB14. This vector, a derivative of the episomal mammalian expression vector pCEP4 (Invitrogen), carries the EBV replication origin, encodes the EBV nuclear antigen (EBNA-1) to permit extrachromosomal replication, and contains a puromycin selection marker in place of the original hygromycin B resistance gene.

[00161] *In-house expression and purification*: pCB14-based expression vectors were transfected into HEK293T cells using Lipofectamine® LTX Reagent with PLUS™ Reagent (Thermo Fisher Scientific, Reinach, Switzerland, 15388100); following a 1-day incubation (37°C, 5% CO_2, growth media: Dulbecco's Modified Eagle Medium (DMEM) High Glucose (4.5 g/l) with L-Glutamine with 10% (v/v) Fetal Calf Serum (FCS), 100 IU/mL of Pen-Strep-Fungizone and 2 mM L-glutamine (all Bioconcept, Allschwil, Switzerland)), cells were expanded under selection conditions (2 µg/mL of puromycin (Sigma-Aldrich, Buchs SG, Switzerland, P8833-25 mg stock at 2 mg/mL)). Cells were split and further expanded (37°C, 5% CO_2); once confluency was reached, tissue culture dishes were coated with 20 µg/ml poly-L-Lysine (Sigma-Aldrich, P1524) for 2h at 37°C and washed twice with PBS. Then, cells were trypsinized and split 1:3 onto poly-L-lysine-coated plates. Again after reaching confluency, cells were washed with PBS followed by media replacement to production media (DMEM/F-12, Gibco/Thermo Fisher Scientific, 31330-03) supplemented with 1 µg/mL puromycin (Sigma, P8833), 100 IU/mL of Pen-Strep-Fungizone (Bioconcept), 161 µg/mL of N-acetyl-L-cysteine (Sigma-Aldrich, A8199) and 10 µg/mL of L-glutathione

reduced (Sigma-Aldrich, G6529). Supernatant, harvested bi-weekly and filtered (0.22 μm) to remove cells, was stored at 4°C until purification.

[00162] For purification, filtered supernatant was loaded onto a PBS-equilibrated Protein A HiTrap column (GE Healthcare, Frankfurt am Main, Germany, 17-0405-01) or a JSR Amsphere™ Protein A column (JSR Life Sciences, Leuven, Belgium, JWT203CE) and washed with PBS; elution was performed using 0.1 M glycine (pH 2.5) on an AEKTA pure (GE Healthcare). Fractions were immediately neutralized with 1 M Tris-HCl buffer (pH 8.0), and analyzed for protein purity and integrity by SDS-PAGE. Protein-containing fractions were mixed and subjected to buffer exchange using Amicon filtration units (Millipore, Schaffhausen, Switzerland, UFC901008) to reach a dilution of 1:100 in the buffer listed in Table 2, and then sterile filtered using a low retention filter (0.20 μm, Carl Roth, Karlsruhe, Germany, PA49.1).

[00163] Antibodies were transiently expressed in CHO cells by methods known in the art and recombinant antibodies were purified by standard protein A purification from CHO cell supernatants, as known in the art. The purity and the integrity of the recombinant antibodies were analyzed by SDS-PAGE.

[00164] Table 2 lists the antibodies used in subsequent examples, along with their final concentration and buffer.

Table 2. List of antibodies used in the Examples

Antibody (ref.)	Format	Antibody SEQ ID HC/LC	C-Terminal Tags (HC: Heavy Chain, LC: Light Chain)	Buffer	Final conc. (mg/mL)
XBR1-402 (mAb031)	IgG	HC: SEQ ID NO. 1 LC: SEQ ID NO. 14	HC: LPETG-Strep LC: G_5SLPETG-Strep	PBS	3.9
ERR1-301 (mAb027)	IgG	HC: SEQ ID NO. 2 LC: SEQ ID NO. 15	HC: LPETG-Strep LC: G_5SLPETG-Strep	PBS	3.8
ERR1-306 (mAb033)	IgG	HC: SEQ ID NO. 3 LC: SEQ ID NO. 16	HC: LPETG-Strep LC: G_5SLPETG-Strep	PBS	3.0
ERR1-324 (mAb034)	IgG	HC: SEQ ID NO. 5 LC: SEQ ID NO. 18	HC: LPETG-Strep LC: G_5SLPETG-	PBS	3.0

			Strep		
ERR1-403 (mAb035)	IgG	HC: SEQ ID NO. 6 LC: SEQ ID NO. 19	HC: LPETG-Strep LC: G_5SLPETG-Strep	PBS	2.9
ERR1-Top43 (mAb036)	IgG	HC: SEQ ID NO. 12 LC: SEQ ID NO. 25	HC: LPETG-Strep LC: G_5SLPETG-Strep	PBS	3.0
XBR1-402 (mAb186)	IgG	HC: SEQ ID NO. 1 LC: SEQ ID NO. 14	HC: LPETG-Strep LC: G_5SLPETG-Strep	PBS	3.9
ERR1-324 (mAb188)	IgG	HC: SEQ ID NO. 5 LC: SEQ ID NO. 18	HC: LPETG-Strep LC: G_5SLPETG-Strep	PBS	7.1
ERR1-Top43 (mAb189)	IgG	HC: SEQ ID NO. 12 LC: SEQ ID NO. 25	HC: LPETG-Strep LC: G_5SLPETG-Strep	PBS	7.0
XBR1-402 (mAb202)	IgG	HC: SEQ ID NO. 1 LC: SEQ ID NO. 14	HC: LPETG-Strep LC: G_5SLPETG-Strep	PBS	6.3
Ms961 (mAb190)	IgG	HC: SEQ ID NO. 148 LC: SEQ ID NO. 149	HC: LPETG-Strep LC: G_5SLPETG-Strep	PBS	6.4
2A2 (mAb066)	IgG	HC: SEQ ID NO. 150 LC: SEQ ID NO. 151	HC: LPETG-Strep LC: G_5SLPETG-Strep	PBS	8.0
hu2A2 (mAb038)	IgG	HC: SEQ ID NO. 152 LC: SEQ ID NO. 153	HC: LPETG-Strep LC: G_5SLPETG-Strep	PBS	4.7
R11 (mAb062)	IgG	HC: SEQ ID NO. 154 LC: SEQ ID NO. 155	HC: LPETG-Strep LC: G_5SLPETG-Strep	PBS	6.6
R12 (mAb067)	IgG	HC: SEQ ID NO. 156 LC: SEQ ID NO. 157	HC: LPETG-Strep LC: G_5SLPETG-Strep	PBS	5.7
Trastuzumab ("Tras" mAb042)	IgG	HC: SEQ ID NO. 158 LC: SEQ ID NO. 159	HC: LPETG-Strep LC: G_5SLPETG-Strep	PBS	2.7
Ac10	IgG	HC: SEQ ID NO. 160	HC: LPETG-Strep	PBS	7.9

(mAb046)		LC: SEQ ID NO. 161	LC: G_4SLPETG-Strep		

[00165] Ms961 corresponds to an anti-ROR1 antibody with a heavy chain according to SEQ ID NO. 1 and light chain according to SEQ ID NO. 3 of WO 2014/031174. 2A2 refers to an anti-ROR1 antibody as described in WO 2010/124188, while hu2A2 refers to a humanized 2A2 as described in unpublished PCT/EP2016/076244. R11 and R12 are anti-ROR1 antibodies described in WO 2012/075158. Isotype control antibodies trastuzumab and Ac10 target HER-2 and CD30, respectively. The heavy and light chain variable region sequences of monoclonal antibody brentuximab (clone cAc10) specific for the human CD30 target were obtained from patent US2008213289A1, those of the human HER-2 specific trastuzumab antibody contained in the commercial antibody Herceptin (trastuzumab), or the ADC Kadcyla® derived thereof, were derived from the online IMGT database (VH: http://www.imgt.org/3Dstructure-DB/cgi/details.cgi?pdbcode=7637&Part=Chain&Chain=7637H & VL: http://www.imgt.org/3Dstructure-DB/cgi/details.cgi?pdbcode=7637&Part=Chain&Chain=7637L.

Example 7. mAb ROR1 and ROR2-binding - characterization by ELISA

[00166] Each well of a 96-well plate was coated with 100 µL of 2 µg/mL strep-tagged human ROR1 (from Example 5) in 0.1 M bicarbonate coating buffer (pH 9.6), and incubated for 12h at 4°C. A second 96-well plate was likewise prepared with twin-strep tagged human ROR2 (from Example 5).

[00167] After blocking with 150 µL of 3% (w/v) bovine serum albumin (BSA)/TBS for 1h at 37°C, the following antibodies were added to a well within each plate at a concentration of 0.5 µg/mL, and serially diluted (dilution factor 4) with 1% (w/v) BSA/TBS, before incubation for 1h at 37°C: ERR1-301 (mAb027), XBR1-402 (mAb031), ERR1-306 (mAb033), ERR1-324 (mAb034), ERR1-403 (mAb035) and ERR1-Top43 (mAb036). HRP-conjugated $F(ab')_2$ anti-human FC-gamma (Jackson Immunoresearch, 109-036-008) was then added at a 1:20'000 dilution, 100 µl per well, and incubated for 1h at 37°C prior to detection using an Spark 10M plate reader (Tecan). As shown in Figure 10, the anti-human ROR1 antibodies bind human ROR1 (panel A) and are not cross-reactive with human ROR2 (panel B).

Example 8. Humanization of anti-hROR1-specific antibody XBR1-402

[00168] Humanized variable region sequences (seven hu4-2 VH variants and 4 hu4-2 VL variants) were designed by Fusion Antibodies (Belfast, Ireland). Briefly, frameworks in rabbit variable regions were exchanged with human framework regions (following an in-silico assisted CDR-grafting approach based on proprietary algorithms) to form 28 possible heavy chain/light chain pairs.

[00169] Expression of antibodies representing all 28 possible heavy chain/light chain pairs was achieved by transiently transfecting pCB14-based expression constructs into HEK-293T cells and harvesting cell supernatants.

[00170] For transient antibody expression, cells were transfected in 24-well-plates using Avanti Transfection Reagent I (Avanti Polar Lipids, Alabaster, USA). Per well, 0.5µg of total DNA was transfected, and fresh growth medium was added the next day and conditioned for 4 days. Supernatants were sterile-filtered and stored at -20°C until analysis.

[00171] Affinity screening was then performed to select the best binders. Affinities were determined using a Biacore T200 instrument (GE Healthcare, Buckinghamshire, UK) and data was evaluated using Biacore Evaluation T200 V2.0 software. To capture mAbs, goat α-human Fc-gamma-specific IgG (Jackson ImmunoResearch, # 109-005-098) was covalently immobilized on a CM5 chip (GE Healthcare, # BR-1005-30).

[00172] Briefly, for capturing mAbs in HEK293T supernatants, the undiluted supernatants were captured with a flow of 30µl/min for 120s. ROR1-strep was diluted in running buffer (HBS-EP+ pH 7.4 (10 mM HEPES, 150 mM NaCl, 3 mM EDTA, 0.05 % Tween 20) to 20nM. Association was measured at a flow of 30µl/min for 120s, and dissociation was followed for 200s at a flow of 30µl/min. Capture levels ranged from 31.8 RU to 59.4 RU.

[00173] Selected antibodies were expressed and purified as per Example 6, subject to the conditions of Table 3 below.

Table 3. Protocols and concentrations of humanized mAbs used in the Examples

Antibody (ref.)	Format	Antibody SEQ ID HC/LC	C-Terminal Tags (HC: Heavy Chain, LC: Light Chain)	Buffer	Final conc. (µg/mL)	KD (nM)
HuXBR1-402(3)	IgG	HC: SEQ ID NO. 130	HC: LPETG-TwinStrep	PBS	0.49	3.16

(mAb288)		LC: SEQ ID NO. 136	LC: G_5SLPETG-TwinStrep			
HuXBR1-402(8) (mAb289)	IgG	HC: SEQ ID NO. 131 LC: SEQ ID NO. 137	HC: LPETG-TwinStrep LC: G_5SLPETG-TwinStrep	PBS	0.48	2.14
HuXBR1-402(15) (mAb290)	IgG	HC: SEQ ID NO. 132 LC: SEQ ID NO. 138	HC: LPETG-TwinStrep LC: G_5SLPETG-TwinStrep	PBS	0.45	3.55
HuXBR1-402(17) (mAb291)	IgG	HC: SEQ ID NO. 133 LC: SEQ ID NO. 139	HC: LPETG-TwinStrep LC: G_5SLPETG-TwinStrep	PBS	0.63	3.34
HuXBR1-402(19) (mAb295)	IgG	HC: SEQ ID NO. 134 LC: SEQ ID NO. 140	HC: LPETG-TwinStrep LC: G_5SLPETG-TwinStrep	PBS	0.50	2.98
HuXBR1-402(26) (mAb296)	IgG	HC: SEQ ID NO. 135 LC: SEQ ID NO. 141	HC: LPETG-TwinStrep LC: G_5SLPETG-TwinStrep	PBS	0.49	3.13

Example 9. FACS staining of cells for hROR1 expression

[00174] $5x10^5$ of each cell type were added per well to 96-well plates. Plates were centrifuged (3 min, 1300 rpm) with re-suspension in buffer (PBS supplemented with 2% (v/v) of FCS). 2A2 (mAb066) was added to each well to reach a concentration of 2 µg/mL. Plates were then incubated on ice for 30 min and washed with 200 µL of buffer prior to resuspension in 200 µL of buffer supplemented with anti-human IgG antibody (Fc gamma-specific) PE (eBioscience 12-4998-82) at a 1:250 dilution. Following 30 min incubation on ice and one washing, cells were analyzed using a FACSCalibur instrument (BD Biosciences) and data was analyzed using FlowJo analytical software (Tree Star, Ashland, OR).

[00175] Figure 7 shows the FACS analysis data of ROR1-positive human ALL cell lines 697 and Kasumi-2, human triple-negative breast cancer cell lines MDA-MB-231, MDA-MB-468 and HS-578T, and ROR1-negative human breast cancer cell line T47D as a negative control.

Example 10. Generation of site-specifically conjugated ADCs using SMAC-technology

[00176] *Sortase A enzyme.* Recombinant and affinity purified Sortase A enzyme from *Staphylococcus aureus* was produced in *E. coli* as disclosed in WO2014140317A1.

[00177] *Generation of glycine-modified toxins.* In order to generate SMAC-technology™ conjugated ADCs with pentaglycine-modified PNU-159682 derivative Gly_5-EDA-PNU (Figure 11 B) was manufactured as disclosed in WO2016102697. The identity and the purity of the pentaglycine-modified PNU toxin was confirmed by mass-spectrometry and HPLC. The Gly_5-modified toxin exhibited > 95% purity, as determined by the single peak in the HPLC chromatogram.

[00178] *Sortase-mediated antibody conjugation.* The above-mentioned toxin was conjugated to anti-ROR1 antibodies as per Table 3 by incubating LPETG-tagged mAbs [10μM] with glycine modified toxin [200μM] and 3 μM Sortase A in the listed conjugation buffer for 3.5h at 25°C. The reaction was stopped by passing it through an rProtein A GraviTrap column (BioRad). Bound conjugate was eluted with 5 column volumes of elution buffer (0.1 M glycine pH 2.5, 50 nM NaCl), with 1 column volume fractions collected into tubes containing 25% v/v 1M HEPES pH 8 to neutralize the acid. Protein containing fractions were pooled and formulated in the formulation buffer of Table 7 using a ZebaSpin desalting column.

[00179] *ADC analytics.* DAR was assessed by Reverse Phase Chromatography performed on a Polymer Labs PLRP 2.1mm x 5cm, 5μm column run at 1mL/min/80°C with a 25 minute linear gradient between 0.05 to 0.1% TFA/H_2O and 0.04 to 0.1% TFA/CH_3CN. Samples were first reduced by incubation with DTT at pH 8.0 at 37°C for 15 minutes. The DAR determined by Reverse Phase Chromatography is summarized in Table 4 below.

Table 4: Manufacturing conditions and analytical summary of ADCs manufactured in this study. DAR, drug-to-antibody ratio. ND, not determined.

ADC (ref.)	mAb (ref.)	Toxin	Conjugation Buffer	Formulation Buffer	DAR
XBR1-402-G5-PNU (Adc135)	XBR1-402 (mAb031)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 5mM $CaCl_2$	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	ND
ERR1-301-G5-PNU	ERR1-301 (mAb027)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$	PBS without Ca^{2+} and Mg^{2+} (Amimed-	3.7

(Adc200)				Bioconcept)	
ERR1-306-G5-PNU (Adc201)	ERR1-306 (mAb033)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	3.7
ERR1-324-G5-PNU (Adc202)	ERR1-324 (mAb034)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	3.6
ERR1-403-G5-PNU (Adc203)	ERR1-403 (mAb035)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	3.7
Top43-G5-PNU (Adc204)	ERR1-Top43 (mAb036)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	3.6
XBR1-402-G5-PNU (Adc262)	XBR1-402 (mAb186)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 5mM $CaCl_2$	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	3.7
XBR1-402-G5-PNU (Adc288)	XBR1-402 (mAb186)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	3.7
XBR1-402-G5-PNU (Adc394)	XBR1-402 (mAb202)	G5-PNU	50mM HEPES (pH 7.5), 10% (v/v) glycerol, 1mM $CaCl_2$	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	3.9
ERR1-324-G5-PNU (Adc395)	ERR1-324 (mAb188)	G5-PNU	50mM HEPES (pH 7.5), 10% (v/v) glycerol, 1mM $CaCl_2$	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	3.8
XBR1-402-G5-PNU (Adc409)	XBR1-402 (mAb202)	G5-PNU	50mM HEPES (pH 7.5), 10% (v/v) glycerol, 1mM $CaCl_2$	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	ND
2A2-G5-PNU (adc165)	2A2 (mAb066)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$	HEPES buffer saline pH 6.8	3.8
hu2A2-G5-PNU (adc287)	hu2A2 (mAb038)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	3.7
R11-G5-PNU (adc041)	R11 (mAb062)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	ND
R12-G5-	R12	G5-PNU	50mM HEPES (pH 7.5),	PBS without Ca^{2+} and	3.6

PNU (adc263)	(mAb067)		150mM NaCl, 1mM $CaCl_2$	Mg^{2+} (Amimed-Bioconcept)	
R12-G5-PNU (adc292)	R12 (mAb067)	G5-PNU	25mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$, 10% (v/v) glycerol	10 mM Succinate pH 5.0, 175 mM Sucrose, 0.02% Tween 20	3.8
R12-G5-PNU (adc327)	R12 (mAb067)	G5-PNU	25mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$, 10% (v/v) glycerol	10 mM Succinate pH 5.0, 175 mM Sucrose, 0.02% Tween 20	3.8
Ms961-G5-PNU (adc396)	Ms961 (mAb190)	G5-PNU	50mM HEPES (pH 7.5), 1mM $CaCl_2$, 10% (v/v) glycerol	10 mM Succinate pH 5.0, 175 mM Sucrose, 0.02% Tween 20	ND
Tras-G5-PNU (adc196)	Trastuzumab (mAb042)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	3.6
Tras-G5-PNU (adc286)	Trastuzumab (mAb042)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$	25 mM HEPES pH6.8, 15mM NaCl	3.7
Ac10-G5-PNU (adc159)	Ac10 (mAb046)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	3.8
HuXBR1-402(3)-G5-PNU (Adc456)	HuXBR1-402(3) (mAb288)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$, 2% (w/v) Glycerol	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	ND
HuXBR1-402(8)-G5-PNU (Adc457)	HuXBR1-402(8) (mAb289)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$, 2% (w/v) Glycerol	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	ND
HuXBR1-402(15)-G5-PNU (Adc458)	HuXBR1-402(15) (mAb290)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$, 2% (w/v) Glycerol	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	ND
HuXBR1-402(17)-G5-PNU (Adc459)	HuXBR1-402(17) (mAb291)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$, 2% (w/v) Glycerol	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	ND
HuXBR1-402(19)-G5-	HuXBR1-402(19)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM	PBS without Ca^{2+} and Mg^{2+} (Amimed-	ND

PNU (Adc460)	(mAb295)		$CaCl_2$, 2% (w/v) Glycerol	Bioconcept)	
HuXBR1-402(26)-G5-PNU (Adc461)	HuXBR1-402(26) (mAb296)	G5-PNU	50mM HEPES (pH 7.5), 150mM NaCl, 1mM $CaCl_2$, 2% (w/v) Glycerol	PBS without Ca^{2+} and Mg^{2+} (Amimed-Bioconcept)	ND

[00180] From these analyses it can be concluded that the SMAC-technology™ conjugation has proceeded at high efficiency resulting in overall average DARs in the range of ca. 3.5 to 4.0 for IgG-format anti-ROR1 antibody-toxin combinations.

Example 11. *In vitro* serum stability of ROR1-targeting ADC XBR1-402-G5-PNU

[00181] The *in vitro* serum stability of XBR1-402-G5-PNU was evaluated in an ELISA-based serum stability assay. Briefly, the ADC was diluted to a concentration of 100 µg/mL in NOD SCID mouse (kind gift from Prof. Dr. med. Alfred Zippelius, University Hospital of Basel, Switzerland) and human serum (from the SRK blood donation center, Basel, Switzerland; 50:50 mixture of male:female blood centrifuged 15 min. at 2000 g to obtain serum), and incubated at 37°C. Samples were snap-frozen in liquid nitrogen on days 0, 3, 7 and 14 and stored at -80°C until ELISA analysis. For mouse serum, dilution series of ADC serum samples (dilution factor 3.5, from 5 to 0.0008 µg/ml) were captured on ELISA plates coated with 2 µg/ml of an in-house developed mouse anti-PNU mAb (generated by immunizing mice with a human IgG-PNU conjugate and screening with a BSA-PNU conjugate) to bind ADC, or with goat anti-human Fc F(ab')2 (Jackson Immunoresearch, 109-006-098) to bind total IgG, and detected with a 1:2500 dilution of an HRP-conjugated donkey anti-human IgG (Jackson Immunoresearch, 709-035-149). For human serum, 2 µg/ml of recombinant human ROR1 (strep-tagged, Example 5) was coated on ELISA plates and a 1:2500 dilution of HRP-conjugated donkey anti-human IgG (Jackson Immunoresearch, 709-035-149) or 2 µg/ml of a mouse anti-PNU IgG (produced in-house) followed by a 1:5000 diluted HRP-conjugated goat anti-mouse Fcγ F(ab')2 (Jackson Immunoresearch, 115-036-071) was used for detection of total IgG and ADC, respectively. Serum concentrations of ADC and total IgGs were calculated from half maximal values of the sample titrations by comparison with a sample of the same ADC of known concentration. As shown in Figure 19, XBR1-402-G5-PNU remains essentially stable in both sera.

Example 12. *In vitro* cytotoxicity assays of anti-ROR1 antibody-based ADCs on wild type EMT-6 and ROR1-overexpressing EMT-6 breast cancer cells

[00182] Cytotoxicity of anti-ROR1 ADC XBR1-402-G5-PNU (adc262) was investigated using wild type (WT) EMT-6 and EMT-6 cells engineered to overexpress human ROR1 (from Example 2). Tras-G5-PNU (adc286) was included as isotype control.

[00183] For this, 1×10^3 WT EMT-6 and hROR1 overexpressing EMT-6 cells per well were plated on 96-well plates (excluding edge wells, which contained water) in 75 µL DMEM supplemented with 10% by vol. FCS, 100 IU/ml Pen-Strep-Fungizone and 2 mM L-Glutamine and were grown at 37°C in a humidified incubator at 7.5% CO_2 atmosphere. After 1-day incubation, each ADC was added to respective wells in an amount of 25µL of 3.5-fold serial dilutions in growth medium (resulting in final ADC concentrations from 20 µg/mL to 0.88 ng/ml). After 4 additional days, plates were removed from the incubator and equilibrated to room temperature. After approximately 30 min, 50 µL was removed from each well, and then 50 µL of CellTiter-Glo® 2.0 Luminescent Solution (Promega, G9243) was added to each well. After shaking the plates at 450 rpm for 5 min followed by 10 min incubation without shaking, luminescence was measured on a Tecan Spark 10M plate reader with an integration time of 250 ms per well. Curves of luminescence versus ADC concentration (ng/mL) were fitted with Graphpad Prism Software. The IC50 values, determined using the built-in "log(inhibitor) vs. response -- Variable slope (four parameters)" IC_{50} determination function of Prism Software, are reported in Table 5.

Table 5: *In vitro* cell killing of EMT-6 cells (WT and engineered clone 14) by anti-ROR1 or isotype control ADCs (IC_{50}, ng/mL)

ADC	WT EMT-6	hROR1-overexpressing EMT-6
XBR1-402-G5-PNU (adc262)	3'359	15
Tras-G5-PNU (adc286)	4'713	4'293

[00184] Figure 16 shows the dose-repose curves of the *in vitro* cell killing assays on WT and hROR1-overexpressing EMT6 cells with the ADCs of Table 5. As per the above Table and Figure 16, XBR1-402-G5-PNU provides specific killing dependent on ROR1 expression status.

Example 13. *In vitro* cytotoxicity assays of novel and known anti-ROR1 antibody-based ADCs on ROR1-overexpressing EMT-6 cells

[00185] Cytotoxicity of anti-ROR1 ADC XBR1-402-G5-PNU (adc409) was investigated using human EMT-6 cells engineered to overexpress human ROR1 (from Example 2), and compared to an anti-ROR1 ADC based on antibody Ms961 (adc396). Tras-G5-PNU (adc394) was included as isotype control.

[00186] For this, 1×10^3 hROR1 overexpressing EMT-6 cells per well were plated on 96-well plates (excluding edge wells, which contained water) in 75 µL DMEM supplemented with 10% by vol. FCS, 100 IU/ml Pen-Strep-Fungizone and 2 mM L-Glutamine and were grown at 37°C in a humidified incubator at 7.5% CO_2 atmosphere. After 1-day incubation, each ADC was added to respective wells in an amount of 25µL of 3.5-fold serial dilutions in growth medium (resulting in final ADC concentrations from 20 µg/mL to 0.88 ng/ml). After 4 additional days, plates were removed from the incubator and equilibrated to room temperature. After approximately 30 min, 50 µL was removed from each well, and then 50 µL of CellTiter-Glo® 2.0 Luminescent Solution (Promega, G9243) was added to each well. After shaking the plates at 450 rpm for 5 min followed by 10 min incubation without shaking, luminescence was measured on a Tecan Spark 10M plate reader with an integration time of 250 ms per well. Curves of luminescence versus ADC concentration (ng/mL) were fitted with Graphpad Prism Software. The IC50 values, determined using the built-in "log(inhibitor) vs. response -- Variable slope (four parameters)" IC_{50} determination function of Prism Software, are reported in Table 6.

Table 6: *In vitro* cell killing of engineered EMT-6 cells by inventive and known anti-ROR1 or isotype control ADCs (IC_{50}, ng/mL)

ADC	hROR1-overexpressing EMT-6
XBR1-402-G5-PNU (adc409)	1.1
Ms961-G5-PNU (adc396)	11.5
Tras-G5-PNU (adc394)	3469

[00187] Figure 17 shows the dose-repose curves of the *in vitro* cell killing assays on hROR1-overexpressing EMT6 cells with the ADCs of Table 6. As per the above Table and

Figure 17, XBR1-402-G5-PNU provides more potent killing than a comparable ADC based on antibody Ms961.

Example 14. *In vitro* cytotoxicity assays of novel and known anti-ROR1 antibody-based ADCs on human 697 and Kasumi-2 ALL cells

[00188] Cytotoxicity of anti-ROR1 ADC XBR1-402-G5-PNU (adc262) was investigated using human cell line 697, and compared to anti-ROR1 ADCs based on known antibodies 2A2, R11 and R12 (Fig 13), or by a separate experiment using again 697 and Kasumi-2 ALL cells to 2A2 and R12.

[00189] For this, 2.5×10^3 697 or Kasumi-2 cells per well were plated on 96-well plates (excluding edge wells, which contained water) in 75 µL RPMI supplemented with 10% by vol. FCS, 100 IU/ml Pen-Strep-Fungizone and 2 mM L-Glutamine and were grown at 37°C in a humidified incubator at 7.5% CO_2 atmosphere. After 1-day incubation, each ADC was added to respective wells in an amount of 25µL of 3.5-fold serial dilutions of in growth medium (resulting in final ADC concentrations from 20µg/mL to 0.88 ng/ml). After 4 additional days, plates were removed from the incubator and equilibrated to room temperature. After approximately 30 min, 50 µL was removed from each well, and then 50 µL of CellTiter-Glo® Luminescent Solution (Promega, G7570) was added to each well. After shaking the plates at 750 rpm for 5 min followed by 20 min incubation without shaking, luminescence was measured on a Tecan Infinity F200 plate reader with an integration time of 1 second per well. Curves of luminescence versus ADC concentration (ng/mL) were fitted with Graphpad Prism Software. The IC_{50} values, determined using the built-in "log(inhibitor) vs. response -- Variable slope (four parameters)" IC_{50} determination function of Prism Software, are reported in Table 7.

Table 7: *In vitro* cell killing of 697 cells by anti-ROR1 or isotype control ADCs (IC_{50}, ng/mL)

ADC	697
2A2-G5-PNU	38.0
R11-G5-PNU (adc041)	469.9
R12-G5-PNU (adc292)	72.1
XBR1-402-G5-PNU (adc262)	17.6

[00190] Figure 13 shows the dose-repose curves of the *in vitro* cell killing assays on 697 cells with the ADCs of Table 7. As per the above Table and Figure 13, ADCs of the invention provide killing of human 697 B cell precursor leukemia cells that is superior to ADCs based on the known anti-ROR1 antibodies.

Example 15. *In vitro* cytotoxicity assays of anti-ROR1 antibody-based ADCs on breast cancer MDA-MB-468 and HS 578T cells

[00191] Cytotoxicity of anti-ROR1 ADCs 2A2-G5-PNU (adc165), XBR1-402-G5-PNU (adc135), R12-G5-PNU (adc292), ERR1-Top43-G5-PNU (adc204), and 50:50 by weight mixtures of ERR1-324-G5-PNU (adc202) and 2A2-G5-PNU (adc165), of ERR1-324-G5-PNU (adc202) and XBR1-402-G5-PNU (adc135), of ERR1-324-G5-PNU (adc202) and R12-G5-PNU (adc292), and of ERR1-324-G5-PNU (adc202) and ERR1-Top43-G5-PNU (adc204) was investigated using human cell lines: MDA-MB-468, HS 578T. Ac10-G5-PNU (adc159) was included as isotype control.

[00192] For this, the following cells per well were plated on 96-well plates (excluding edge wells, which contained water) and were grown at 37°C in a humidified incubator at 7.5% CO_2 atmosphere in growth medium (DMEM supplemented with 10% by vol. FCS, 100 IU/ml Pen-Strep-Fungizone and 2 mM L-Glutamine).

Table 8. Cell plating of Example 17

Cell type	Cells per well
MDA-MD-468	6.7×10^3
HS 578T	2.7×10^3

[00193] After 1-day incubation, each ADC was added to respective wells in an amount of 25μL of 3.5-fold serial dilutions in growth medium (resulting in final ADC concentrations from 20μg/mL to 0.88 ng/ml). After 4 additional days, plates were removed from the incubator and equilibrated to room temperature. After approximately 30 min, 50 μL was removed from each well, and then 50 μL of CellTiter-Glo® 2.0 Luminescent Solution (Promega, G9423) was added to each well. After shaking the plates at 750 rpm for 5 min followed by 20 min incubation without shaking, luminescence was measured on a Tecan Infinity F200 plate reader with an integration time of 1 second per well. Curves of luminescence versus ADC concentration (ng/mL) were fitted with Graphpad Prism

Software. The IC_{50} values, determined using the built-in "log(inhibitor) vs. response -- Variable slope (four parameters)" IC_{50} determination function of Prism Software, are reported in Table 9.

Table 9. *In vitro* cell killing of various human cancer cells by anti-ROR1 ADCs as well as an isotype control (IC_{50} values are provided in ng/mL)

ADC / Cell type	MDA-MD-468	HS 578T
hROR1 status	positive	positive
2A2-G5-PNU (adc165)	456	1'784
XBR1-402-G5-PNU (adc135)	ND	1'403
R12-G5-PNU (adc292)	349	3'498
ERR1-Top43-G5-PNU (adc204)	143	707
Ac10-G5-PNU (adc159)	3'593	8'408

[00194] Figure 12 shows the dose-repose curves of the *in vitro* cell killing assays on MDA-MB-468 and HS 578T cells with the ADCs of Table 9. As per the above Table and Figure 12, selected ADCs of the invention provides killing of certain human cancer cells that is superior to the known anti-ROR1 antibodies 2A2 and R12.

Example 16. *In vitro* cytotoxicity assays of humanized anti-ROR1 antibody-based ADCs on 697 cells

[00195] Cytotoxicity of humanized anti-ROR1 ADCs huXBR1-402-3-G5-PNU (adc456), huXBR1-402-8-G5-PNU (adc457), huXBR1-402-15-G5-PNU (adc458), huXBR1-402-17-G5-PNU (adc459), huXBR1-402-19-G5-PNU (adc460) and huXBR1-402-26-G5-PNU (adc461) was investigated using human 697 cells. Tras-G5-PNU (adc286) was included as isotype control.

[00196] For this, $5x10^4$ 697 cells per well were plated on 96-well plates (excluding edge wells, which contained water) in 75 µL RPMI supplemented with 10% by vol. FCS, 100

IU/ml Pen-Strep-Fungizone and 2 mM L-Glutamine and were grown at 37°C in a humidified incubator at 7.5% CO_2 atmosphere. After 1-day incubation, each ADC was added in duplicate to respective wells in an amount of 25µL of 3.5-fold serial dilutions in growth medium (resulting in final ADC concentrations from 20 µg/mL to 0.88 ng/ml). After 4 additional days, plates were removed from the incubator and equilibrated to room temperature. After approximately 30 min, 50 µL was removed from each well, and then 50 µL of CellTiter-Glo® 2.0 Luminescent Solution (Promega, G9243) was added to each well. After shaking the plates at 450 rpm for 5 min followed by 10 min incubation without shaking, luminescence was measured on a Tecan Spark 10M plate reader with an integration time of 250 ms per well. Curves of luminescence versus ADC concentration (ng/mL) were fitted with Graphpad Prism Software. The IC_{50} values, determined using the built-in "log(inhibitor) vs. response -- Variable slope (four parameters)" IC_{50} determination function of Prism Software, are reported in Table 10.

Table 10. *In vitro* cell killing of 697 cells by non-humanized and humanized anti-ROR1 or isotype control ADCs (IC_{50}, ng/mL)

ADC	IC_{50} values on 697 cells (ng/ml)
XBR1-402-G5-PNU (adc394)	211.6
HuXBR1-402(3)-G5-PNU (Adc456)	98.1
HuXBR1-402(8)-G5-PNU (Adc457)	164.2
HuXBR1-402(15)-G5-PNU (Adc458)	105.6
HuXBR1-402(17)-G5-PNU (Adc459)	70.6
HuXBR1-402(19)-G5-PNU (Adc460)	91.7
HuXBR1-402(26)-G5-PNU (Adc461)	93.9
Tras-G5-PNU (Adc286)	5214

[00197] Figure 25 shows the dose-repose curves of the *in vitro* cell killing assays on 697 cells with the humanized ADCs of Table 10. As per the above Table and Figure 25, the humanized ADCs are more potent compared to ADCs manufactured with the parental, non-humanized mAb.

Example 17. *In vivo* pharmacokinetic study of the anti-ROR1 XBR1-402 antibody and XBR1-402-G5-PNU ADC in CD-1 wild-type mouse strain

[00198] The following study was performed at ABPRO (Burlington, MA, USA). Female CD-1 mice (at least 6-weeks of age at study start, from Taconic Biosciences, Germantown, NY, USA), housed in groups of up to 5 animals per cage, were randomized by weight into two groups of 9 animals each. One group received, by intravenous administration, a single dose of 1 mg/kg of XBR1-402 (mAb202), while the second group received a single dose of 1 mg/kg of XBR1-402-G5-PNU (adc409). Post-dose blood samples were collected according to the protocol of Table 11 from subgroups consisting of 3 animals each. Blood sampling proceeded by lancet puncture of the submandibular vein (collecting approximately 200 µL), with the exception of the sampling at 21 days, which was by cardiac puncture (collecting approximately 600 µL). Samples from subgroups were pooled for each time point. Plasma was isolated by blood centrifugation at 1'500g for 10 min., and stored in sterile cryovials at -80°C until in-house analysis by ELISA.

Table 11. Pharmacokinetic study blood sampling protocol

Treatment group (no. of animals)	Subgroup (no. of animals)	Blood samplings post dose
1 mg/kg XBR1-402 (9)	1 (3)	1h, 7 days
	2 (3)	24h, 14 days
	3 (3)	3 days, 21 days (terminal bleed)
1 mg/kg XBR1-402-G5-PNU (9)	1 (3)	1h, 7 days
	2 (3)	24h, 14 days
	3 (3)	3 days, 21 days (terminal bleed)

[00199] Plasma was isolated from blood by centrifugation at 1500g for 10 min, and transferred to sterile cryovials for storage at -80°C until analysis by ELISA. The *in vivo* stability of mAb XBR1-402 and of ADC XBR1-402-G5-PNU was evaluated by an ELISA-based assay. Dilution series of ADC serum samples were captured on ELISA plates coated with 2 µg/ml of a mouse anti-PNU mAb (produced in-house by immunizing mice with a human IgG-PNU conjugate and screening with a BSA-PNU conjugate) to bind ADC, or with anti-human Fc F(ab')2 (Jackson Immunoresearch) to bind total IgG, and detected with a 1:2500 dilution of an HRP-conjugated anti-human IgG F(ab')2 (Jackson Immunoresearch). Serum concentrations of ADC and total IgGs were calculated from half maximal values of the sample titrations by comparison with a sample of the same ADC of known concentration.

[00200] The data in Figure 20 shows the high stability of the ADC of the invention.

Example 18. Evaluation of *in vivo* potency of ADCs in a disseminated xenograft model of human acute lymphocytic leukemia (ALL) cell line 697 in NOD-SCID mice

[00201] The following study was performed at Pipeline Biotech (Trige, Denmark). The efficacy of XBR1-402-G5-PNU (adc288) and humanized hu2A2-G5-PNU (adc287; based on unpublished PCT/EP2016/076244) was compared in a disseminated xenograft model in female NOD-SCID mice injected with hROR1 positive 697 ALL cells. An ADC based in HER2 specific anti body Trastuzumab, Tras-G5-PNU (adc286) served as a negative isotype-matched control ADC.

[00202] 9-week old mice, each weighing at least 20 g, were inoculated with 697 tumor cells ($5x10^6$ cell/animal, in 200 µL PBS) on study day 0. Each ADC, formulated in PBS, was administered (i.v.) to a group of 6 mice at 1.0 mg/kg on days 7, 14 and 21, with administration of mouse IgG (Jackson ImmunoResearch, 015-000-003), 30 mg/kg) 20 hours before each ADC administration. Any animal showing clinical signs of moderate pain, moderate distress, any degree of suffering, or any clinical signs exceeding the limits of the study specific humane endpoints, according to the European and Danish legislation on animals in experimental studies, was euthanized. Blood (90 µL in EDTA vials) was collected from the tail vein each animal on days 12 and 19. Plasma was isolated by blood centrifugation according to standard procedures. Samples from treatment groups were pooled for each time point.

[00203] Dilution series of ADC plasma samples were captured on ELISA plates coated with 2 µg/ml of a mouse anti-PNU mAb (produced in-house by immunizing mice with a human IgG-PNU conjugate and screening with a BSA-PNU conjugate) to bind ADC, or with anti-human Fc F(ab')2 (Jackson Immunoresearch, 109-006-098) to bind total IgG, and detected with a 1:2500 dilution of an HRP-conjugated anti-human IgG F(ab')2 (Jackson Immunoresearch, 709-035-149). Serum concentrations of ADC and total IgGs were calculated from half maximal values of the sample titrations by comparison with a sample of the same ADC of known concentration.

[00204] Data analysis was performed using the software PRISM. Mice treated with the inventive XBR1-402-G5-PNU ADC showed prolonged survival relative to those treated with comparable ROR1-targeting hu2A2-G5-PNU ADC, or with isotype control ADC

(Figure 15, panel A). Moreover, the concentration of XBR1-402-G5-PNU ADC remains higher in plasma than the known or isotype control ADC (Figure 15, panel B).

Example 19. Evaluation of in vivo efficacy of anti-ROR1 ADCs in orthotopic breast cancer models established with hROR1-overexpressing EMT-6 cells

[00205] ADC based on novel anti-ROR1 antibody XBR1-402-G5-PNU (adc262) was compared to R12-G5-PNU (adc327), an ADC based on known antibody R12 and isotype control Tras-G5-PNU (adc286) ADCs in the following mouse model according to the study protocol of Table 13.

Table 12. Orthotopic breast cancer models used for evaluation of ADCs

Model	Mouse Strain and Sex	Tumor Establishment
hROR1-overexpressing EMT-6, clone 14 (from Example 2)	Syngeneic female BALB/c mice, implantation at 4-8 weeks of age	Injection of $1x10^6$ cells into the mammary fat pads. Tumor volume at randomization from 100-150 mm^3

Table 13. Protocols used for evaluation of anti-ROR1 XBR1-402-G5-PNU ADC in orthotopic breast cancer models with orthotopically implanted EMT6 cells overexpressing ROR1 (clone (cl 14))

Group	No. of Mice	Total Dose	Dosing Days post implantation	Route
1 (Tras-G5-PNU, adc286)	6	1 mg/kg/day of Tras-G5-PNU (in PBS)	14, 21, 28	Intravenous
2 (XBR1-402-G5-PNU, adc409)	6	1 mg/kg/day of XBR1-402-G5-PNU (in PBS)	14, 21, 28	Intravenous
3 (R12-G5-PNU, adc327)	6	1 mg/kg/day of R12-G5-PNU (in PBS)	14, 21, 28	Intravenous

[00206] Figure 18 shows the tumor volume evolving over the study in each of the 6 individual mice. Orthotopic breast cancer models established with breast cancer cells having high hROR1 expression respond significantly to treatment with the ADC of the invention, as opposed to the non-response of the ROR1-negative WT EMT-6 model. The remarkable

response of the ADC of the invention moreover demonstrates a significant improvement over a comparable ADC based on the known R12 ROR1-targeting antibody.

Example 20. Analysis of hROR1 expression in human patient derived tumor lysates by Western Blot

[00207] Tumor lysates of human patient-derived xenograft (PDX) models (Charles River, Freiburg, Germany) and lysate of a highly ROR1-positive immortalized cell line (Kasumi-2) as a control, as well as lysate from immortalized A549 cancer cells, were probed for hROR1 protein expression by Western blot. For this, lysates were denatured by mixing with 5x SDS-PAGE loading buffer (250 mM Tris-HCl pH 6.8, 10% SDS, 30% Glycerol, 5% μ-mercaptoethanol) and heating to 99°C for 5 min. After separation by SDS-PAGE, proteins were transferred to PVDF membranes using an eblot transfer System (Genscript). Membranes were then incubated at 4°C overnight with commercially available polyclonal rabbit anti-ROR1 antibody 4102 (Cell Signaling Technology, Danvers, USA) diluted 1:200 in TBST (20 mM Tris-HCl, 150 mM NaCl, pH 7.6, 0.1% Tween-20) containing 10% horse serum (Amimed, Bioconcept, Switzerland). After two washes with TBST, membranes were incubated with HRP-coupled anti-rabbit secondary antibodies (WesternSure HRP goat-anti-rabbit IgG, LiCor, Lincoln, USA) for 1 hour at room temperature. Signals were revealed by incubating membranes in luminescent substrate (SuperSignal West Femto (34094, Thermo Fisher) and imaging using a cDigit Western blot reader (LiCor, Lincoln, USA). Detection of the housekeeping gene GAPDH served as a loading control.

Table 14. Tumor lysate hROR1 status of Example 22

Tumor Designation	Tumor Origin	hROR1 status
PXF 1118	lung, peuramesothelioma	+++
RXF 486	kidney tumor, hypernephroma	+
PXF 541	lung, peuramesothelioma	+++
SXFS 1407	soft tissue sarcoma, neurofibrosarcoma	++
CX 533	colon cancer, adenocarcinoma	+
Kasumi-2	B cell precursor leukemia	+++
A549	lung carcinoma	+

[00208] Figure 21 shows the Western Blot analysis of human tumor lysates, as well as lysates from immortalized cancer cells.

Example 21. Analysis of *in vivo* efficacy of ADC XBR1-402-G5-PNU in patient-derived tumor xenograft models

[00209] The following study was performed at Charles River (at Oncotest GmbH, Freiburg, Germany).

Table 15. Patient-derived tumor xenograft models used for evaluation of anti-ROR1 XBR1-402-G5-PNU ADC

Model	Mouse Strain and Sex	Tumor Establishment
PXF 1118 (lung, peuramesothelioma), unilateral	Female NMRI nude mice, implantation at 5-7 weeks of age	Tumor implantation unilateral or bilateral, and subcutaneous. Tumor volume at randomization from 50-250 mm^3
RXF 486 (kidney tumor, hypernephroma)		
PXF 541 (lung, peuramesothelioma)		
SXFS 1407 (soft tissue sarcoma, neurofibrosarcoma)		
CX 533 (colon cancer, adenocarcinoma)		

[00210] The XBR1-402-G5-PNU (adc409) ADC, previously confirmed to be endotoxin-free, was investigated in each model according to the following study protocol:

Table 16. Protocols used for evaluation of anti-ROR1 XBR1-402-G5-PNU ADC in patient-derived tumor xenograft models

Group	No. of Mice	Total Daily Dose	Dosing Days	Route
1 (vehicle control)	3	10 ml/kg/day of PBS	0, 8, 15	Intravenous
2 (XBR1-402-G5-PNU, adc409)	3	1 mg/kg/day of XBR1-402-G5-	0, 8, 15	Intravenous

		PNU (in PBS)		

[00211] Mice were subcutaneously implanted with PDX material (either one-sided (PXF 111, RXF 486, CX 533) or bilaterally (SXFS 1407, PXF 541). Mice were randomized when tumors reached a size of 100 cm^3 and were treated with ADC at 1mg/kg or vehicle for a total of 3 times. Tumor volumes were determined by caliper measurement and body weight was recorded twice weekly. Mice were euthanized on reaching a tumor burden of 2000 mm^3 (unilateral) or 1700 mm^3 (bilateral), or on significant body weight loss (overall more than 30%, or more than 20% in two days).

[00212] Figure 22 shows the tumor volume evolution over the study. Tumor xenografts established with patient-derived tumor material having high hROR1 expression respond significantly to treatment with the ADC of the invention.

Example 22. *In vitro* activity of XBR1-402 CAR-T

[00213] CAR-T cells based on XBR1-402 were engineered using methods previously described for ROR1-targeting mAbs R11 and R12 (Hudecek, M., Lupo-Stanghellini, M. T., Kosasih, P. L., Sommermeyer, D., Jensen, M. C., Rader, C., and Riddell, S. R. (2013) Receptor affinity and extracellular domain modifications affect tumor recognition by ROR1-specific chimeric antigen receptor T cells. *Clin. Cancer Res.* 19, 3153-3164). *Ex vivo* expanded primary human $CD8^+$ $CD62L^+$ T cells were lentivirally transduced with XBR1-402 or R12-derived CARs containing CD3ζ and 4-1BB signaling domains and a short spacer. Transduced T cells were purified via tEGFR by FACS and their phenotype was assesed the day before functional assays. CD8+ purity varied between 97% and 99%, tEGFR expression varied between 95% and 99%. Following 72 h co-culture with ROR1-positive or ROR1-negative human breast cancer cells, CFSE-stained CD8+ CD62L+ cells were analyzed by flow cytometry, revealing target-dependent proliferation of XBR1-402 and R12 CAR-T (Figure 26; upper left panel). IFNγ and IL2 concentrations in the supernatant taken after 24 h of co-culture were measured by ELISA (Figure 26; upper right panel). Selective cytotoxicity was measured with a luciferase-based cytotoxity assay following 11 h of co-culture with ROR1-positive and ROR1-negative cells (Figure 26; lower panel).

[00214] The same experiments were repeated to compare XBR1-402 CAR-T with a short spacer to XBR1-402 CAR-T with a long spacer. Following 72 h co-culture with ROR1-positive or ROR1-negative human breast cancer cells, CFSE-stained CD8+ CD62L+ cells

were analyzed by flow cytometry, revealing stronger proliferation of the XBR1-402 CAR-T with the short spacer (Figure 27; upper panel). Selective cytotoxicity with the luciferase-based cytotoxity assay following 11 h of co-culture with ROR1-positive and ROR1-negative cells revealed selective cytotoxicity for both XBR1-402 CAR-Ts with short and long spacer (Figure 27; lower panel).

Example 23. Specificity analysis of XBR1-402

[00215] Figure 28 provides an overview of the Retrogenix Cell Microarray Platform. *Primary screen:* Purified chimeric rabbit/human IgG1 XBR1-402 and purified chimeric rabbit/human IgG1 XBR2-401 were pooled to a concentration of 2 µg/mL each. The pool was screened for binding against fixed HEK293 cells/slides expressing 4,336 human plasma membrane proteins individually (13 slide sets; n=2 slides per slide set). All transfection efficiencies exceeded the minimum threshold. An AlexaFluor647 anti-human IgG Fc detection antibody was used. Primary hits (duplicate spots) were identified by analyzing fluorescence (AlexaFluor647 and ZsGreen1) on ImageQuant. Vectors encoding all hits were sequenced to confirm their correct identities. Confirmation screen: Vectors encoding all hits, plus control vectors, were spotted in duplicate on new slides, and used to reverse transfect human HEK293 cells as before. All transfection efficiencies exceeded the minimum threshold. Identical fixed slides were treated with each of the two test antibodies (XBR1-402 and XBR2-401) individually, plus positive and negative controls (n=2 slides per treatment). Slides were analyzed as before (Figure 29).

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[00216] Although the foregoing invention has been described in some detail by way of illustration and example for purposes of clarity of understanding, it will be readily apparent to one of ordinary skill in the art in light of the teachings of this invention that certain changes and modifications may be made thereto without departing from the spirit or scope of the appended claims.

[00217] All publications, databases, GenBank sequences, patents, and patent applications cited in this specification are herein incorporated by reference as if each was specifically and individually indicated to be incorporated by reference.