

ARGININE DEIMINASE WITH REDUCED CROSS-REACTIVITY TOWARD ADI – PEG 20 ANTIBODIES FOR CANCER TREATMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

5 This application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Application No. 61/790,833, filed March 15, 2013, which is hereby incorporated by reference in its entirety.

STATEMENT REGARDING SEQUENCE LISTING

10 The Sequence Listing associated with this application is provided in text format in lieu of a paper copy, and is hereby incorporated by reference into the specification. The name of the text file containing the Sequence Listing is POLA_003_01WO_ST25.txt. The text file is about 117 KB, was created on March 11, 2014, and is being submitted electronically via EFS-Web.

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BACKGROUND

Technical Field

 The present invention relates generally to arginine deiminase (ADI) proteins, including ADI proteins having reduced cross-reactivity with ADI-PEG 20
20 antibodies. Such ADI proteins are useful for treating arginine-dependent or related diseases such as cancer.

Description of the Related Art

 Amino acid deprivation therapy can be an effective treatment of some
25 forms of cancer. To date, there is one known clinical example relevant to this approach which utilizes asparaginase to lower circulating levels of asparagine and inhibit protein synthesis. This treatment is particularly effective for acute lymphoblastic leukemia (Avramis 2005, Viera Pinheiro 2004). Acute lymphoblastic leukemia cells require the amino acid asparagine for growth and proliferation. In
30 contrast, most normal human cells are capable of synthesizing asparagine and are unaffected by asparagine depletion. Therefore, decreasing serum asparagine with asparaginase can selectively kill the cancer cells without harming the normal cells, tissues, and host. An *E. coli* derived form of asparaginase has been approved for

human use. However, asparaginase is found only in microbes; which makes it highly immunogenic in humans and also has a short serum half-life following injection (Avramis 2005). To make asparaginase a more effective drug, these drawbacks were minimized by formulating the *E. coli* derived asparaginase with polyethylene glycol (PEG) to reduce the immunogenicity of this enzyme and the associated allergic reactions. In addition, PEG greatly prolongs the circulating half-life of asparaginase, which reduces both the frequency of treatment and the total cost of the therapy. PEG formulated asparaginase is approved for use and is marketed under the trade name Oncaspar® (Oncaspar® 2011, Avramis 2005, Viera Pinheiro 2004, Fu 2007, Zeidan 2008).

Arginine is another non-essential amino acid for humans and mice (for review see Rogers 1994). In humans, arginine can be synthesized from citrulline in two steps via the Krebs (urea) cycle enzymes argininosuccinate synthetase (ASS, L-citrulline:L-aspartate ligase [AMP-forming], EC 6.3.4.5) and argininosuccinate lyase (ASL, L-argininosuccinate arginine-lyase, EC 4.3.2.) (Haines 2011, Wu 2009, Morris 2006, Husson 2003, Tapiero 2002, Rogers 1994). ASS catalyzes the conversion of citrulline and aspartic acid to argininosuccinate, which is then converted to arginine and fumaric acid by ASL. An arginine deficient diet in humans does not evoke hyperammonemia, orotic aciduria, nor alter the rate of whole body nitric oxide (NO) synthesis in adult humans (Tapiero 2002, Castillo 1995, Rogers 1994, Carey 1987, Barbul 1986, Snyderman 1959, Rose 1949). Although preterm infants appear to require arginine (Wu 2004), arginine levels do not correlate with age among infants, children and young adults (Lücke 2007). In 1992, Takaku and Sugimura separately reported that human melanomas and hepatocellular carcinoma (HCC) cell lines appear to require arginine for growth. Other studies showed that pegylated ADI was effective for the treatment of melanomas and hepatomas with few adverse effects.

ADI-PEG 20 treatment requires multiple doses over a period of time. After a number of treatments, anti-ADI-PEG 20 antibodies can develop that may limit its continued effectiveness. Therefore, there is a need in the art for ADI that has reduced cross-reactivity to anti-ADI-PEG20 antibodies for use in treatment in order to improve and extend the efficacy of arginine depletion therapy. The present invention provides this and other advantages for the treatment of cancers.

References: Avramis VI, Panosyan EH. 2005. Clin Pharmacokinet 44:367-393; Barbul A. 1986. J Parenteral Enteral Nutr 10:227-238; Carey GP, *et al.*

1987. J Nutr 117:1734-1739; Castillo L, *et al.* 1995. Am J Physiol 268 (Endocrinol Metab 31):E360-367; Fu CH, Sakamoto KM. 2007. Expert Opin Pharmacother 8:1977-1984; Haines RJ, *et al.* 2011. Int J Biochem Mol Biol 2:8-23; Husson A, *et al.* 2003. Eur J Biochem 270:1887-1899; Lücke T, *et al.* 2007. Clin Chem Lab Med 5 45:1525-1530; Morris SM Jr. 2006. Am J Clin Nutr 83(Suppl):598S-512S; Rogers QR. 1994. In Proceedings from a Symposium Honoring Willard J. Visek - from Ammonia to Cancer and Gene Expression. Special Publication 86 - April, 1994, Agriculture Experiment Station, University of Illinois, 211 Mumford Hall, Urbana, IL 61801, pp. 9-21; Tapiero H, *et al.* 2002. Biomed Pharmacother 56:439- 445, 2002; 10 Viera Pinheiro JP, Boos J. 2004. Br J Haematol 125: 117-127; Wu G, *et al.* 2009. Amino Acids 37:153-168; Wu G, *et al.* 2004. J Nutr Biochem 15:442-451; Zeidan A, *et al.* 2008. Expert Opin Biol Ther 9:111-119).

BRIEF SUMMARY

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In one aspect of the present disclosure, there is provided a therapeutic composition comprising an isolated arginine deiminase (ADI) and a pharmaceutically-acceptable carrier, wherein the isolated ADI comprises the amino acid sequence set forth in any one of SEQ ID Nis: 2, 6, 8, or 14, or a sequence at 20 least 95% sequence identity to any one of SEQ ID NOs: 2, 6, 8, or 14 having arginine deiminase activity.

In another aspect of the present disclosure, there is provided a use of a therapeutic composition as disclosed herein in the manufacture of a medicament for 25 treating, ameliorating the symptoms of, or inhibiting the progression of a cancer.

In a further aspect of the present disclosure, there is provided a use of a therapeutic composition comprising ADI-PEG 20 and a therapeutic composition as disclosed

herein in the manufacture of a medicament for ameliorating the symptoms of, or inhibiting the progression of a cancer in a patient in need thereof, wherein said therapeutic composition is to be administered after said composition comprising ADI-PEG 20 after a period of time.

5 In another aspect of the present disclosure, there is provided a therapeutic composition as disclosed herein for use in treating, ameliorating the symptoms of, or inhibiting the progression of a cancer.

 In a further of the present disclosure, there is provided a composition comprising ADI-PEG 20 and a therapeutic composition as disclosed herein for use in
10 treating, ameliorating the symptoms of, or inhibiting the progression of a cancer.

 The present disclosure provides an isolated arginine deiminase, wherein the isolated arginine deiminase has reduced cross-reactivity with patient anti-ADI-PEG 20 antibodies. Also included are therapeutic or pharmaceutical compositions comprising an isolated arginine deiminase or a fragment thereof having
15 ADI activity, and a pharmaceutically-acceptable carrier. In certain embodiments, the composition is sterile and/or substantially free of pyrogens such as endotoxins. In one embodiment, the isolated arginine deiminase having reduced cross-reactivity with patient anti-ADI-PEG 20 antibodies is not from *M. hominis*. In another
20 embodiment, the isolated arginine deiminase having reduced cross-reactivity with patient anti-ADI-PEG 20 antibodies is from an organism listed in Table 1. In certain
embodiments the isolated arginine deiminase having reduced cross-reactivity with patient anti-ADI-PEG 20 antibodies has one or more properties comparable to or better than those of ADI-PEG 20. In this regard, the one or more properties includes, but is not limited to, Kcat, Km, pH optimum, stability, *in vivo* proteolytic stability, or no
25 requirement for ions or cofactors that are not already present in blood, or any combination thereof. In one embodiment, the isolated arginine deiminase having reduced cross-reactivity with patient anti-ADI-PEG 20 antibodies, has at least 20 surface residue changes as compared to *M. hominis* arginine deiminase. In another
30 embodiment, the isolated arginine deiminase having reduced cross-reactivity with patient anti-ADI-PEG 20 antibodies has between 20 and 135 surface residue

changes, between 40 and 100 surface residue changes, between 30 and 60 surface residue changes, between 80 and 100 surface residues changes, or between 100 and 120 surface residues changes, as compared to *M. hominis* arginine deiminase.

In another embodiment, the isolated arginine deiminase having
5 reduced cross-reactivity with patient anti-ADI-PEG 20 antibodies is from *M. arginini*,
M. arthritidis, *M. phocicerebrale*, *M. gateae*, *M. phocidae*, *M. columbinum*, *M. iowae*,
M. crocodyli, *M. alligatoris*, *H. orenii*, or *M. bovis*. Illustrative arginine deiminase
having reduced cross-reactivity with patient anti-ADI-PEG 20 antibodies comprise
the amino acid sequence set forth in any one of SEQ ID NOs:2-32.

10 In another embodiment, the isolated arginine deiminase having
reduced cross-reactivity with patient anti-ADI-PEG 20 antibodies has been modified
to remove at least one pegylation site. In another embodiment of the arginine
deiminase having reduced cross-reactivity with patient anti-ADI-PEG 20 antibodies,
at least one lysine residue has been modified by an amino acid substitution. In this
15 regard, in certain embodiments, at least 5 lysine residues, at least 10 lysine
residues, or at least 20 lysine residues have been modified by an amino acid
substitution.

In another embodiment, the arginine deiminase having reduced cross-
reactivity with patient anti-ADI-PEG 20 antibodies is covalently bonded via a linker to
20 a PEG molecule. In this regard, the arginine deiminase having reduced cross-
reactivity with patient anti-ADI-PEG 20 antibodies may be covalently bonded to one
or more PEG molecule, such as to about 1 to about 10 or about 2 to about 8 PEG
molecules. The PEG molecules may be straight chain or branch chain PEG
molecules and may have a total weight average molecular weight of from about
25 1,000 to about 40,000, or a total weight average molecular weight of from about
10,000 to about 30,000. In those embodiments where the PEG is covalently bonded
to the ADI of the present disclosure, via a linker, the linker may comprise a succinyl
group, an amide group, an imide group, a carbamate group, an ester group, an
epoxy group, a carboxyl group, a hydroxyl group, a carbohydrate, a tyrosine group, a
30 cysteine group, a histidine group, a methylene group, or any combinations thereof.
In one embodiment, the source of the succinyl group is succinimidyl succinate.

The present disclosure further provides a polynucleotide encoding an
isolated arginine deiminase described herein, vectors comprising the polynucleotide,
and isolated host cells comprising the vectors.

The present disclosure further provides a composition comprising the isolated arginine deiminase having reduced cross-reactivity with patient anti-ADI-PEG 20 antibodies as described herein and a physiologically acceptable carrier. In certain embodiments, the compositions further comprise a chemotherapeutic agent.

5 Exemplary chemotherapeutic agents include, but are not limited to, docetaxel, carboplatin, cyclophosphamide, gemcitabine, cisplatin, sorafenib, sunitinib, and everolimus.

The present disclosure further provides a method of treating, ameliorating the symptoms of, or inhibiting the progression of a cancer comprising
10 administering to a patient in need thereof a therapeutically effective amount of a composition comprising the isolated arginine deiminase having reduced cross-reactivity with patient anti-ADI-PEG 20 antibodies as described herein and a physiologically acceptable carrier, thereby treating, ameliorating the symptoms of, or inhibiting the progression of the cancer. In certain embodiments, the patient in need
15 thereof has been determined to have anti-ADI-PEG 20 antibodies. In another embodiment, the cancer is selected from the group consisting of hepatocellular carcinoma, melanoma including metastatic melanoma, pancreatic cancer, prostate cancer, small cell lung cancer, mesothelioma, lymphocytic leukemia, chronic myelogenous leukemia, lymphoma, hepatoma, sarcoma, leukemia, acute myeloid
20 leukemia, relapsed acute myeloid leukemia, breast cancer, ovarian cancer, colorectal cancer, gastric cancer, glioma, glioblastoma multiforme, non-small cell lung cancer (NSCLC), kidney cancer, bladder cancer, uterine cancer, esophageal cancer, brain cancer, head and neck cancers, cervical cancer, testicular cancer, and stomach cancer.

25 The present disclosure further provides a method of treating, ameliorating the symptoms of, or inhibiting the progression of a cancer comprising administering to a patient in need thereof a therapeutically effective amount of a composition comprising ADI-PEG 20, and after a period of time, administering to the patient a composition comprising the isolated arginine deiminase having reduced
30 cross-reactivity with patient anti-ADI-PEG 20 antibodies as described herein and a physiologically acceptable carrier, thereby treating, ameliorating the symptoms of, or inhibiting the progression of the cancer. In this regard, the period of time may be determined, for example, by detecting a predetermined level of anti-ADI-PEG 20 antibodies in the patient and/or measuring or otherwise observing ADI activity in the

patient, wherein the composition comprising the isolated arginine deiminase having reduced cross-reactivity with patient anti-ADI-PEG 20 antibodies is administered following detection of the predetermined level of said anti-ADI-PEG 20 antibodies and/or measurement or observation of a predetermined level of ADI activity in the

5 patient.

Also included are isolated arginine deiminase proteins described herein for use in the preparation or manufacture of a medicament for treating, ameliorating the symptoms of, or inhibiting the progression of a cancer.

10 DETAILED DESCRIPTION

Embodiments of the present invention relate to selected ADI enzymes, which in some embodiments are engineered to have a small number of surface lysine residues, and conjugated with PEG through a stable linker. The selected ADI enzymes are chosen from a large number of ADI enzymes, from different organisms, based on their beneficial properties. These properties include the ability of the enzyme to establish and maintain low arginine concentrations in human blood through ADI conversion of arginine to citrulline and ammonia. In addition, the selected ADI molecules have reduced cross-reactivity toward anti-ADI-PEG 20 antibodies as compared to ADI-PEG 20, such antibodies possibly resulting from a patient's previous treatment with ADI-PEG 20.

In certain embodiments, the enzymes in this invention are pegylated to provide protection against renal clearance and proteolysis, as well as reduced immunogenicity or antigenicity. To increase the effectiveness of the pegylation, modifications to the enzymes may be engineered to reduce the number of surface lysine residues and therefore limit the number of available PEG attachment sites. This provides more complete and uniform pegylation at the remaining lysine attachment residues.

The PEG linker selected to attach methoxy-PEG to ADI is chosen to provide a chemically stable linkage. It is expected this will increase the molecule's bioactive lifetime. A chemically stable linker will also eliminate hydrolysis and reduce an immune response that might occur to a de-pegylated linker attached to the enzyme surface.

These cumulative specifications result in one or more molecules that effectively remove arginine from a patient's blood and are not neutralized or cleared

by anti-ADI-PEG 20 antibodies from previous arginine depletion therapy. The molecules are pegylated so as to delay neutralization and clearance due to their own immunogenicity. These factors will permit their use instead of ADI-PEG 20 or in addition to ADI-PEG 20 (e.g., as a follow-on drug) to extend arginine depletion therapy and therefore increase effectiveness of arginine depletion treatment as an anti-cancer therapeutic.

Normal cells do not require arginine for growth, since they can synthesize arginine from citrulline in a two step process catalyzed by ASS and ASL. In contrast, certain cancers do not express ASS. Certain cancers do not express ASL, and other cancers may have diminished expression of, or may not express ASS and/or ASL. Therefore, these cancers are auxotrophic for arginine. This metabolic difference may be capitalized upon to develop a safe and effective therapy to treat these forms of cancer. ADI catalyzes the conversion of arginine to citrulline via the arginine dihydrolase pathway, and may thus be used to eliminate arginine.

The practice of the present invention will employ, unless indicated specifically to the contrary, conventional methods of virology, immunology, microbiology, molecular biology and recombinant DNA techniques within the skill of the art, many of which are described below for the purpose of illustration. Such techniques are explained fully in the literature. See, e.g., *Current Protocols in Protein Science*, *Current Protocols in Molecular Biology* or *Current Protocols in Immunology*, John Wiley & Sons, New York, N.Y. (2009); Ausubel *et al.*, *Short Protocols in Molecular Biology*, 3rd ed., Wiley & Sons, 1995; Sambrook and Russell, *Molecular Cloning: A Laboratory Manual* (3rd Edition, 2001); Maniatis *et al.* *Molecular Cloning: A Laboratory Manual* (1982); *DNA Cloning: A Practical Approach*, vol. I & II (D. Glover, ed.); *Oligonucleotide Synthesis* (N. Gait, ed., 1984); *Nucleic Acid Hybridization* (B. Hames & S. Higgins, eds., 1985); *Transcription and Translation* (B. Hames & S. Higgins, eds., 1984); *Animal Cell Culture* (R. Freshney, ed., 1986); Perbal, *A Practical Guide to Molecular Cloning* (1984) and other like references.

As used in this specification and the appended claims, the singular forms "a," "an" and "the" include plural references unless the content clearly dictates otherwise.

Throughout this specification, unless the context requires otherwise, the word "comprise", or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated element or integer or group of elements

or integers but not the exclusion of any other element or integer or group of elements or integers.

By "about" is meant a quantity, level, value, number, frequency, percentage, dimension, size, amount, weight or length that varies by as much as 30, 25, 20, 15, 10, 9, 8, 7, 6, 5, 4, 3, 2 or 1% to a reference quantity, level, value, number, frequency, percentage, dimension, size, amount, weight or length.

By "statistically significant," it is meant that the result was unlikely to have occurred by chance. Statistical significance can be determined by any method known in the art. Commonly used measures of significance include the p-value, which is the frequency or probability with which the observed event would occur, if the null hypothesis were true. If the obtained p-value is smaller than the significance level, then the null hypothesis is rejected. In simple cases, the significance level is defined at a p-value of 0.05 or less.

Each embodiment in this specification is to be applied *mutatis mutandis* to every other embodiment unless expressly stated otherwise.

Standard techniques may be used for recombinant DNA, oligonucleotide synthesis, and tissue culture and transformation (e.g., electroporation, lipofection). Enzymatic reactions and purification techniques may be performed according to manufacturer's specifications or as commonly accomplished in the art or as described herein. These and related techniques and procedures may be generally performed according to conventional methods well known in the art and as described in various general and more specific references that are cited and discussed throughout the present specification. Unless specific definitions are provided, the nomenclature utilized in connection with, and the laboratory procedures and techniques of, molecular biology, analytical chemistry, synthetic organic chemistry, and medicinal and pharmaceutical chemistry described herein are those well known and commonly used in the art. Standard techniques may be used for recombinant technology, molecular biological, microbiological, chemical syntheses, chemical analyses, pharmaceutical preparation, formulation, and delivery, and treatment of patients.

"Patient" or "subject" refers to an animal, in certain embodiments a mammal, and in a specific embodiment, a human.

"Biocompatible" refers to materials or compounds which are generally not injurious to biological functions and which will not result in any degree of unacceptable toxicity, including allergenic and disease states.

5 The term "reference sequence" refers generally to a nucleic acid coding sequence, or amino acid sequence, to which another sequence is being compared. All polypeptide and polynucleotide sequences described herein are included as references sequences, including those described by name and those described in the Tables and the Sequence Listing.

10 Throughout the present disclosure, the following abbreviations may be used: PEG, polyethylene glycol; ADI, arginine deiminase; SS, succinimidyl succinate; SSA, succinimidyl succinimide; SPA, succinimidyl propionate; NHS, N-hydroxy-succinimide; ASS1 or ASS, argininosuccinate synthetase; ASL, argininosuccinate lyase.

15 In the present invention, a polynucleotide encoding ADI may be derived, cloned, isolated, synthesized or produced from any source, including, for example, microorganisms, recombinant biotechnology or any combination thereof. For example, arginine deiminase may be cloned from microorganisms of the genera *Mycoplasma*, *Clostridium*, *Bacillus*, *Borrelia*, *Enterococcus*, *Streptococcus*, *Lactobacillus*, and/or *Giardia*. In certain embodiments, arginine deiminase is cloned
20 from *Mycoplasma arthritidis*, *Mycoplasma pneumoniae*, *Mycoplasma hominis*, *Mycoplasma arginini*, *Streptococcus pyogenes*, *Streptococcus pneumoniae*, *Borrelia burgdorferi*, *Borrelia afzelii*, *Giardia intestinalis*, *Clostridium perfringens*, *Bacillus licheniformis*, *Enterococcus faecalis*, *Lactobacillus sake*, or any combination thereof. In other embodiments, the arginine deiminase is cloned from a species listed in
25 Table 1. In particular, the ADI used in the present invention may comprise the amino acid sequence of any one of SEQ ID NOs: 1-32, or a variant or fragment or extension thereof having ADI activity (e.g., able to metabolize arginine into citrulline and ammonia). Some of the sequences provided in the sequence listing do not represent full-length ADI protein sequences. Thus, in certain embodiments,
30 additional amino acid residues can be added to either end of the sequences provided herein to make a full-length protein having ADI activity. The specific amino acids to be added can be determined by the skilled person based on alignments of known ADI sequences. Such ADI molecules can be synthesized using known

techniques. Illustrative “extended” ADI(r) are provided, for example, in SEQ ID NOs:26-32.

In certain embodiments, the ADI enzymes as described herein are compared to the benchmark ADI-PEG 20 molecule derived from *M. hominis*. As used herein, “ADI-PEG 20” refers to the ADI molecule known in the art and described for example in US6183738; US6635462; Ascierto PA, *et al.* (2005) Pegylated arginine deiminase treatment of patients with metastatic melanoma: results from phase I and II studies. *J Clin Oncol* 23(30): 7660– 7668; Izzo F, *et al.* (2004) Pegylated arginine deiminase treatment of patients with unresectable hepatocellular carcinoma: results from phase I/II studies. *J Clin Oncol* 22(10): 1815–1822; Holtsberg FW, *et al.* (2002), Poly(ethylene glycol) (PEG) conjugated arginine deiminase: effects of PEG formulations on its pharmacological properties. *J Control Release* 80(1– 3): 259–271; Kelly *et al.*, (2012) *British Journal of Cancer* 106, 324 – 332. As would be recognized by the skilled artisan, this molecule is a pegylated (PEG 20,000) ADI enzyme derived from *M. hominis*, and has two substitutions (K112E; P210S) relative to the wild type *M. hominis* ADI enzyme.

The arginine deiminase enzymes as described herein were screened from a large number of ADI enzymes and have a reduced level of reactivity with anti-ADI-PEG 20 antibodies from patients. Anti-ADI-PEG 20 antibodies can appear in subjects treated with ADI-PEG 20 and can be measured using known methodologies. Reactivity to anti-ADI-PEG 20 antibodies can be determined for example using ELISA or other similar assays known to the skilled artisan.

In this regard, ADI-PEG 20 can be used as a comparison to assess cross-reactivity level to patient anti-ADI-PEG 20 antibodies. A cross-reactivity level that is statistically significantly lower than that of ADI-PEG 20 to patient anti-ADI-PEG 20 antibodies may be useful herein. In certain embodiments, the arginine deiminase enzymes as described herein have low or no cross-reactivity to anti-ADI-PEG 20 antibodies. In another embodiment, any reduction in reactivity to anti-ADI-PEG 20 antibodies as compared to reactivity with ADI-PEG 20 can be beneficial as such an ADI enzyme would improve treatment options for patients in need of arginine depletion therapy. Thus, the arginine deiminase enzymes as described herein have reduced cross-reactivity to patient anti-ADI-PEG 20 antibodies as compared to ADI-PEG 20 reactivity to such antibodies.

“ADIr” is used herein to refer to an ADI enzyme of the present invention having reduced cross-reactivity to anti-ADI-PEG 20 antibodies as compared to ADI-PEG 20 reactivity to such antibodies. “ADIr” nomenclature is used to distinguish the molecules identified herein from ADI and ADI-PEG 20 as known in the art.

5 The ADIr enzymes of the invention have characteristics or properties comparable to or better than those of ADI-PEG 20, in order to reduce and maintain low blood arginine levels for effective cancer treatment. Such properties include Kcat, Km, pH optimum, stability, *in vivo* proteolytic stability and lack of requirement for ions or cofactors not already present in the blood, or any combination thereof. In
10 certain embodiments, an ADIr as described herein has properties that are about or at least 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% or higher, than comparable properties of ADI-PEG 20. In other embodiments an ADIr described herein has properties that are about or at
15 least about 100%, 105%, 110%, 120%, 140%, 150%, 160%, 180%, 200%, 220%, 240%, 250%, 260%, 280%, 300%, 320%, 340, 350%, 360%, 400%, 420%, 450%, 460%, 500%, 520%, 550% or higher than the specific property of ADI-PEG 20 being compared.

 Thus, in certain embodiments, an ADIr has a Kcat that is about or at
20 least about 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% of the Kcat of ADI-PEG 20, or better. In certain embodiments, an ADIr has a Kcat that is about or at least about 100%, 105%, 110%, 120%, 125%, 140%, 150%, 160%, 180%, 200%, 220%, 240%, 250%, 260%, 280%,
25 300%, 320%, 340, 350%, 360%, 400%, 420%, 450%, 460%, 500%, 520%, 550% or higher, times that of the ADI-PEG 20 Kcat. In certain embodiments, the Kcat of the ADIr enzymes described herein, or compositions comprising same, is about 0.5 sec⁻¹ to about 15 sec⁻¹, and in a further embodiment, is from about 1 sec⁻¹ to about 12 sec⁻¹, about 1 sec⁻¹ to about 10 sec⁻¹, about 1.5 sec⁻¹ to about 9 sec⁻¹, about 2 sec⁻¹ to
30 about 8 sec⁻¹ or about 2.5 sec⁻¹ to about 7 sec⁻¹. In certain embodiments, the ADIr or ADIr-PEG in a composition has a Kcat of about 2.5 sec⁻¹ to about 7.5 sec⁻¹. In some embodiments, the ADIr or ADIr-PEG in a composition has a Kcat of about 2.5 sec⁻¹, about 3 sec⁻¹, about 3.5 sec⁻¹, about 4 sec⁻¹, about 4.5 sec⁻¹, about 5 sec⁻¹, about 5.5 sec⁻¹, about 6 sec⁻¹, about 6.5 sec⁻¹, about 7 sec⁻¹, about 7.2 sec⁻¹, about 7.5 sec⁻¹,

about 8 sec⁻¹, about 10 sec⁻¹, about 15 sec⁻¹, about 20 sec⁻¹, about 25 sec⁻¹, about 30 sec⁻¹, about 35 sec⁻¹, about 40 sec⁻¹, about 45 sec⁻¹, about 50 sec⁻¹, about 55 sec⁻¹, about 60 sec⁻¹, about 65 sec⁻¹, about 70 sec⁻¹, about 75 sec⁻¹, about 80 sec⁻¹, about 85 sec⁻¹, about 90 sec⁻¹, about 95 sec⁻¹, or about 100 sec⁻¹.

5 Thus, in certain embodiments, an ADIr has a Km that is about or at least about 5%, 6%, 7%, 8%, 9%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% of the Km of ADI-PEG 20, or better. Thus, in certain embodiments, an ADIr has a Km that is
10 about or at least about 100%, 105%, 110%, 120%, 130%, 140%, 150%, 160%, 180%, 200%, 220%, 240%, or 250% that of the Km of ADI-PEG 20. In one embodiment, an ADIr, or a pegylated formulation thereof, has a Km of from about 0.5 µM to about 50 µM, or about 1.6 µM to about 48 µM, or about 0.5 µM to about 15 µM, and in a further embodiment, is from about 1 µM to about 12 µM, about 1 µM to
15 about 10 µM, about 1.5 µM to about 9 µM, about 1.5 µM to about 8 µM or about 1.5 µM to about 7 µM. In certain embodiments, the ADIr or ADIr-PEG in a composition has a Km of about 1.5 µM to about 6.5 µM. In some embodiments, the ADIr or pegylated formulation thereof has a Km of about 1.5 µM, about 1.6 µM, about 2 µM, about 2.5 µM, about 3 µM, about 3.5 µM, about 4 µM, about 4.5 µM, about 5 µM,
20 about 5.5 µM, about 6 µM, about 6.5 µM, about 7 µM, about 8 µM, about 9 µM, about 10 µM, about 12 µM, about 14 µM, about 15 µM, about 16 µM, about 18 µM, about 20 µM, about 22 µM, about 24 µM, about 25 µM, about 26 µM, about 28 µM, about 30 µM, about 32 µM, about 34 µM, about 35 µM, about 36 µM, about 38 µM, about 40 µM, about 42 µM, about 44 µM, about 45 µM, about 46 µM, about 48 µM,
25 or about 50 µM.

 In certain embodiments, an ADIr functions at a pH close to the physiological pH of human blood. Thus, in one embodiment, an ADIr functions at a pH of about 4 to about 10.8, or about 6 to about 8, or about 6.5 to about 7.5. In one embodiment, an ADIr has good enzyme activity at about pH 7.4.

30 In certain embodiments, an ADIr has stability during long term storage and temperature and proteolytic stability during treatment in the human body. In further embodiments, an ADIr does not require ions or cofactors for activity that are not already present in blood.

In certain embodiments, an ADIr described herein generally has an amino acid sequence sufficiently different from *M. hominis* so that there are surface residue changes which will reduce or eliminate antigenic sites for anti-ADI-PEG 20 antibodies. In one embodiment, there will be no cross reactivity between the selected ADIr molecule and existing anti-ADI-PEG 20 antibodies in a subject, and a completely new immune response will be generated in a subject rather than a maturation of the existing response to *M. hominis* ADI. Thus, in one embodiment, an ADIr as described herein has from 20% - 85% sequence identity to *M. hominis* ADI as set forth in SEQ ID NO:1. In certain embodiments, an ADIr as described herein has even lower percent sequence identity to *M. hominis* ADI, such as 10% or 15% identity. In another embodiment, an ADIr as described herein has 20%, 21%, 22%, 23%, 24%, 25%, 26%, 27%, 28%, 29%, 30%, 31%, 32%, 33%, 34%, 35%, 36%, 37%, 38%, 39%, 40%, 41%, 42%, 43%, 44%, 45%, 46%, 47%, 48%, 49%, 50%, 51%, 52%, 53%, 54%, 55%, 56%, 57%, 58%, 59%, 60%, 61%, 62%, 63%, 64%, 65%, 66%, 67%, 68%, 69%, 70%, 71%, 72%, 73%, 74%, 75%, 76%, 77%, 78%, 79%, 80%, 81%, 82% or even 83% identity to *M. hominis* ADI, and still has reduced cross-reactivity toward anti-ADI-PEG 20 antibodies.

In one embodiment, an ADIr as described herein has from about 25-140 surface residue changes as compared to *M. hominis* ADI. Surface residues can be identified from the crystal structure of *M. hominis* ADI and surface residues for ADI from other organisms can be determined by sequence homology. An ADIr as described herein may have about 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, or about 140 surface residue changes as compared to *M. hominis* ADI (see SEQ ID NO:1).

In another embodiment, an ADIr as described herein has from about 25-140 residue changes as compared to *M. hominis* ADI. Such residue changes need not only be of surface amino acid residues. Such residue changes (or additions or deletions) can be at either end of the molecule or may be at any residue of the ADI, such that the modified ADI has the desired ADI activity as described herein. Residues to be changed can be identified from the crystal structure of *M. hominis* ADI and residues for ADI from other organisms can be determined by sequence homology. An ADIr as described herein may have about 25, 30, 35, 40,

45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, or about 140 amino acid residue changes as compared to *M.*

5 *hominis* ADI (see SEQ ID NO:1).

From a large number of ADI enzymes, Table 1 lists 24 ADI_r enzymes with their sequence percent identity relative to *M. hominis* ADI. From the literature, *M. hominis*, *M. arginini*, and *M. arthritidis* ADI amino acid sequences are closely related and these enzymes have good catalytic properties. More recently, additional
10 ADI enzymes have been discovered that have sequences closely related to these three. More distantly related Mycoplasma ADI enzymes have been identified, although less is known about them. And even more distantly related ADI enzymes from bacterial and other sources exist.

In certain embodiments, the ADI_r enzymes identified herein from a
15 number of selected species, have surface lysine residues (in certain embodiments, up to 30 or more). However, in certain embodiments an ADI_r enzyme may have many fewer surface lysine residues, such as just 2 lysine residues as in the case of *Mycobacterium bovis* ADI, or even no lysine residues (see e.g., ADI from *Mycobacterium* sp. MCS; GenBank No. ABG10381). Therefore, the ADI_r enzymes
20 identified herein that have reduced cross-reactivity with anti-ADI-PEG 20 antibodies, have about 0, 1, 2, 3, 4, 5, 10, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, or more surface lysine residues.

The terms "polypeptide," "protein" and "peptide" are used
25 interchangeably and mean a polymer of amino acids not limited to any particular length. The terms do not exclude modifications such as myristoylation, sulfation, glycosylation, phosphorylation and addition or deletion of signal sequences. The terms "polypeptide" or "protein" means one or more chains of amino acids, wherein each chain comprises amino acids covalently linked by peptide bonds, and wherein
30 said polypeptide or protein can comprise a plurality of chains non-covalently and/or covalently linked together by peptide bonds, having the sequence of native proteins, that is, proteins produced by naturally-occurring and specifically non-recombinant cells, or genetically-engineered or recombinant cells, and comprise molecules having the amino acid sequence of the native protein, or molecules having deletions from,

additions to, and/or substitutions of one or more amino acids of the native sequence. The terms "polypeptide" and "protein" specifically encompass the ADlr proteins of the present disclosure, or sequences that have deletions from, additions to, and/or substitutions of one or more amino acid of the ADlr proteins. In certain embodiments, the polypeptide is a "recombinant" polypeptide, produced by recombinant cell that comprises one or more recombinant DNA molecules, which are typically made of of heterologous polynucleotide sequences or combinations of polynucleotide sequences that would not otherwise be found in the cell.

The term "isolated protein" referred to herein means that a subject protein (1) is free of at least some other proteins with which it would typically be found in nature, (2) is essentially free of other proteins from the same source, *e.g.*, from the same species, (3) is expressed by a cell from a different species, (4) has been separated from at least about 50 percent of polynucleotides, lipids, carbohydrates, or other materials with which it is associated in nature, (5) is not associated (by covalent or noncovalent interaction) with portions of a protein with which the "isolated protein" is associated in nature, (6) is operably associated (by covalent or noncovalent interaction) with a polypeptide with which it is not associated in nature, or (7) does not occur in nature. Such an isolated protein can be encoded by genomic DNA, cDNA, mRNA or other RNA, or may be of synthetic origin, or any combination thereof. In certain embodiments, the isolated protein is substantially free from proteins or polypeptides or other contaminants that are found in its natural environment that would interfere with its use (therapeutic, diagnostic, prophylactic, research or otherwise).

The term "variant" includes a polypeptide that differs from a reference polypeptide specifically disclosed herein (*e.g.*, SEQ ID NOS:1-32) by one or more substitutions, deletions, additions and/or insertions. Variant polypeptides are biologically active, that is, they continue to possess the enzymatic or binding activity of a reference polypeptide. Such variants may result from, for example, genetic polymorphism and/or from human manipulation.

In many instances, a biologically active variant will contain one or more conservative substitutions. A "conservative substitution" is one in which an amino acid is substituted for another amino acid that has similar properties, such that one skilled in the art of peptide chemistry would expect the secondary structure and hydropathic nature of the polypeptide to be substantially unchanged. As described

above, modifications may be made in the structure of the polynucleotides and polypeptides of the present invention and still obtain a functional molecule that encodes a variant or derivative polypeptide with desirable characteristics.

For example, certain amino acids may be substituted for other amino acids in a protein structure without appreciable loss of interactive binding capacity with structures such as, for example, antigen-binding regions of antibodies or binding sites on substrate molecules. Since it is the interactive capacity and nature of a protein that defines that protein's biological functional activity, certain amino acid sequence substitutions can be made in a protein sequence, and, of course, its underlying DNA coding sequence, and nevertheless obtain a protein with like properties. It is thus contemplated that various changes may be made in the peptide sequences of the disclosed compositions, or corresponding DNA sequences which encode said peptides without appreciable loss of their utility.

In making such changes, the hydropathic index of amino acids may be considered. The importance of the hydropathic amino acid index in conferring interactive biologic function on a protein is generally understood in the art (Kyte & Doolittle, 1982, incorporated herein by reference). It is accepted that the relative hydropathic character of the amino acid contributes to the secondary structure of the resultant protein, which in turn defines the interaction of the protein with other molecules, for example, enzymes, substrates, receptors, DNA, antibodies, antigens, and the like. Each amino acid has been assigned a hydropathic index on the basis of its hydrophobicity and charge characteristics (Kyte & Doolittle, 1982). These values are: isoleucine (+4.5); valine (+4.2); leucine (+3.8); phenylalanine (+2.8); cysteine (+2.5); methionine (+1.9); alanine (+1.8); glycine (−0.4); threonine (−0.7); serine (−0.8); tryptophan (−0.9); tyrosine (−1.3); proline (−1.6); histidine (−3.2); glutamate (−3.5); glutamine (−3.5); aspartate (−3.5); asparagine (−3.5); lysine (−3.9); and arginine (−4.5). It is known in the art that certain amino acids may be substituted by other amino acids having a similar hydropathic index or score and still result in a protein with similar biological activity, *i.e.*, still obtain a biological functionally equivalent protein. In making such changes, the substitution of amino acids whose hydropathic indices are within ± 2 is preferred, those within ± 1 are particularly preferred, and those within ± 0.5 are even more particularly preferred.

It is also understood in the art that the substitution of like amino acids can be made effectively on the basis of hydrophilicity. U.S. Patent 4,554,101 (specifically incorporated herein by reference in its entirety), states that the greatest local average hydrophilicity of a protein, as governed by the hydrophilicity of its adjacent amino acids, correlates with a biological property of the protein. As detailed in U. S. Patent 4,554,101, the following hydrophilicity values have been assigned to amino acid residues: arginine (+3.0); lysine (+3.0); aspartate (+3.0 $\pm$ 1); glutamate (+3.0 $\pm$ 1); serine (+0.3); asparagine (+0.2); glutamine (+0.2); glycine (0); threonine (−0.4); proline (−0.5 $\pm$ 1); alanine (−0.5); histidine (−0.5); cysteine (−1.0); methionine (−1.3); valine (−1.5); leucine (−1.8); isoleucine (−1.8); tyrosine (−2.3); phenylalanine (−2.5); tryptophan (−3.4). It is understood that an amino acid can be substituted for another having a similar hydrophilicity value and still obtain a biologically equivalent, and in particular, an immunologically equivalent protein. In such changes, the substitution of amino acids whose hydrophilicity values are within ± 2 is preferred, those within ± 1 are particularly preferred, and those within ± 0.5 are even more particularly preferred.

As outlined above, amino acid substitutions are generally therefore based on the relative similarity of the amino acid side-chain substituents, for example, their hydrophobicity, hydrophilicity, charge, size, and the like. Exemplary substitutions that take various of the foregoing characteristics into consideration are well known to those of skill in the art and include: arginine and lysine; glutamate and aspartate; serine and threonine; glutamine and asparagine; and valine, leucine and isoleucine.

Amino acid substitutions may further be made on the basis of similarity in polarity, charge, solubility, hydrophobicity, hydrophilicity and/or the amphipathic nature of the residues. For example, negatively charged amino acids include aspartic acid and glutamic acid; positively charged amino acids include lysine and arginine; and amino acids with uncharged polar head groups having similar hydrophilicity values include leucine, isoleucine and valine; glycine and alanine; asparagine and glutamine; and serine, threonine, phenylalanine and tyrosine. Other groups of amino acids that may represent conservative changes include: (1) ala, pro, gly, glu, asp, gln, asn, ser, thr; (2) cys, ser, tyr, thr; (3) val, ile, leu, met, ala, phe; (4) lys, arg, his; and (5) phe, tyr, trp, his.

A variant may also, or alternatively, contain non-conservative changes. In a preferred embodiment, variant polypeptides differ from a native sequence by substitution, deletion or addition of fewer than about 10, 9, 8, 7, 6, 5, 4, 3, 2 amino acids, or even 1 amino acid. Variants may also (or alternatively) be modified by, for example, the deletion or addition of amino acids that have minimal influence on the immunogenicity, secondary structure, enzymatic activity, and/or hydrophobic nature of the polypeptide.

In general, variants will display about or at least about 30%, 40%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% similarity or sequence identity or sequence homology to a reference polypeptide sequence (e.g., SEQ ID NOS:1-32). Moreover, sequences differing from the native or parent sequences by the addition (e.g., C-terminal addition, N-terminal addition, both), deletion, truncation, insertion, or substitution of about 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 30, 40, 50, 60, 70, 80, 90, 100 or more amino acids but which retain the properties or activities of a parent or reference polypeptide sequence are contemplated.

In some embodiments, variant polypeptides differ from reference sequence by at least one but by less than 50, 40, 30, 20, 15, 10, 8, 6, 5, 4, 3 or 2 amino acid residue(s). In other embodiments, variant polypeptides differ from a reference sequence by about or at least 0.5% or 1% but less than 20%, 15%, 10% or 5% of the residues. (If this comparison requires alignment, the sequences should be aligned for maximum similarity. "Looped" out sequences from deletions or insertions, or mismatches, are considered differences.).

The term "polypeptide fragment" refers to a polypeptide that has an amino-terminal deletion, a carboxyl-terminal deletion, and/or an internal deletion or substitution of a naturally-occurring or recombinantly-produced polypeptide. In certain embodiments, a polypeptide fragment can comprise an amino acid chain at least 5 to about 400 amino acids long. It will be appreciated that in certain embodiments, fragments are at least 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 110, 150, 200, 250, 300, 350, or 400 amino acids long. Particularly useful polypeptide fragments include functional domains, including the catalytic ADI domains of the

ADIr described herein. In the case of an ADIr, useful fragments include, but are not limited to, the catalytic domain and the α -helical domain.

Many activated PEGs used for conjugation to ADI covalently bond to lysine residues. There are usually many fewer PEG molecules attached to ADI than there are lysine residues. Both the number and distribution of attachments can be heterogeneous from molecule to molecule. Any particular lysine residue will be modified in only a small fraction of the ADI molecules. This site modification heterogeneity and low PEG occupancy can result in problems with both drug characterization and the effectiveness of PEG shielding at antigenic sites.

Therefore, in certain embodiments, the selected ADIr enzymes as described herein, are modified by lysine replacement with other residue types to reduce the number of lysine residues. This produces a more uniformly pegylated protein and increases the PEG occupancy at the remaining lysine residues. Specific lysine residues chosen to be changed to other residues will be selected in order to preserve enzyme activity.

This more uniform pegylation is expected to provide increased protection against proteolysis in blood and increased shielding of antigenic sites from patient antibodies.

In certain embodiments, the ADIr of the present disclosure may be modified as described in US Patent No. 6,635,462. In particular, modifications of one or more of the naturally occurring amino acid residues of an ADIr can provide for an enzyme that is more easily renatured and formulated thereby improving the manufacture of ADIr and therapeutic compositions comprising the same. In one embodiment, the ADIr of the present disclosure is modified to remove one or more lysine residues (e.g., the lysine can be substituted with another amino acid or analogues thereof, or a non-natural amino acid). In particular, in one embodiment, the ADIr is modified to be free of the lysine at a position equivalent to 112, 374, 405 or 408 of SEQ ID NO:1 (*M. hominis* ADI), or a combination of one or more of these positions. In a further embodiment, the ADIr is modified to be free of one or more lysines, for example, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, or more lysine residues, should they be present, can be substituted with another amino acid or analogues thereof, or a nonnatural amino acid. In one embodiment, an ADIr has 5 lysines substituted, for example, at an equivalent position to position 7, 88, 137, 209, and 380 of SEQ ID NO: 1. In another embodiment, an ADIr has 10 lysines substituted, for example, at positions equivalent to positions 7, 9, 59, 88, 115,

116, 137, 178, 209, and 380 of SEQ ID NO: 1. In yet another embodiment, an ADIr has 15 lysines substituted, for example, at positions equivalent to positions 7, 9, 59, 66, 88, 91, 93, 115, 116, 137, 141, 178, 209, 279, and at position 380 of SEQ ID NO: 1. In one embodiment, an ADIr comprises 21 lysines substituted, for example, at
5 positions equivalent to positions 7, 9, 56, 59, 66, 88, 91, 93, 96, 115, 116, 137, 141, 178, 209, 254, 279, 325, 326, 380, and 406 of SEQ ID NO: 1.

A native ADIr may be found in microorganisms and is immunogenic and rapidly cleared from circulation in a patient. These problems may be overcome by modifying an ADIr. Thus, the present disclosure provides ADIr modified by a
10 modifying agent, including, but not limited to macromolecule polymers, proteins, peptides, polysaccharides, or other compounds. Arginine deiminase as described herein and the modifying agent may be linked by either covalent bonds or non-covalent interaction to form a stable conjugate or a stable composition to achieve a desired effect. In certain embodiments, the modified ADIr retains the biological
15 activity of an unmodified ADIr and has a longer half life *in vivo* and lower antigenicity than the unmodified, ADIr. In certain embodiments, the modified ADIr retains at least 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99% or more of the biological activity of unmodified ADIr. Generally, the modified ADIr retains biological activity sufficient for therapeutic use.

20 In one embodiment, a modifying agent can be a polymer or a protein or a fragment thereof that is biocompatible and can increase the half life of ADIr in blood. The modifying agent can be either chemically coupled to ADIr or where applicable, linked to the ADIr via fusion protein expression.

Macromolecule polymers may include a non-peptide macromolecule
25 polymer, which in certain embodiments, may have its own bioactivity. Suitable polymers include, but are not limited to, polyenol compounds, polyether compounds, polyvinylpyrrolidone, poly amino acids, copolymer of divinyl ether and maleic anhydride, N-(2-hydroxypropyl)-methacrylamide, polysaccharide, polyoxyethylated polyol, heparin or its fragment, poly-alkyl-ethylene glycol and its derivatives,
30 copolymers of poly-alkyl-ethylene glycol and its derivatives, poly(vinyl ethyl ether), a,P-Poly[(2-hydroxyethyl)-DL-aspartamide], polycarboxylates, poly oxyethylene-oxy methylenes, polyacryloyl morpholines, copolymer of amino compounds and oxyolefin, poly hyaluronic acid, polyoxiranes, copolymer of ethanedioic acid and malonic acid, poly (1,3-dioxolane), ethylene and maleic hydrazide copolymer, poly

sialic acid, cyclodextrin, etc. In certain embodiments, the polymer is polyethylene glycol.

The polyenol compounds as used herein include, but are not limited to, polyethylene glycol (including monomethoxy polyethylene glycol, monohydroxyl polyethylene glycol), polyvinyl alcohol, polyallyl alcohol, polybutenol and the like, and their derivatives, such as lipids.

The polyether compounds include, but are not limited to poly alkylene glycol ($\text{HO}((\text{CH}_2)_x\text{O})_n\text{H}$), polypropylene glycol, polyoxyethylene ($\text{HO}((\text{CH}_2)_2\text{O})_n\text{H}$), polyvinyl alcohol ($(\text{CH}_2\text{CHOH})_n$).

Poly amino acids include, but are not limited to, polymers of one type of amino acid or copolymers of two or more types of amino acids, for example, polyalanine or polylysine, or block co-polymers thereof.

Polysaccharides include but are not limited to, glucosan and its derivatives, for example dextran sulfate, cellulose and its derivatives (including methyl cellulose and carboxymethyl cellulose), starch and its derivatives, polysucrose, etc.

In one specific embodiment of the present invention, ADIr is modified by coupling with proteins or peptides, wherein one or more proteins or peptides are directly or indirectly linked to ADIr. The proteins can either be naturally existing proteins or their fragments, including but not limited to naturally existing human serum proteins or their fragments, such as thyroxine-binding protein, transthyretin, α 1-acid glycoprotein, transferrin, fibrinogen, immunoglobulin, Ig Fc regions, albumin, and fragments thereof. By "fragment" is meant any portion of a protein that is smaller than the whole protein but which retains the desired function of the protein. The ADIr as described herein may be directly or indirectly linked to a protein via a covalent bond. Direct linking means that one amino acid of ADIr is directly linked to one amino acid of the modifying protein, via a peptide bond or a disulfide bridge. Indirect linking refers to the linkages between a ADIr and a modifying protein, via originally existing chemical groups therebetween or specific chemical groups added through biological or chemical means, or the combination of the above-mentioned linkages.

In one particular embodiment, ADIr is modified by covalent attachment with PEG. ADIr covalently modified with PEG (with or without a linker) may be hereinafter referred to as "ADIr-PEG." When compared to unmodified ADIr, ADIr-PEG retains most of its enzymatic activity, is far less immunogenic or antigenic, has

a greatly extended circulating half-life, and is much more efficacious in the treatment of tumors.

"Polyethylene glycol" or "PEG" refers to mixtures of condensation polymers of ethylene oxide and water, in a branched or straight chain, represented by the general formula $H(OCH_2CH_2)_nOH$, wherein n is at least 4. "Polyethylene glycol" or "PEG" is used in combination with a numeric suffix to indicate the approximate weight average molecular weight thereof. For example, PEG5,000 refers to PEG having a total weight average molecular weight of about 5,000; PEG12,000 refers to PEG having a total weight average molecular weight of about 12,000; and PEG20,000 refers to PEG having a total weight average molecular weight of about 20,000.

In one embodiment of the present invention, the PEG has a total weight average molecular weight of about 1,000 to about 50,000; in one embodiment from about 3,000 to about 40,000, and in another embodiment from about 5,000 to about 30,000; in certain embodiments from about 8,000 to about 30,000; in other embodiments from about 11,000 to about 30,000; in additional embodiments, from about 12,000 to about 28,000; in still other embodiments, from about 16,000 to about 24,000; and in other embodiments, about 18,000 to about 22,000; in another embodiment, from 19,000 to about 21,000, and in one embodiment, the PEG has a total weight average molecular weight of about 20,000. Generally, PEG with a molecular weight of 30,000 or more is difficult to dissolve, and yields of the formulated product may be reduced. The PEG may be a branched or straight chain. Generally, increasing the molecular weight of the PEG decreases the immunogenicity of the ADI_r. The PEG having a molecular weight described in this embodiment may be used in conjunction with ADI_r, and, optionally, a biocompatible linker, to treat cancer, including, for example, acute myeloid leukemia, such as relapsed acute myeloid leukemia, breast cancer, ovarian cancer, colorectal cancer, gastric cancer, glioma, glioblastoma multiforme, non-small cell lung cancer (NSCLC), kidney cancer, bladder cancer, uterine cancer, esophageal cancer, brain cancer, head and neck cancers, cervical cancer, testicular cancer, stomach cancer and esophageal cancer.

In another embodiment of the present invention, the PEG has a total weight average molecular weight of about 1,000 to about 50,000; in certain embodiments about 3,000 to about 30,000; in other embodiments from about 3,000

to about 20,000; in one embodiment from about 4,000 to about 12,000; in still other embodiments from about 4,000 to about 10,000; in additional embodiments from about 4,000 to about 8,000; still further embodiments from about 4,000 to about 6,000; and about 5,000 in another embodiment. The PEG may be a branched or straight chain, and in certain embodiments is a straight chain. The PEG having a molecular weight described in this embodiment may be used in conjunction with ADIr, and optionally, a biocompatible linker, to treat graft versus host disease (GVHD) or cancer.

While ADIr-PEG is the illustrative modified ADIr described herein, as would be recognized by the skilled person ADIr may be modified with other polymers or appropriate molecules for the desired effect, in particular reducing antigenicity and increasing serum half-life.

ADIr may be covalently bonded to a modifying agent, such as PEG, with or without a linker, although a preferred embodiment utilizes a linker.

The linker used to covalently attach ADIr to a modifying agent, e.g. PEG, may be any biocompatible linker. As discussed above, "biocompatible" indicates that the compound or group is non-toxic and may be utilized *in vitro* or *in vivo* without causing injury, sickness, disease, or death. A modifying agent, such as PEG, can be bonded to the linker, for example, via an ether bond, a thiol bond, or an amide bond. The linker group includes, for example, a succinyl group, an amide group, an imide group, a carbamate group, an ester group, an epoxy group, a carboxyl group, a hydroxyl group, a carbohydrate, a tyrosine group, a cysteine group, a histidine group, a methylene group, and combinations thereof. In one embodiment, the source of the biocompatible linker is succinimidyl succinate (SS). Other suitable sources of linker may include an oxycarbonylimidazole group (including, for example, carbonylimidazole (CDI)), a nitro phenyl group (including, for example, nitrophenyl carbonate (NCP) or trichlorophenyl carbonate (TCP)), a trysylate group, an aldehyde group, an isocyanate group, a vinylsulfone group, or a primary amine. In another embodiment, the linker is derived from SS, SPA, SCM, or NHS; in certain embodiments, SS, SPA, or NHS are used, and in other embodiments, SS or SPA are used. Thus, in certain embodiments, potential linkers can be formed from methoxy-PEG succinimidyl succinate(SS), methoxy-PEG succinimidyl glutarate(SG), methoxy-PEG succinimidyl carbonate (SC), methoxy-PEG succinimidyl carboxymethyl ester (SCM), methoxy-PEG2 N-hydroxy

succinimide (NHS), methoxy-PEG succinimidyl butanoate (SBA), methoxy-PEG succinimidyl propionate (SPA), methoxy-PEG succinimidyl glutaramide, and methoxy-PEG succinimidyl succinamide.

Alternatively, ADIr may be coupled directly to a modifying agent, such as PEG (i.e., without a linker) through an amino group, a sulfhydryl group, a hydroxyl group or a carboxyl group.

ADIr may be covalently bonded to PEG, via a biocompatible linker, using methods known in the art, as described, for example, by Park *et al*, Anticancer Res., 1:373-376 (1981); and Zaplisky and Lee, Polyethylene Glycol Chemistry: Biotechnical and Biomedical Applications, J. M. Harris, ed., Plenum Press, NY, Chapter 21 (1992), the disclosures of which are hereby incorporated by reference herein in their entirety.

The attachment of PEG to ADIr increases the circulating half-life of ADIr. Generally, PEG is attached to a primary amine of ADIr. Selection of the attachment site of PEG, or other modifying agent, on the ADIr is determined by the role of each of the sites within the active domain of the protein, as would be known to the skilled artisan. PEG may be attached to the primary amines of ADIr without substantial loss of enzymatic activity. For example, the lysine residues present in ADIr are all possible points at which ADIr as described herein can be attached to PEG via a biocompatible linker, such as SS, SPA, SCM, SSA and/or NHS. PEG may also be attached to other sites on ADIr, as would be apparent to one skilled in the art in view of the present disclosure.

From 1 to about 30 PEG molecules may be covalently bonded to ADIr. In certain embodiments, ADIr is modified with one PEG molecule. In other embodiments, ADIr is modified with more than one PEG molecule. In one embodiment, ADIr is modified with about 1 to about 10, or from about 7 to about 15 PEG molecules, and in one embodiment from about 2 to about 8 or about 9 to about 12 PEG molecules. In another embodiment, the ADIr is modified with 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15 PEG molecules. In one specific embodiment, ADIr is modified with 4.5 – 5.5 PEG molecules per ADIr. In another embodiment, ADIr is modified with 5 ± 1.5 PEG molecules.

In another embodiment, about 15% to about 70% of the primary amino groups in ADIr are modified with PEG, in one embodiment about 20% to about 65%, about 25% to about 60%, or in certain embodiments about 30% to about 55%, or

45% to about 50%, and in other embodiments about 50% of the primary amino groups in arginine deiminase are modified with PEG. When PEG is covalently bonded to the end terminus of ADIr, it may be desirable to have only 1 PEG molecule utilized. Increasing the number of PEG units on ADIr increases the circulating half life of the enzyme. However, increasing the number of PEG units on ADIr decreases the specific activity of the enzyme. Thus, a balance needs to be achieved between the two, as would be apparent to one skilled in the art in view of the present disclosure.

In the present invention, a common feature of biocompatible linkers is that they attach to a primary amine of arginine deiminase via a succinimide group. Once coupled with ADIr, SS-PEG has an ester linkage next to the PEG, which may render this site sensitive to serum esterase, which may release PEG from ADIr in the body. SPA-PEG and PEG2-NHS do not have an ester linkage, so they are not sensitive to serum esterase.

In certain embodiments, a biocompatible linker is used in the present invention. PEG which is attached to the protein may be either a straight chain, as with SS-PEG, SPA-PEG and SC-PEG, or a branched chain of PEG may be used, as with PEG2-NHS.

In certain embodiments, pegylation sites associated with ADIr located at or adjacent to the catalytic region of the enzyme are modified. For purposes of the present invention, the phrase "pegylation site" may be defined as any site or position of ADI or a ADIr that may be covalently modified with polyethylene glycol. A "pegylation site" can be considered located at or adjacent the catalytic region of the enzyme where pegylation of the site results in a significant reduction in catalytic activity of the enzyme. The pegylation of such sites has traditionally resulted in the inactivation of the enzyme. For example, ADI from *Mycoplasma hominis* has a lysine at the 112 position which can be considered to be at or adjacent the catalytic region of the enzyme. The attachment of PEG to this lysine at the 112 position can inactivate the enzyme. In addition, ADI from *Mycoplasma hominis* has a cysteine at the 397 position which can be considered to be at or adjacent the catalytic region of the enzyme. The amino acid substitutions for cysteine at the 397 position can inactivate the enzyme. In particular, substituting alanine, histidine, arginine, serine, lysine or tyrosine for cysteine at the 397 position can result in a loss of all detectable enzyme activity. ADI from *Mycoplasma hominis* also has three lysines located near

this conserved cysteine, in particular Lys374, Lys405 and Lys408. The attachment of PEG to Lys374, Lys405, Lys408 or combinations thereof can inactivate the enzyme.

It is to be understood that ADIr derived from other organisms may also have pegylation sites corresponding to 112 position of ADI from *Mycoplasma*

5 *hominis*. In addition, ADI from some organisms may have lysines corresponding to the same general location as the 112 position of ADI from *Mycoplasma hominis*. The location of lysine in ADI from such organisms are known to the skilled person and are described in US Patent No. 6,635,462.

Thus, in one embodiment, the present invention provides for certain
10 amino acid substitutions in the polypeptide chain of ADIr. These amino acid substitutions provide for modified ADIr that loses less activity when modified by a modifying agent, e.g., upon pegylation. By eliminating pegylation sites, or other known modification sites, at or adjacent to the catalytic region of enzyme, optimal modification, e.g., pegylation, can be achieved without the loss of activity.

15 It is to be understood that other embodiments of the invention are based on the understanding that certain structural characteristics of arginine deiminase may prevent or interfere with the proper and rapid renaturation when produced via recombinant technology. In particular, these structural characteristics hinder or prevent the enzyme from assuming an active conformation during
20 recombinant production. For purposes of the present invention, the phrase "active conformation" may be defined as a three-dimensional structure that allows for enzymatic activity by unmodified or modified arginine deiminase. The active conformation may, in particular, be necessary for catalyzing the conversion of arginine into citrulline. The phrase "structural characteristic" may be defined as any
25 trait, quality or property of the polypeptide chain resulting from a particular amino acid or combination of amino acids. For instance, arginine deiminase may contain an amino acid that results in a bend or kink in the normal peptide chain and thus hinders the enzyme from assuming an active conformation during renaturation of the enzyme. In particular, arginine deiminase from *Mycoplasma hominis* has a proline at
30 the 210 position that may result in a bend or kink in the peptide chain, making it more difficult to renature the enzyme during recombinant production. It is to be understood that arginine deiminase derived from other organisms may also have sites corresponding to the 210 position of arginine deiminase from *Mycoplasma hominis*.

The present invention thus again provides for certain amino acid substitutions in the polypeptide chain of wild type arginine deiminases. Such amino acid substitutions can eliminate the problematic structural characteristics in the peptide chain of arginine deiminase. Such amino acid substitutions provide for improved renaturation of the modified arginine deiminase. These amino acid substitutions make possible rapid renaturing of modified arginine deiminases using reduced amounts of buffer. These amino acid substitutions may also provide for increased yields of renatured modified arginine deiminase. In one embodiment of the invention, the modified arginine deiminase has an amino acid substitution at P210 or the equivalent residue. As mentioned above, arginine deiminase derived from *Mycoplasma hominis* has the amino acid proline located at the 210 position. While not limiting the present invention, it is presently believed that the presence of the amino acid proline at position 210 results in a bend or kink in the normal polypeptide chain that increases the difficulty of renaturing (i.e., refolding) arginine deiminase. Substitutions for proline at position 210 make possible the rapid renaturation of modified arginine deiminase using reduced amounts of buffer. Substitutions for proline at position 210 may also provide for increased yields of renatured modified arginine deiminase. In one embodiment, the proline at position 210 is substituted with serine. It is to be understood that in accordance with this aspect of the invention, other substitutions at position 210 may be made. Examples of other substitutions include Pro210 to Thr210, Pro210 to Arg210, Pro210 to Asn210, Pro210 to Gln210 or Pro210 to Met210. By eliminating those structural characteristics associated with the amino acid of position 210 of the wild-type arginine deiminase, proper refolding of the enzyme can be achieved.

The methods of the present invention can involve either *in vitro* or *in vivo* applications. In the case of *in vitro* applications, including cell culture applications, the compounds described herein can be added to the cells in cultures and then incubated. The compounds of the present invention may also be used to facilitate the production of monoclonal and/or polyclonal antibodies, using antibody production techniques well known in the art. The monoclonal and/or polyclonal antibodies can then be used in a wide variety of diagnostic applications, as would be apparent to one skilled in the art.

The *in vivo* means of administration of the compounds of the present invention will vary depending upon the intended application. Administration of the

ADIr compositions described herein, in pure form or in an appropriate pharmaceutical composition, can be carried out via any of the accepted modes of administration of agents for serving similar utilities. The pharmaceutical compositions can be prepared by combining ADIr, *e.g.*, ADIr-PEG, ADIr-PEG 20, with an appropriate physiologically acceptable carrier, diluent or excipient, and may be formulated into preparations in solid, semi-solid, liquid or gaseous forms, such as tablets, capsules, powders, granules, ointments, solutions, suppositories, injections, inhalants, gels, microspheres, and aerosols. In addition, other pharmaceutically active ingredients (including other anti-cancer agents as described elsewhere herein) and/or suitable excipients such as salts, buffers and stabilizers may, but need not, be present within the composition. Administration may be achieved by a variety of different routes, including oral, parenteral, nasal, intravenous, intradermal, subcutaneous or topical. Modes of administration depend upon the nature of the condition to be treated or prevented. Thus, ADIr-PEG, *e.g.*, ADIr-PEG 20, may be administered orally, intranasally, intraperitoneally, parenterally, intravenously, intralymphatically, intratumorally, intramuscularly, interstitially, intra-arterially, subcutaneously, intraocularly, intrasynovial, transepithelial, and transdermally. An amount that, following administration, reduces, inhibits, prevents or delays the progression and/or metastasis of a cancer is considered effective. In certain embodiment, the ADIr compositions herein increase median survival time of patients by a statistically significant amount. In one embodiment, the ADIr treatments described herein increase median survival time of a patient by 4 weeks, 5 weeks, 6 weeks, 7 weeks, 8 weeks, 9 weeks, 10 weeks, 15 weeks, 20 weeks, 25 weeks, 30 weeks, 40 weeks, or longer. In certain embodiments, ADIr treatments increase median survival time of a patient by 1 year, 2 years, 3 years, or longer. In one embodiment, the ADIr treatments described herein increase progression-free survival by 2 weeks, 3 weeks, 4 weeks, 5 weeks, 6 weeks, 7 weeks, 8 weeks, 9 weeks, 10 weeks or longer. In certain embodiments, the ADIr treatments described herein increase progression-free survival by 1 year, 2 years, 3 years, or longer.

In certain embodiments, the amount administered is sufficient to result in tumor regression, as indicated by a statistically significant decrease in the amount of viable tumor, for example, at least a 10%, 20%, 30%, 40%, 50% or greater decrease in tumor mass, or by altered (*e.g.*, decreased with statistical significance) scan dimensions. In certain embodiments, the amount administered is sufficient to

result in stable disease. In other embodiments, the amount administered is sufficient to result in clinically relevant reduction in symptoms of a particular disease indication known to the skilled clinician.

In certain embodiments the amount administered is sufficient to inhibit
5 NO synthesis, inhibit angiogenesis, and or is sufficient to induce apoptosis in tumor cells or any combination thereof. NO synthesis, angiogenesis and apoptosis may be measured using methods known in the art, see, *e.g.*, *Current Protocols in Immunology* or *Current Protocols in Molecular Biology*, John Wiley & Sons, New York, N.Y.(2009 and updates thereto); Ausubel *et al.*, *Short Protocols in Molecular Biology*, 3rd ed., Wiley & Sons, 1995; and other like references. In one particular
10 embodiment the amount administered inhibits NO synthesis and inhibits the growth of melanoma and complements, adds to, or synergizes with other chemotherapies as described herein, such as cisplatin. Accordingly, one embodiment of the present disclosure provides a method of treating melanoma by administering ADIr-PEG 20 in
15 combination with cisplatin, wherein the treatment depletes endogenous nitric oxide (NO).

The precise dosage and duration of treatment is a function of the disease being treated and may be determined empirically using known testing protocols or by testing the compositions in model systems known in the art and
20 extrapolating therefrom. Controlled clinical trials may also be performed. Dosages may also vary with the severity of the condition to be alleviated. A pharmaceutical composition is generally formulated and administered to exert a therapeutically useful effect while minimizing undesirable side effects. The composition may be administered one time, or may be divided into a number of smaller doses to be
25 administered at intervals of time. For any particular subject, specific dosage regimens may be adjusted over time according to the individual need.

The ADIr compositions may be administered alone or in combination with other known cancer treatments, such as radiation therapy, chemotherapy, transplantation, immunotherapy, hormone therapy, photodynamic therapy, *etc.* The
30 compositions may also be administered in combination with antibiotics.

The ADIr compositions may also be administered alone or in combination with ADI-PEG 20 therapy. In certain embodiments, the ADIr as described herein are used in patients who have been treated with ADI-PEG 20 and who have developed anti-ADI-PEG 20 antibodies. Such patients no longer benefit

from ADI-PEG 20 treatment as the enzyme is neutralized by the antibodies. Thus, in certain embodiments, the invention provides a method of treating, ameliorating the symptoms of, or inhibiting the progression of a cancer comprising administering to a patient in need thereof a therapeutically effective amount of a composition

5 comprising ADI-PEG 20, and after a period of time, administering to the patient a composition comprising an ADIr as described herein, thereby treating, ameliorating the symptoms of, or inhibiting the progression of the cancer.

In one embodiment of the method, the period of time is determined by detecting a predetermined level of anti-ADI-PEG 20 antibodies in the patient,

10 wherein the composition comprising an ADIr is administered following detection of the predetermined level of said anti-ADI-PEG 20 antibodies. In certain embodiments, threshold level(s) or predetermined levels of anti-ADI-PEG 20 antibodies in patients to be treated with ADI-PEG 20 and the ADIr of the present invention can be established. A "predetermined threshold level" (also referred to as "predetermined
15 level" or "predetermined cut-off value"), or sometimes referred to as a predetermined cut off, of anti-ADI-PEG 20 antibodies may be established using methods known in the art, for example, using Receiver Operator Characteristic curves or "ROC" curves. In one embodiment, even very low levels of anti-ADI-PEG 20 antibodies is deemed sufficient to warrant switching treatment from ADI-PEG 20 to an ADIr-PEG of the
20 present invention. In certain embodiments, an appropriate level of anti-ADI-PEG 20 that will determine when to terminate ADI-PEG 20 treatment and begin treatment with an ADIr-PEG of the present invention can be determined by the skilled clinician.

In some embodiments, the period of time is determined by detecting or otherwise observing ADI activity in the patient, wherein the composition is

25 administered following detection or observation of a predetermined level of ADI activity. In particular embodiments, the composition is administered following detection or observation of a reduced level of ADI activity in the patient. ADI activity can be measured directly, for example, by assaying a biological sample for at least one indicator of ADI activity, or indirectly, for example, by observing the desired or
30 intended effect of the ADI-PEG 20 treatment. In certain embodiments, an appropriate level of ADI activity that will determine when to terminate ADI-PEG 20 treatment and begin treatment with an ADIr-PEG of the present invention can be determined by the skilled clinician.

Typical routes of administering these and related pharmaceutical compositions thus include, without limitation, oral, topical, transdermal, inhalation, parenteral, sublingual, buccal, rectal, vaginal, and intranasal. The term parenteral as used herein includes subcutaneous injections, intravenous, intramuscular,

5 intrasternal injection or infusion techniques.

Pharmaceutical compositions according to certain embodiments of the present invention are formulated so as to allow the active ingredients contained therein to be bioavailable upon administration of the composition to a patient.

Compositions that will be administered to a subject or patient may take the form of one or more dosage units, where for example, a tablet may be a single dosage unit, and a container of a herein described ADIr composition in aerosol form may hold a plurality of dosage units. Actual methods of preparing such dosage forms are known, or will be apparent, to those skilled in this art; for example, see *Remington: The Science and Practice of Pharmacy*, 20th Edition (Philadelphia College of Pharmacy and Science, 2000). The composition to be administered will, in any event, contain a therapeutically effective amount of an ADIr-PEG of the present disclosure, such as ADIr-PEG 20, for treatment of a disease or condition of interest in accordance with teachings herein. In certain embodiments, the pharmaceutical or therapeutic compositions are sterile and/or pyrogen-free.

20 A pharmaceutical composition may be in the form of a solid or liquid. In one embodiment, the carrier(s) are particulate, so that the compositions are, for example, in tablet or powder form. The carrier(s) may be liquid, with the compositions being, for example, an oral oil, injectable liquid or an aerosol, which is useful in, for example, inhalatory administration. When intended for oral administration, the pharmaceutical composition is generally either solid or liquid form, where semi-solid, semi-liquid, suspension and gel forms are included within the forms considered herein as either solid or liquid.

As a solid composition for oral administration, the pharmaceutical composition may be formulated into a powder, granule, compressed tablet, pill, capsule, chewing gum, wafer or the like. Such a solid composition will typically contain one or more inert diluents or edible carriers. In addition, one or more of the following may be present: binders such as carboxymethylcellulose, ethyl cellulose, microcrystalline cellulose, gum tragacanth or gelatin; excipients such as starch, lactose or dextrans, disintegrating agents such as alginic acid, sodium alginate,

Primogel, corn starch and the like; lubricants such as magnesium stearate or Sterotex; glidants such as colloidal silicon dioxide; sweetening agents such as sucrose or saccharin; a flavoring agent such as peppermint, methyl salicylate or orange flavoring; and a coloring agent. When the pharmaceutical composition is in the form of a capsule, for example, a gelatin capsule, it may contain, in addition to materials of the above type, a liquid carrier such as polyethylene glycol or oil.

The pharmaceutical composition may be in the form of a liquid, for example, an elixir, syrup, solution, emulsion or suspension. The liquid may be for oral administration or for delivery by injection, as two examples. When intended for oral administration, preferred composition contain, in addition to the present compounds, one or more of a sweetening agent, preservatives, dye/colorant and flavor enhancer. In a composition intended to be administered by injection, one or more of a surfactant, preservative, wetting agent, dispersing agent, suspending agent, buffer, stabilizer and isotonic agent may be included.

The liquid pharmaceutical compositions, whether they be solutions, suspensions or other like form, may include one or more of the following adjuvants: sterile diluents such as water for injection, saline solution, in certain embodiments, physiological saline, Ringer's solution, isotonic sodium chloride, fixed oils such as synthetic mono or diglycerides which may serve as the solvent or suspending medium, polyethylene glycols, glycerin, propylene glycol or other solvents; antibacterial agents such as benzyl alcohol or methyl paraben; antioxidants such as ascorbic acid or sodium bisulfite; chelating agents such as ethylenediaminetetraacetic acid; buffers such as acetates, citrates or phosphates and agents for the adjustment of tonicity such as sodium chloride or dextrose. The parenteral preparation can be enclosed in ampoules, disposable syringes or multiple dose vials made of glass or plastic. Physiological saline is a preferred adjuvant. An injectable pharmaceutical composition is preferably sterile.

A liquid pharmaceutical composition intended for either parenteral or oral administration should contain an amount of ADIr as herein disclosed, such as ADIr-PEG 20, such that a suitable dosage will be obtained. Typically, this amount is at least 0.01% of ADIr in the composition. When intended for oral administration, this amount may be varied to be between 0.1 and about 70% of the weight of the composition. Certain oral pharmaceutical compositions contain between about 4% and about 75% of ADIr-PEG. In certain embodiments, pharmaceutical compositions

and preparations according to the present invention are prepared so that a parenteral dosage unit contains between 0.01 to 10% by weight of ADIr-PEG prior to dilution.

The pharmaceutical composition may be intended for topical administration, in which case the carrier may suitably comprise a solution, emulsion, ointment or gel base. The base, for example, may comprise one or more of the following: petrolatum, lanolin, polyethylene glycols, bee wax, mineral oil, diluents such as water and alcohol, and emulsifiers and stabilizers. Thickening agents may be present in a pharmaceutical composition for topical administration. If intended for transdermal administration, the composition may include a transdermal patch or iontophoresis device. The pharmaceutical composition may be intended for rectal administration, in the form, for example, of a suppository, which will melt in the rectum and release the drug. The composition for rectal administration may contain an oleaginous base as a suitable nonirritating excipient. Such bases include, without limitation, lanolin, cocoa butter and polyethylene glycol.

The pharmaceutical composition may include various materials, which modify the physical form of a solid or liquid dosage unit. For example, the composition may include materials that form a coating shell around the active ingredients. The materials that form the coating shell are typically inert, and may be selected from, for example, sugar, shellac, and other enteric coating agents. Alternatively, the active ingredients may be encased in a gelatin capsule. The pharmaceutical composition in solid or liquid form may include an agent that binds to ADIr-PEG and thereby assists in the delivery of the compound. Suitable agents that may act in this capacity include monoclonal or polyclonal antibodies, one or more proteins or a liposome. The pharmaceutical composition may consist essentially of dosage units that can be administered as an aerosol. The term aerosol is used to denote a variety of systems ranging from those of colloidal nature to systems consisting of pressurized packages. Delivery may be by a liquefied or compressed gas or by a suitable pump system that dispenses the active ingredients. Aerosols may be delivered in single phase, bi-phasic, or tri-phasic systems in order to deliver the active ingredient(s). Delivery of the aerosol includes the necessary container, activators, valves, subcontainers, and the like, which together may form a kit. One of ordinary skill in the art, without undue experimentation may determine preferred aerosols.

The pharmaceutical compositions may be prepared by methodology well known in the pharmaceutical art. For example, a pharmaceutical composition intended to be administered by injection can be prepared by combining a composition that comprises ADIr-PEG as described herein and optionally, one or more of salts, buffers and/or stabilizers, with sterile, distilled water so as to form a solution. A surfactant may be added to facilitate the formation of a homogeneous solution or suspension. Surfactants are compounds that non-covalently interact with the ADIr-PEG composition so as to facilitate dissolution or homogeneous suspension of the ADIr-PEG in the aqueous delivery system.

The compositions may be administered in a therapeutically effective amount, which will vary depending upon a variety of factors including the activity of the specific compound (*e.g.*, ADIr-PEG) employed; the metabolic stability and length of action of the compound; the age, body weight, general health, sex, and diet of the patient; the mode and time of administration; the rate of excretion; the drug combination; the severity of the particular disorder or condition; and the subject undergoing therapy.

A therapeutically effective amount of one of the compounds of the present invention is an amount that is effective to inhibit tumor growth. Generally, treatment is initiated with small dosages which can be increased by small increments until the optimum effect under the circumstances is achieved. Generally, a therapeutic dosage of compounds of the present invention may be from about 1 to about 200 mg/kg twice a week to about once every two weeks. For example, the dosage may be about 1 mg/kg once a week as a 2 ml intravenous injection to about 20 mg/kg once every 3 days. In a further embodiment, the dose may be from about 50 IU/m² to about 700 IU/m², administered about once every 3 days, about once a week, about twice a week, or about once every 2 weeks. In certain embodiments, the dose may be about 50 IU/m², 60 IU/m², 70 IU/m², 80 IU/m², 90 IU/m², 100 IU/m², 110 IU/m², 120 IU/m², 130 IU/m², 140 IU/m², 150 IU/m², 160 IU/m², 170 IU/m², 180 IU/m², 190 IU/m², 200 IU/m², 210 IU/m², 220 IU/m², 230 IU/m², 240 IU/m², 250 IU/m², 260 IU/m², 270 IU/m², 280 IU/m², 290 IU/m², 300 IU/m², 310 IU/m², about 320 IU/m², about 330 IU/m², 340 IU/m² about 350 IU/m², 360 IU/m², 370 IU/m², 380 IU/m², 390 IU/m², 400 IU/m², 410 IU/m², 420 IU/m², 430 IU/m², 440 IU/m², 450 IU/m², 500 IU/m², 550 IU/m², 600 IU/m², 620 IU/m², 630 IU/m², 640 IU/m², 650 IU/m², 660 IU/m², 670 IU/m², 680 IU/m², 690 IU/m², or about 700 IU/m²

administered about once every 3 days, about once a week, about twice a week, or about once every 2 weeks. In certain embodiments, the dose may be modified as desired by the skilled clinician.

5 The optimum dosage with ADIr-SS-PEG5,000 may be about twice a week, while the optimum dosage with ADIr-SS-PEG20,000 may be from about once a week to about once every two weeks. In certain embodiments, the optimum dosage with ADIr-SS-PEG20,000 may be about twice a week.

ADIr-PEG may be mixed with a phosphate buffered saline solution, or any other appropriate solution known to those skilled in the art, prior to injection. In
10 one embodiment, a liquid composition comprising ADIr-PEG comprises about 10 to about 12 mg of ADIr, about 20 to about 40 mg of polyethylene glycol, 1.27 mg +5% monobasic sodium phosphate, USP; about 3 mg +5% dibasic sodium phosphate, USP; 7.6 mg +5% sodium chloride, USP; at a pH of about 6.6 to about 7; in an appropriate amount of water for injection (e.g., about 1 ml or about 2 ml). In one
15 embodiment, a liquid composition comprising an ADIr-PEG comprises histidine – HCl, and in certain embodiments, the composition buffer is from about 0.0035 M Histidine-HCl to about 0.35 M Histidine-HCl. In one particular embodiment, the composition is formulated in a buffer comprising 0.035 M Histidine-HCl at pH 6.8 with 0.13 M sodium chloride. In another embodiment, the composition is formulated in a
20 buffer comprising 0.02 M sodium phosphate buffer at pH 6.8 with 0.13 M sodium chloride.

In one embodiment, a composition comprising ADIr or ADIr-PEG has a pH of about 5 to about 9, about 6 to about 8, or about 6.5 to about 7.5. In some embodiments, the composition comprising ADIr has a pH of about 6.8 ± 1.0 .

25 In one embodiment, free PEG in a composition comprising ADIr-PEG is between 1-10%, and in a further embodiment, is less than 7%, less than 6%, less than 5%, less than 4%, less than 3%, less than 2% or less than 1% of the total PEG. In certain embodiments, the unmodified ADIr in a composition comprising ADIr-PEG is less than about 1%, 0.9%, 0.8%, 0.7%, 0.6%, 0.5%, 0.4%, 0.3%, 0.2% or less
30 than 0.1%. Generally, compositions comprising ADIr-PEG have total impurities less than or equal to about 4%, 3%, 2%, 1.5%, 1% or 0.5%. In one embodiment, the endotoxin limit meets the requirements stated in USP, i.e., ≤ 50 EU/mL.

In one embodiment, the free sulfhydryl in a composition comprising ADIr or ADIr-PEG is greater than about 90%. In some embodiments, the free

sulfhydryl in a composition comprising ADIr or ADIr-PEG is about 91%, about 92%, about 93%, about 94% or about 95%, about 96% about 97%, about 98% about 99% or more.

5 In one embodiment, the ADIr or ADIr-PEG in a composition has a K_m of from about 0.1 μM or 0.5 μM to about 15 μM , and in a further embodiment, is from about 1 μM to about 12 μM , about 1 μM to about 10 μM , about 1.5 μM to about 9 μM , about 1.5 μM to about 8 μM or about 1.5 μM to about 7 μM . In certain embodiments, the ADIr or ADIr-PEG in a composition has a K_m of about 1.0 μM to about 10 μM or about 1.5 μM to about 6.5 μM . In some embodiments, the ADIr or
10 ADIr-PEG in a composition has a K_m of about, at least about, or less than about 0.1 μM , about 0.5 μM , about 1.0 μM , about 1.5 μM , about 2 μM , about 2.5 μM , about 3 μM , about 3.5 μM , about 4 μM , about 4.5 μM , about 5 μM , about 5.5 μM , about 6 μM , about 6.5 μM , or about 7 μM , or about 8 μM , or about 9 μM , or about 10 μM .

In one embodiment, the ADIr or ADIr-PEG in a composition has a K_{cat}
15 of from about 0.5 sec^{-1} to about 80 sec^{-1} , or about 0.5 sec^{-1} to about 70 sec^{-1} , or about 0.5 sec^{-1} to about 60 sec^{-1} , or about 0.5 sec^{-1} to about 50 sec^{-1} , or about 0.5 sec^{-1} to about 40 sec^{-1} , or about 0.5 sec^{-1} to about 30 sec^{-1} , or about 0.5 sec^{-1} to about 20 sec^{-1} , or about 0.5 sec^{-1} to about 15 sec^{-1} , and in a further embodiment, is from about 0.5 sec^{-1} to about 80 sec^{-1} , or about 1 sec^{-1} to about 80 sec^{-1} , or about 5
20 sec^{-1} to about 80 sec^{-1} , or about 10 sec^{-1} to about 80 sec^{-1} , or about 20 sec^{-1} to about 80 sec^{-1} , or about 30 sec^{-1} to about 80 sec^{-1} , or about 40 sec^{-1} to about 80 sec^{-1} , or about 50 sec^{-1} to about 80 sec^{-1} , or about 60 sec^{-1} to about 80 sec^{-1} , or about 70 sec^{-1} to about 80 sec^{-1} , or about 1 sec^{-1} to about 12 sec^{-1} , about 1 sec^{-1} to about 10 sec^{-1} , about 1.5 sec^{-1} to about 9 sec^{-1} , about 2 sec^{-1} to about 8 sec^{-1} or about 2.5 sec^{-1}
25 sec^{-1} to about 7 sec^{-1} . In certain embodiments, the ADIr or ADIr-PEG in a composition has a K_{cat} of about 2.5 sec^{-1} to about 7.5 sec^{-1} . In some embodiments, the ADIr or ADIr-PEG in a composition has a K_{cat} of about or at least about 2.5 sec^{-1} , about 3 sec^{-1} , about 3.5 sec^{-1} , about 4 sec^{-1} , about 4.5 sec^{-1} , about 5 sec^{-1} , about 5.5 sec^{-1} , about 6 sec^{-1} , about 6.5 sec^{-1} , about 7 sec^{-1} , about 7.5 sec^{-1} or about 8 sec^{-1} , about
30 10 sec^{-1} , about 15 sec^{-1} , about 20 sec^{-1} , about 25 sec^{-1} , about 30 sec^{-1} , about 35 sec^{-1} , about 40 sec^{-1} , about 45 sec^{-1} , about 50 sec^{-1} , about 55 sec^{-1} , about 60 sec^{-1} , about 65 sec^{-1} , about 70 sec^{-1} , about 75 sec^{-1} , about 80 sec^{-1} , about 85 sec^{-1} , about 90 sec^{-1} , about 95 sec^{-1} , or about 100 sec^{-1} .

In one embodiment, the ADIr or ADIr-PEG in a composition has a conductivity (also referred to in the art as specific conductance) of about 5 mS/cm to about 20 mS/cm, and in further embodiments, from about 5 mS/cm to about 15 mS/cm, about 7 mS/cm to about 15 mS/cm, about 9 mS/cm to about 15 mS/cm or about 10 mS/cm to about 15 mS/cm. In some embodiments, the ADIr or ADIr-PEG in a composition has a conductivity of about 9 mS/cm, about 10 mS/cm, about 11 mS/cm, about 12 mS/cm or about 13 mS/cm, about 14 mS/cm or about 15 mS/cm. In certain embodiments, the ADIr or ADIr-PEG in a composition has a conductivity of about 13 mS/cm $\pm$ 1.0 mS/cm.

In one embodiment, the ADIr or ADIr-PEG in a composition has an osmolality of about 50 mOsm/kg to about 500 mOsm/kg, about 100 mOsm/kg to about 400 mOsm/kg, about 150 mOsm/kg to about 350 mOsm/kg, about 200 mOsm/kg to about 350 mOsm/kg or about 250 mOsm/kg to about 350 mOsm/kg. In certain embodiments, the ADIr or ADIr-PEG in a composition has an osmolality of about 300 $\pm$ 30 mOsm/kg.

In one embodiment, the protein concentration is about 11.0 $\pm$ 1.0 mg/mL. In certain embodiments, the protein concentration is between about 8 and about 15 mg/mL. In another embodiment, the protein concentration is about 8, 9, 10, 10.5, 11, 11.5, 12, 12.5, 13, 13.5, 14, or 15 mg/mL.

In one embodiment, the specific enzyme activity is between about 5.0 and 90 IU/mg or between about 5 and 55 IU/mg, where 1 IU is defined as the amount of enzyme that converts one μ mol of arginine into one μ mol of citrulline and 1 μ mol of ammonia in one minute at 37° C and the potency is 100 $\pm$ 20 IU/mL. In another embodiment, the specific enzyme activity is about 5.5, 6, 6.5, 7, 7.5, 8, 8.5, 9.0, 9.5, 10, 10.5, 11, 11.5, 12, 12.5, 13, 13.5, 14, 14.5, 15, 15.5, 16, 16.5, 17, 17.5, 18, 18.5, 19, 19.5, 20, 20.5, 21, 21.5, 22, 22.5, 23, 23.5, 24, 24.5, 25, 25.5, 26, 26.5, 27, 27.5, 28, 28.5, 29, 29.5, 30, 30.5, 35, 40, 45, 50, 55, 55, 60, 65, 70, 75, 80, 85, 90, 95, or 100 $\pm$ 2.0 IU/mg. In one particular embodiment, the specific enzyme activity is 9 $\pm$ 2.0 IU/mg.

Compositions comprising ADIr-PEG of the present disclosure may also be administered simultaneously with, prior to, or after administration of one or more other therapeutic agents, including ADI-PEG 20. Such combination therapy may include administration of a single pharmaceutical dosage formulation which contains

a compound of the invention and one or more additional active agents, as well as administration of compositions comprising ADIr-PEG (e.g., ADIr-PEG 20) of the invention and each active agent in its own separate pharmaceutical dosage formulation. For example, ADIr-PEG as described herein and the other active agent
5 can be administered to the patient together in a single oral dosage composition such as a tablet or capsule, or each agent administered in separate oral dosage formulations. Similarly, ADIr-PEG as described herein and the other active agent can be administered to the patient together in a single parenteral dosage composition such as in a saline solution or other physiologically acceptable solution,
10 or each agent administered in separate parenteral dosage formulations, by the same or different routes (e.g., one by injection, one by oral). Where separate dosage formulations are used, the compositions comprising ADIr-PEG and one or more additional active agents can be administered at essentially the same time, *i.e.*, concurrently, or at separately staggered times, *i.e.*, sequentially and in any order;
15 combination therapy is understood to include all these regimens.

Thus, in certain embodiments, also contemplated is the administration of the ADIr compositions of this disclosure in combination with one or more other therapeutic agents. Such therapeutic agents may be accepted in the art as a standard treatment for a particular disease state as described herein, such as a
20 particular cancer or GVHD. Exemplary therapeutic agents contemplated include cytokines, growth factors, steroids, NSAIDs, DMARDs, anti-inflammatories, chemotherapeutics, radiotherapeutics, autophagy inhibitors, or other active and ancillary agents.

In certain embodiments, the ADIr compositions disclosed herein may
25 be administered in conjunction with any number of chemotherapeutic agents. Examples of chemotherapeutic agents include alkylating agents such as thiotepa and cyclophosphamide (CYTOXANTM); alkyl sulfonates such as busulfan, improsulfan and piposulfan; aziridines such as benzodopa, carboquone, meturedopa, and uredopa; ethylenimines and methylamelamines including
30 altretamine, triethylenemelamine, trietylenephosphoramide, triethylenethiophosphoramide and trimethylolomelamine; nitrogen mustards such as chlorambucil, chlornaphazine, cholophosphamide, estramustine, ifosfamide, mechlorethamine, mechlorethamine oxide hydrochloride, melphalan, novembichin, phenesterine, prednimustine, trofosfamide, uracil mustard; nitrosureas such as

carmustine, chlorozotocin, fotemustine, lomustine, nimustine, ranimustine; antibiotics such as aclacinomysins, actinomycin, authramycin, azaserine, bleomycins, cactinomycin, calicheamicin, carabycin, carminomycin, carzinophilin, chromomycins, dactinomycin, daunorubicin, detorubicin, 6-diazo-5-oxo-L-norleucine, doxorubicin, 5 epirubicin, esorubicin, idarubicin, marcellomycin, mitomycins, mycophenolic acid, nogalamycin, olivomycins, peplomycin, potfiromycin, puromycin, quelamycin, rodorubicin, streptonigrin, streptozocin, tubercidin, ubenimex, zinostatin, zorubicin; anti-metabolites such as methotrexate and 5-fluorouracil (5-FU); folic acid analogues such as denopterin, methotrexate, pteropterin, trimetrexate; purine analogs such as 10 fludarabine, 6-mercaptopurine, thiamiprine, thioguanine; pyrimidine analogs such as ancitabine, azacitidine, 6-azauridine, carmofur, cytarabine, dideoxyuridine, doxifluridine, enocitabine, floxuridine, 5-FU; androgens such as calusterone, dromostanolone propionate, epitiostanol, mepitiothane, testolactone; anti-adrenals such as aminoglutethimide, mitotane, trilostane; folic acid replenisher such as frolinic 15 acid; aceglatone; aldophosphamide glycoside; aminolevulinic acid; amsacrine; bestrabucil; bisantrene; edatraxate; defofamine; demecolcine; diaziquone; elformithine; elliptinium acetate; etoglucid; gallium nitrate; hydroxyurea; lentinan; lonidamine; mitoguazone; mitoxantrone; mopidamol; nitracrine; pentostatin; phenamet; pirarubicin; podophyllinic acid; 2-ethylhydrazide; procarbazine; 20 PSK.RTM.; razoxane; sizofiran; spirogermanium; tenuazonic acid; triaziquone; 2, 2',2"-trichlorotriethylamine; urethan; vindesine; dacarbazine; mannomustine; mitobronitol; mitolactol; pipobroman; gacytosine; arabinoside ("Ara-C"); cyclophosphamide; thiotepa; taxoids, e.g. paclitaxel (TAXOL®, Bristol-Myers Squibb Oncology, Princeton, N.J.) and docetaxel (TAXOTERE®, Rhne-Poulenc Rorer, 25 Antony, France); chlorambucil; gemcitabine; 6-thioguanine; mercaptopurine; methotrexate; platinum analogs such as cisplatin and carboplatin; vinblastine; platinum; etoposide (VP-16); ifosfamide; mitomycin C; mitoxantrone; vincristine; vinorelbine; navelbine; novantrone; teniposide; daunomycin; aminopterin; xeloda; ibandronate; CPT-11; topoisomerase inhibitor RFS 2000; difluoromethylomithine 30 (DMFO); retinoic acid derivatives such as Targretin™ (bexarotene), Panretin™ (alitretinoin) ; ONTAK™ (denileukin diftitox) ; esperamicins; capecitabine; and pharmaceutically acceptable salts, acids or derivatives of any of the above. Also included in this definition are anti-hormonal agents that act to regulate or inhibit hormone action on tumors such as anti-estrogens including for example tamoxifen,

raloxifene, aromatase inhibiting 4(5)-imidazoles, 4-hydroxytamoxifen, trioxifene, keoxifene, LY117018, onapristone, and toremifene (Fareston); and anti-androgens such as flutamide, nilutamide, bicalutamide, leuprolide, and goserelin. Further chemotherapeutic agents include sorafenib and other protein kinase inhibitors such as afatinib, axitinib, bevacizumab, cetuximab, crizotinib, dasatinib, erlotinib, fostamatinib, gefitinib, imatinib, lapatinib, lenvatinib, mubritinib, nilotinib, panitumumab, pazopanib, pegaptanib, ranibizumab, ruxolitinib, trastuzumab, vandetanib, vemurafenib, and sunitinib; sirolimus (rapamycin), everolimus and other mTOR inhibitors. Pharmaceutically acceptable salts, acids or derivatives of any of the above are also contemplated for use herein.

In certain embodiments, the ADIr compositions disclosed herein may be administered in conjunction with any number of autophagy inhibitors. In some preferred embodiments, the autophagy inhibitor is selected from the group consisting of: chloroquine, 3-methyladenine, hydroxychloroquine (Plaquenil.TM.), bafilomycin A1, 5-amino-4-imidazole carboxamide riboside (AICAR), okadaic acid, autophagy-suppressive algal toxins which inhibit protein phosphatases of type 2A or type 1, analogues of cAMP, and drugs which elevate cAMP levels, adenosine, N6-mercaptopurine riboside, wortmannin, and vinblastine. In addition, antisense or siRNA that inhibits expression of proteins essential for autophagy, such as for example ATG5, may also be used.

In one embodiment, the combination of ADIr-PEG with one or more therapeutic agents acts complementary, additively, or synergistically. In this regard, complementary or synergizing agents are described herein, which include a therapeutic agent (e.g., chemotherapeutic agent, autophagy inhibitor, mTOR inhibitor, or any other therapeutic agent used for the treatment of cancer, GVHD, or inflammatory bowel disease as described herein) that is capable of acting complementary or synergistically with ADIr-PEG as provided herein, where such complementarity or synergy manifests as a detectable effect that is greater (i.e., in a statistically significant manner relative to an appropriate control condition) in magnitude than the effect that can be detected when the chemotherapeutic agent is present but the ADIr-PEG composition is absent, and/or when the ADIr-PEG is present but the chemotherapeutic agent is absent. Methods for measuring synergy and complementarity are known in the art (see e.g., Cancer Res January 15, 2010 70; 440).

The compositions comprising ADI_r, and optionally other therapeutic agents, as described herein may be used in therapeutic methods for treating cancer and methods for preventing metastasis of a cancer. Thus, the present invention provides for methods for treating, ameliorating the symptoms of, or inhibiting the progression of or prevention of a variety of different cancers. In another embodiment, the present disclosure provides methods for treating, ameliorating the symptoms of, or inhibiting the progression of GVHD. In particular the present disclosure provides methods for treating, ameliorating the symptoms of, or inhibiting the progression of a cancer or GVHD in a patient comprising administering to the patient a therapeutically effective amount of ADI_r composition as described herein, optionally, following treatment with ADI-PEG 20, particularly where a patient develops anti-ADI-PEG 20 antibodies, thereby treating, ameliorating the symptoms of, or inhibiting the progression of the cancer or GVHD. Thus, the ADI_r compositions described herein may be administered to an individual afflicted with inflammatory bowel disease (*e.g.*, Crohn's disease; ulcerative colitis), GVHD or a cancer, including, but not limited to hepatocellular carcinoma, leukemia (*e.g.* acute myeloid leukemia and relapsed acute myeloid leukemia), melanoma including metastatic melanoma, sarcomas (including, but not limited to, metastatic sarcomas, uterine leiomyosarcoma), pancreatic cancer, prostate cancer (such as, but not limited to, hormone refractory prostate cancer), mesothelioma, lymphatic leukemia, chronic myelogenous leukemia, lymphoma, small cell lung cancer, breast cancer, ovarian cancer, colorectal cancer, gastric cancer (including, but not limited to, gastric adenocarcinoma), glioma, glioblastoma multi-form, retinoblastoma, neuroblastoma, non-small cell lung cancer (NSCLC), kidney cancer (including but not limited to renal cell carcinoma), bladder cancer, uterine cancer, esophageal cancer, brain cancer, head and neck cancers (including, but not limited to, squamous cell carcinoma of the head and neck; cancer of the tongue), cervical cancer, testicular cancer, gallbladder, cholangiocarcinoma, and stomach cancer.

In another embodiment, the present disclosure provides a method of treating, ameliorating the symptoms of, or inhibiting the progression of a cancer in a patient comprising administering to the patient a composition comprising ADI_r, and optionally one or more other therapeutic agents, as described herein, wherein the cancer is deficient in ASS, ASL, or both. In this regard, ASS or ASL deficiency may be a reduction in expression as measured by mRNA expression or protein

expression, or may be a reduction in protein activity, and generally comprises a statistically significant reduction in expression or activity as determined by the skilled person. Reduced ASS or ASL expression or activity may be a reduction in expression or activity of about 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%,
5 50%, 55%, 60%, 65%, 70%, or more, as compared to expression or activity in an appropriate control sample known to be cancer free. In certain embodiments, ASS or ASL expression or activity is reduced by at least twofold as compared to expression or activity in a non-cancer control sample.

10 In certain embodiments, the reduced expression or activity of ASS or ASL results from methylation of the ASS or ASL promoter or inhibition of the ASS or ASL promoter. In another embodiment the reduction in expression or activity of ASS or ASL results from a DNA mutation (*e.g.*, one or more point mutations, small deletions, insertions, and the like) or a chromosomal abnormality resulting in deletion of the gene. In one embodiment, the cancer is ASS or ASL negative, meaning no
15 expression or activity is observed.

Reduction in ASS or ASL expression or activity may be measured using any methods known in the art, such as but not limited to, quantitative PCR, immunohistochemistry, enzyme activity assays (*e.g.*, assay to measure conversion of citrulline into argininosuccinate or conversion of argininosuccinate into arginine
20 and fumarate), and the like.

Thus, the present invention provides methods for treating, ameliorating the symptoms of, or inhibiting the progression of a cancer in a patient comprising administering to the patient a composition comprising ADIr as described herein, wherein the cancer exhibits reduced expression or activity of ASS or ASL, or both,
25 wherein the cancer includes, but is not limited to hepatocellular carcinoma, leukemia (*e.g.* acute myeloid leukemia and relapsed acute myeloid leukemia), melanoma including metastatic melanoma, sarcomas (including, but not limited to, metastatic sarcomas, uterine leiomyosarcoma), pancreatic cancer, prostate cancer (such as, but not limited to, hormone refractory prostate cancer), mesothelioma, lymphatic
30 leukemia, chronic myelogenous leukemia, lymphoma, small cell lung cancer, breast cancer, ovarian cancer, colorectal cancer, gastric cancer (including, but not limited to, gastric adenocarcinoma), glioma, glioblastoma multi-form, retinoblastoma, neuroblastoma, non-small cell lung cancer (NSCLC), kidney cancer (including but not limited to renal cell carcinoma), bladder cancer, uterine cancer, esophageal

cancer, brain cancer, head and neck cancers (including, but not limited to, squamous cell carcinoma of the head and neck; cancer of the tongue), cervical cancer, testicular cancer, gallbladder, cholangiocarcinoma, and stomach cancer.

Various studies in the literature have shown that ASS is deficient in the following tumors: acute myelogenous leukemia (AML), bladder, breast, colorectal, gastric, glioblastoma, HCC, lymphoma, melanoma, mesothelioma, non-small cell lung, ovarian, pancreatic, prostate, renal, sarcoma, and small cell lung. Accordingly, treatment of these ASS-deficient cancers is specifically contemplated herein, with ADIr-PEG alone or in combination with other treatments, including treatment first with ADI-PEG 20.

The present invention further provides methods for treating, ameliorating the symptoms of, or inhibiting the progression of cancer in a patient comprising administering to the patient a composition comprising ADIr as described herein (e.g., ADIr-PEG and in particular ADIr-PEG 20), in combination with an autophagy inhibitor. In one embodiment, the present invention provides methods for treating cancer in a patient comprising administering to the patient a therapeutically effective amount of a composition comprising ADIr as described herein in combination with autophagy inhibitor wherein the cancer is pancreatic cancer or small cell lung cancer.

In certain embodiments, the present invention provides methods of treatment where administration of the compositions comprising ADIr described herein depletes arginine in the plasma for at least one month, 2 months, 3 months, 4 months, 5 months, 6 months or longer. In another embodiment, the present invention provides methods of treatment where administration of the compositions comprising ADIr described herein depletes arginine in the plasma for at least one month, 2 months, 3 months, 4 months, 5 months, 6 months or longer after terminating treatment with ADI-PEG 20 following detection of anti-ADI-PEG 20 antibodies.

EXAMPLES

EXAMPLE 1

SCREENING AND SELECTION OF ADI ENZYMES THAT HAVE LOW CROSS-REACTIVITY WITH

5

PATIENT ANTI-ADI-PEG 20 ANTIBODIES

This example describes the screening and selection of ADI enzymes that have low cross-reactivity with patient anti-ADI-PEG 20 antibodies.

From a large number of ADI enzymes, Table 1 lists 24 ADI enzymes selected for their sequence percent identity relative to *M. hominis* ADI. From the literature, *M. hominis*, *M. arginini*, and *M. arthritidis* ADI amino acid sequences are closely related and these enzymes have good catalytic properties. More recently, additional ADI enzymes have been discovered that have sequences closely related to these three. More distantly related Mycoplasma ADI enzymes have been identified, although less is known about them. Even more distantly related ADI enzymes from bacterial and other sources exist.

15

Table 1. Selected ADI Sequences with Varying Degrees of Similarity to <i>M. hominis</i> ADI			
ORGANISM	PERCENT IDENTITY	SEQUENCE ACCESSION NUMBER	SEQ ID NO:
<i>Mycoplasma hominis</i>	100.0%	gi 728876	1
<i>Mycoplasma phocicerebrale</i>	82.1%	gi 154184333	2
<i>Mycoplasma arginini</i>	82.1%	gi 728875	3
<i>Mycoplasma arthritidis</i>	80.4%	gi 238692486	4
<i>Mycoplasma orale</i>	77.8%	gi 2170494	5
<i>Mycoplasma gateae</i>	76.8%	gi 148361415	6
<i>Mycoplasma phocidae</i>	75.3%	gi 154184335	7
<i>Mycoplasma columbinum</i>	58.2%	gi 343491689	8
<i>Mycoplasma iowae</i>	55.2%	gi 350546321	9
<i>Mycoplasma crocodyli</i>	52.3%	gi 291600396	10
<i>Mycoplasma fermentans</i>	52.0%	gi 238809916	11
<i>Mycoplasma penetrans</i>	51.7%	gi 26554060	12
<i>Mycoplasma gallisepticum</i>	51.5%	gi 31544533	13
<i>Mycoplasma alligatoris</i>	50.8%	gi 292552899	14
<i>Mycoplasma pneumoniae</i>	50.7%	gi 440453687	15
<i>Mycoplasma mobile</i>	47.3%	gi 47458387	16
<i>Streptococcus pyogenes</i>	37.7%	gi 15675444	17
<i>Enterococcus faecalis</i>	37.1%	gi 60389809	18
<i>Mycoplasma capricolum</i>	36.6%	gi 83319656	19
<i>Halothermothrix orenii</i>	34.8%	gi 254803235	20
<i>Staphylococcus aureus</i>	33.8%	gi 123549453	21

Table 1. Selected ADI Sequences with Varying Degrees of Similarity to *M. hominis* ADI

ORGANISM	PERCENT IDENTITY	SEQUENCE ACCESSION NUMBER	SEQ ID NO:
<i>Pseudomonas plecoglossicida</i>	28.7%	gi 154183755	22
<i>Pseudomonas putida</i>	27.5%	gi 431801013	23
<i>Pseudomonas aeruginosa</i>	27.0%	gi 452183609	24
<i>Mycobacterium bovis</i>	26.8%	gi 378770764	25

Several of the protein sequences available in the public databases may not have been full-length ADI sequences. In those cases, the publicly available sequences were extended where needed to make full-length ADI based on known ADI sequences. In certain cases, the ADI proteins were modified elsewhere (e.g., C251S substitution). These synthesized ADI sequences are provided in SEQ ID NOs:26-32 and correspond to the extended and/or modified ADI sequences of *Mycoplasma arginini* (C251S), *Mycoplasma arthritidis* (C251S), *Mycoplasma phocicerebrale*, *Mycoplasma gateae*, *Mycoplasma phocidae*, *H.orenii*, and *Mycobacterium bovis*.

A number of ADI enzymes from a variety of organisms were characterized to determine which enzymes would be expected to remove and maintain low concentrations of arginine in patient blood, even in the presence of anti-ADI-PEG 20 antibodies. Table 2 (below) lists a selected subset of ADI enzymes from Table 1 that were studied. As detailed below, the data from these studies show that ADI from a number of species that are closely related to *M. hominis*, based on sequence identity, have sufficiently good enzyme catalytic properties and reduced cross-reactivity with anti-ADI-PEG 20 antibodies.

ADI Preparation. Recombinant ADI enzymes were cloned, expressed, and purified for testing according to standard protocols, as described, for example, in Gallego et al., PLOS One, 7(10):e47886, 2012; Monstadt and Holldorf, Biochem. J. 273:739-745, 1990; Joo Noh et al., Molecules and Cells. 13:137-143, 2002; and Sugimura et al., Infection and Immunity. 58:2510-2515, 1990.

Human Anti-ADI-PEG20 Antibody Purification. Anti-ADI-PEG20 antibody was purified from plasma samples of patients who had received ADI-PEG20 during a clinical study. A total of 60 ml of plasma was pooled from 8 different patients that had reached high titer (titer ≥ 4) against ADI-PEG20 as determined by an ELISA assay. A two-step purification was used, a Protein "A" chromatography

(GE Healthcare) followed by an ADI affinity chromatography. ~20 mg of purified antibody was obtained and stored at -80°C in aliquots until needed.

ADI Enzyme Assays. Arginine deiminase (ADI) catalyzes the conversion of L-arginine to L-citrulline and ammonia. The amount of L-citrulline can be detected by a colorimetric endpoint assay (see, for example, Knipp and Vasak, Analytical Biochem. 286:257-264, 2000) and compared to a standard curve of known amounts of L-citrulline in order to calculate the specific activity of ADI expressed as IU/mg of protein. One IU of enzyme activity is defined as the amount of enzyme that produces 1 μ mol of citrulline per minute at the pH and temperature being tested. Standard assay conditions were performed at 37°C in Physiological HEPES Buffer (PHB) 50 mM HEPES, 160 mM NaCl pH 7.4 (Lang and Zander, Clin Chem Lab Med. 37:563-571, 1999) plus 0.1% BSA. All samples and standards were run in duplicate or triplicate where conditions permitted.

K_m and K_{cat} values were determined by using a variation of the activity assay described above. As with the activity assay, all reactions were run at 37°C in PHB plus 0.1% BSA. Enzyme concentration, reaction time, and substrate concentration range were adjusted for each of the ADI or ADIr constructs to account for their differences in activity. In general, 2 nM enzyme, 5 minute reaction time, and a 0 – 160 μ M arginine was used as starting conditions. When optimizing the conditions, particular attention was paid towards the amount of substrate consumed as a percentage of total substrate added to the reaction. The lower limit of detection is 1 μ M of citrulline with the lower limit of quantitation being 2 μ M. A citrulline standard curve was run on every plate and used to quantify the citrulline produced by the enzymatic reaction.

Activity assays were also performed to assess enzymatic activity in the presence of anti-ADI-PEG20 (antibody neutralization profiles). These assays were performed as described above and in the presence of 800 nM, 400 nM, 200 nM, 100 nM, 50 nM, 25 nM, 12.5 nM, and 0 nM of anti-ADI-PEG20 antibodies.

Calculations. The citrulline concentration (μ M) produced in each reaction well was calculated and averaged using the citrulline standard curve. The velocity of each reaction was then calculated in μ M/min/50 nM ADI. Specific activity (IU/mg or μ mol product/min/mg ADI) was calculated by multiplying this value by the “IU” factor (IU factor was calculated from the molecular weight of the ADI and the reaction volume). The results are summarized in Table 2 below.

Table 2. Selected ADI Sequences and Properties

ORGANISM	SEQUENCE PERCENT IDENTITY	SPECIFIC ACTIVITY (IU/MG)***	NUMBER OF SURFACE RESIDUE CHANGES*	REDUCED AB CROSS- REACTIVITY****
<i>Mycoplasma hominis</i>	100.0	+	0	-
<i>Mycoplasma phocicerebrale</i>	82.1	+	33	Y
<i>Mycoplasma arginini</i>	82.1	+	50	Y
<i>Mycoplasma arthritidis</i>	80.4	+	53	Y
<i>Mycoplasma gateae</i>	76.8	+	48	Y
<i>Mycoplasma phocidae</i>	75.3	+	51	Y
<i>Mycoplasma columbinum</i>	58.2	+	93	Y
<i>Mycoplasma iowae</i>	55.2	-	107	ND
<i>Mycoplasma crocodyli</i>	52.3	-	107	ND
<i>Mycoplasma gallisepticum</i>	51.5	-	108	ND
<i>Mycoplasma alligatoris</i>	50.8	+	111	Y
<i>Mycoplasma mobile</i>	47.3	ND	111	ND
<i>Halothermothrix orenii</i>	34.8	-	122	ND
<i>Mycobacterium bovis</i>	26.8	-	132	ND
* Surface residues were identified from the crystal structure of <i>M. hominis</i> ADI and surface residues for ADI from other organisms was determined by sequence homology.				
** ND: Not Determined.				
*** "+" indicates specific enzymatic activity of ≥ 8 IU/mg under physiological conditions and in the absence of anti-ADI-PEG20 antibodies.				
**** "Y" indicates reduced anti-ADI-PEG20 cross-reactivity relative to <i>M. hominis</i> ADI, as measured by specific enzymatic activity in the presence of anti-ADI-PEG20 antibodies.				

These data show that ADI enzymes that are highly homologous to *M. hominis* ADI (about 50-100 percent identity) maintained excellent catalytic activity.

- 5 They also showed reduced affinity toward patient anti-ADI-PEG 20 antibodies, as measured by enzyme activity in the presence of anti-ADI-PEG 20 antibodies, for example, relative to that of *Mycoplasma hominis*. Accordingly, these ADI enzymes may have therapeutic utility for use in therapy for the treatment of cancer, either alone or following ADI-PEG 20 treatment, to extend and/or increase the
- 10 effectiveness of arginine depletion therapy.

The various embodiments described above can be combined to provide further embodiments. All of the U.S. patents, U.S. patent application publications, U.S. patent application, foreign patents, foreign patent application and

15 non-patent publications referred to in this specification and/or listed in the Application

Data Sheet are incorporated herein by reference, in their entirety. Aspects of the embodiments can be modified, if necessary to employ concepts of the various patents, application and publications to provide yet further embodiments.

- 5 These and other changes can be made to the embodiments in light of the above-detailed description. In general, in the following claims, the terms used should not be construed to limit the claims to the specific embodiments disclosed in the specification and the claims, but should be construed to include all possible embodiments along with the full scope of equivalents to which such claims are entitled. Accordingly, the claims are not limited by the disclosure.

CLAIMS

What is claimed is:

1. A therapeutic composition comprising an isolated arginine deiminase (ADI) and a pharmaceutically-acceptable carrier, wherein the isolated ADI comprises the amino acid sequence set forth in any one of SEQ ID NOs: 2, 6, 8, or 14, or a sequence at least 95% sequence identity to any one of SEQ ID NOs: 2, 6, 8, or 14 having arginine deiminase activity.

2. The therapeutic composition of claim 1 wherein the isolated ADI has been modified to remove at least one pegylation site.
3. The therapeutic composition of claim 1 or 2 wherein at least one lysine residue has been modified by an amino acid substitution.
4. The therapeutic composition of claim 3 wherein at least 5 lysine residues have been modified by an amino acid substitution.
5. The therapeutic composition of claim 3 wherein at least 10 lysine residues have been modified by an amino acid substitution.

6. The therapeutic composition of claim 3 wherein at least 15 lysine residues have been modified by an amino acid substitution.
7. The therapeutic composition of claim 3 wherein at least 20 lysine residues have been modified by an amino acid substitution.
8. The therapeutic composition of any one of claims 1-4 wherein the ADI is covalently bonded via a linker to at least one PEG molecule.
9. The therapeutic composition of claim 5 wherein the ADI is covalently bonded to more than one PEG molecule.
10. The therapeutic composition of claim 5 wherein the ADI is covalently bonded to 1 to 10 PEG molecules.
11. The therapeutic composition of claim 5 wherein the ADI is covalently bonded to 2 to 8 PEG molecules.
12. The therapeutic composition of claim 5 wherein the PEG molecules are straight chain or branch chain PEG molecules.
13. The therapeutic composition of claim 5 wherein the PEG has a total weight average molecular weight of from 1,000 to 40,000 or from 10,000 to 30,000.
14. The therapeutic composition of claim 8 wherein the linker is a succinyl group, an amide group, an imide group, a carbamate group, an ester group, an epoxy group, a carboxyl group, a hydroxyl group, a carbohydrate, a tyrosine group, a cysteine group, a histidine group, a methylene group, or any combinations thereof.
15. The therapeutic composition of claim 14 wherein the source of the succinyl group is succinimidyl succinate.

16. The therapeutic composition of any one of claims 1 to 10 further comprising a chemotherapeutic agent.

17. The therapeutic composition of claim 11 wherein the chemotherapeutic agent is selected from the group consisting of docetaxel, carboplatin, cyclophosphamide, gemcitabine, cisplatin, sorafenib, sunitinib and everolimus.

18. Use of a therapeutic composition of any one of claims 1 to 17 in the manufacture of a medicament for treating, ameliorating the symptoms of, or inhibiting the progression of a cancer.

19. The use of claim 18 wherein the patient in need thereof has been determined to have anti-ADI-PEG 20 antibodies.

20. The use of claim 18 or 19 wherein the cancer is selected from the group consisting of hepatocellular carcinoma, melanoma, metastatic melanoma, pancreatic cancer, prostate cancer, small cell lung cancer, mesothelioma, lymphocytic leukemia, chronic myelogenous leukemia, lymphoma, hepatoma, sarcoma, leukemia, acute myeloid leukemia, relapsed acute myeloid leukemia, breast cancer, ovarian cancer, colorectal cancer, gastric cancer, glioma, glioblastoma multiforme, non-small cell lung cancer (NSCLC), kidney cancer, bladder cancer, uterine cancer, esophageal cancer, brain cancer, head and neck cancers, cervical cancer, testicular cancer, and stomach cancer.

21. Use of a therapeutic composition comprising ADI-PEG 20 and a therapeutic composition of any one of claims 1 to 17 in the manufacture of a medicament for ameliorating the symptoms of, or inhibiting the progression of a cancer in a patient in need thereof, wherein said therapeutic composition is to be administered after said composition comprising ADI-PEG 20 after a period of time.

22. The use of claim 21 wherein the period of time is determined by detecting a predetermined level of anti-ADI-PEG 20 antibodies in the patient, wherein the therapeutic composition is administered following detection of the predetermined level of said anti-ADI-PEG 20 antibodies.
23. The use of claim 21 wherein the period of time is determined by detecting ADI activity in the patient, wherein the therapeutic composition is administered following detection of a predetermined or reduced level of ADI activity.
24. A therapeutic composition of any one of claims 1 to 17 for use in treating, ameliorating the symptoms of, or inhibiting the progression of a cancer.
25. A composition comprising ADI-PEG 20 and a therapeutic composition of any one of claims 1 to 17 for use in treating, ameliorating the symptoms of, or inhibiting the progression of a cancer.