

COMPOSITIONS, KITS, AND METHODS TO INDUCE ACQUIRED CYTORESISTANCE USING STRESS PROTEIN INDUCERS

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0001] This invention was made with government support under grant DK38432 awarded by the National Institutes of Health. The government has certain rights in the invention.

CROSS REFERENCES TO RELATED APPLICATIONS

[0002] This Application claims priority to US Provisional Patent Application No. 62/057,047 filed September 29, 2014 and to US Provisional Patent Application No. 62/212,232 filed August 31, 2015, the entire contents of both of which are incorporated by reference herein.

FIELD OF THE DISCLOSURE

[0003] The present disclosure provides compositions, kits, and methods to protect organs by inducing acquired cytoresistance without causing injury to the organ. The compositions, kits, and methods can utilize heme proteins and, optionally, agents that impact heme protein metabolism. Other compounds that up-regulate stress proteins (e.g., iron and vitamin B12) may also be used.

BACKGROUND OF THE DISCLOSURE

[0004] Injury to a bodily organ can elicit protective responses by the organ such that it is able to better protect itself should injurious events (i.e., insults) continue or re-occur. For example, a bout of kidney injury can evoke protective responses that, after an 18 hour lag time, protect the kidney against subsequent, more severe forms of kidney damage. This protection can last for an extended period of time (days to weeks). This protective phenomenon is known in the art as “ischemic preconditioning” or “acquired cytoresistance.”

[0005] One thought has been to use the phenomenon of acquired cytoresistance to preemptively protect organs, especially when a known insult is imminent. For example, the phenomenon could be induced to protect organs before an insult, such as exposure to surgery, cardiopulmonary bypass, or radiocontrast toxicity administrations. This approach has not been deployed into clinical use, however, because there has not been a mechanism to induce acquired cytoresistance in a controlled manner without causing an unacceptable injury to the organ that is to be protected.

SUMMARY OF THE DISCLOSURE

[0006] The current disclosure provides compositions, kits, and methods that allow the induction of acquired cytoresistance without causing injury to the organ. Because acquired cytoresistance can be induced without causing injury to the organ, the phenomenon can be used in a clinical setting to preemptively protect organs, especially when a known insult is approaching.

[0007] Without being bound by theory, the compositions, kits, and methods induce acquired cytoresistance by up-regulating expression of protective stress proteins. Particular embodiments induce acquired cytoresistance through administration of heme proteins at a level, or with an approach, such that the heme proteins do not cause injury to the organ that is to be protected. Induction of acquired cytoresistance can also be achieved by administering other compounds, such as iron and/or vitamin B12.

[0008] Approaches that induce acquired cytoresistance without causing injury include administering a therapeutically effective amount of a heme protein, iron and/or vitamin B12 (B12); increasing the biological half-life of the heme protein, iron and/or B12; potentiating the action of the heme protein, iron and/or B12; and reducing toxicity associated with heme protein, iron and/or B12 administration. Each of these approaches can be practiced alone or in combination.

[0009] The described approaches can be accomplished by one or more of: administering a therapeutically effective amount of a heme protein, iron and/or B12; administering the heme protein, iron and/or B12 in combination with a heme protein degradation inhibitor; administering a modified heme protein, iron and/or B12; and/or choosing an appropriate composition and delivery route.

[0010] Exemplary heme proteins include low molecular weight heme proteins, rapidly-cleared heme proteins, and myoglobin. An exemplary form of iron includes iron sucrose. Exemplary heme protein degradation inhibitors include protoporphyrins, metal protoporphyrins, and hematin. Exemplary modified heme proteins and heme protein degradation inhibitors include PEGylated heme proteins and heme protein degradation inhibitors and nitrated heme proteins and heme protein degradation inhibitors. Exemplary compositions include slow-release depots. Exemplary delivery routes include intravenous, subcutaneous, or intramuscular injection. Exemplary methods to reduce toxicity include administration with mannitol, glycine, and saline. Additional examples, embodiments, and combinations are provided in the Detailed Description.

BRIEF DESCRIPTION OF THE FIGURES

[0011] FIGs. 1A and 1B show heme oxygenase mRNA expression (FIG. 1A) and protein expression (FIG. 1B) following vehicle (control), myoglobin (Mgb) or myoglobin in combination

with Sn-protoporphyrin (SnPP; Mgb + SnPP) administration 18 hours before glycerol insult. This FIG. demonstrates that the administration of myoglobin alone induces the representative cytoprotective molecule heme oxygenase 1 (HO-1), and that the combination of HO-1 plus a transient heme oxygenase inhibitor (SnPP) dramatically increases the myoglobin induced HO-1 mRNA and protein increases.

[0012] FIG. 2 left panels show cellular kidney damage following glycerol induced acute renal failure. Whereas severe injury is seen in the absence of preconditioning (extensive necrosis, top left; severe cast formation, bottom left), pre-treatment with myoglobin + SnPP 18 hrs before glycerol injection resulted in essentially normal renal histology (right panels top and bottom).

[0013] FIG. 3 shows that N-Mgb + SnPP elevates mRNA for the protective stress protein, interleukin-10 (IL-10).

[0014] FIG. 4 shows that N-Mgb + SnPP elevates the haptoglobin mRNA (left) and protein levels (right).

[0015] FIG. 5 shows assessment of the impact of equimolar nitrite binding to myoglobin Fe on the expression of myoglobin toxicity. HK-2 cells (a proximal tubule cell line derived from normal human kidney) were incubated in keratinocyte serum free medium either under normal (control) conditions or in the presence of 10 mg/mL horse skeletal muscle myoglobin or nitrated myoglobin (produced by equimolar Na nitrite addition to 10 mg/ml myoglobin). After 18 hr incubations, the severity of cell injury (% cell death) was assessed by MTT assay. Myoglobin induced 40% cell death (40% decrease in MTT cell uptake), compared to control incubated cells. Nitrite binding to myoglobin reduced cell death by 75%. Thus, nitrite binding is able to reduce myoglobin's cytotoxic effects.

[0016] FIG. 6 shows the dose-response relationship between plasma heme oxygenase 1 (HO-1) and administered N-myoglobin dose. Normal mice were injected intramuscularly (IM) with either 0, 1, 2, or 5 mg/Kg nitrated myoglobin +SnPP (constant dose of 1 μ mole). Eighteen hrs later, plasma HO-1 levels were assessed by ELISA. A steep dose - response relationship between the administered N-myoglobin dose and plasma HO-1 levels was observed. Thus, HO-1 assay has potential biomarker utility for N-Mgb/SnPP induced HO-1 induction.

[0017] FIG. 7 shows maintenance of normal serum creatinine levels over a 25 fold variation in N-myoglobin dose. Mice were subjected to a 2 hr subcutaneous infusion of 1, 3, 6, 12, or 25 mg/Kg of nitrated myoglobin (holding SnPP at a constant dose of 1 μ mole). Eighteen hrs later, potential renal injury was assessed by measuring serum creatinine concentrations. No significant increase was observed at any of the N-Mgb doses, indicating a lack of over toxicity (n, 2-4 mice/group).

[0018] FIG. 8 shows renal histology 18 hours after N-Mgb–SnPP administration. The top 2 panels are PAS-stained kidney sections from a control mouse (C) and a mouse 18 hour after N-Mgb–SnPP treatment (Rx). The tubular epithelium from treated mice maintains a normal histologic appearance with a completely intact brush border (dark staining of luminal membrane). The bottom 2 panels depict hematoxylin and eosin–stained sections. No histologic injury is apparent with N-Mgb–SnPP pretreatment.

[0019] FIG. 9 shows synergistic induction of HO-1 with N-Mgb–SnPP treatment of normal mice. The left panel depicts HO-1 mRNA levels 4 hours after treatment. Whereas N-Mgb alone and SnPP alone induced modest mRNA increases, a 20-fold HO-1 mRNA increase is seen with combined agent administration. At 18 hours after administration, a synergistic HO-1 protein increase was observed (P values vs controls). GAPDH, glyceraldehyde-3-phosphate dehydrogenase; HO-1, heme oxygenase 1; mRNA, messenger RNA; N-Mgb, nitrited myoglobin; SnPP, tin protoporphyrin.

[0020] FIG. 10 shows synergistic induction of IL-10 with N-Mgb–SnPP treatment of normal mice. The left panel depicts IL-10 mRNA levels at 4 hours after treatment. N-Mgb alone and SnPP alone evoked either minimal or no IL-10 mRNA increases. However, with combined administration, a 10-fold IL-10 mRNA increase was observed. As shown in the right panel, only the combined treatment induced IL-10 protein increases as assessed at the 18-hour time point (P values vs controls).

[0021] FIG. 11 shows haptoglobin mRNA and protein expression after N-Mgb–SnPP administration to normal mice. Combined N-Mgb 1 SnPP evoked far greater haptoglobin mRNA increases at 4 hours after injection than did either agent alone. However, by 18 hours after agent administration, N-Mgb alone and N-Mgb + SnPP induced comparable haptoglobin protein increases. This suggests that N-Mgb accounted for the haptoglobin increases that were produced by combined N-Mgb + SnPP administration. (P values vs controls).

[0022] FIG. 12 shows degrees of protection induced by test agents in the glycerol model of rhabdomyolysis-induced AKI. Control mice (C) developed marked AKI as denoted by BUN and creatinine concentrations. SnPP conferred no significant protection, whereas N-Mgb induced a modest protective effect. Conversely, combined N-Mgb–SnPP administration conferred complete functional protection as gauged by normal BUN and creatinine levels at 18 hours after glycerol administration (normal levels are depicted by the solid horizontal line).

[0023] FIG. 13 shows combined N-Mgb 1 SnPP (Rx) treatment confers marked protection against the maleate model of AKI. Maleate injection caused marked BUN and creatinine

increases. Treatment (Rx) conferred a near complete protective effect (horizontal lines represent normal BUN and creatinine concentrations). P value vs no treatment (no Rx).

[0024] FIG. 14 shows maleate- induced cardiotoxicity is reduced by pretreatment with N-Mgb + SnPP. Mice were treated with 1 mg/Kg N-myoglobin + 1 μ mol SnPP or IV vehicle injection). Eighteen hrs later, 800 mg/Kg maleate was administered IP. The extent of myocardial injury was determined 18 hrs post maleate injection by measuring plasma troponin I concentrations (by ELISA). Maleate injection caused a 10 fold increase in plasma troponin levels. Pre-treatment with N-Mgb+SnPP reduced the maleate induced troponin increase by 75%.

[0025] FIG. 15 shows N-Mgb + SnPP (Rx) treatment confers protection against unilateral ischemia-reperfusion (I/R)-induced progressive kidney disease. Mice were subjected to 30 minutes of left renal ischemia with or without N-Mgb–SnPP pretreatment 18 hours earlier. At 2 weeks postischemia, I/R led to a 38% reduction in renal mass (gauged by kidney weight). Pretreatment (Rx) conferred significant protection as gauged by only a 12% reduction in renal mass. Protection was also implied by marked reductions in NGAL mRNA and protein levels in the 2-week post- ischemic left kidneys.

[0026] FIG. 16 shows a dose-response relationship between increasing doses of N-Mgb (with a fixed dose of SnPP, 1 μ mol) and HO-1/haptoglobin protein levels in renal cortex and plasma. Increasing doses of N-Mgb, administered intraperitoneally, led to increasing levels of each protein in plasma and renal cortex. The correlation coefficients for plasma vs renal concentrations were 0.57 and 0.82 for HO-1 and haptoglobin, respectively. The correlations between the dose administered and plasma protein levels were $r = 0.85$ and $r = 0.75$ for HO-1 and haptoglobin, respectively.

[0027] FIG. 17 shows a dose-response relationship between administered IP dose of N-Mgb vs BUN/creatinine concentrations at 18 hours after glycerol administration. Increasing doses of N-Mgb (with a fixed dose of SnPP; 1 μ mol) led to increasing degrees of protection against glycerol-induced AKI. When analyzed with the results given in FIG. 16, strong direct relationships between plasma and renal cortical HO-1/haptoglobin concentrations and degrees of protection against glycerol-induced AKI are apparent. The horizontal lines indicate normal BUN and creatinine concentrations. As shown in the right panel, the administered doses were well tolerated by the kidney as evidenced by maintenance of normal 18-hour plasma creatinine concentrations across the tested dosage range.

[0028] FIG. 18 shows upregulation of HO-1, haptoglobin (hapto), and IL-10 gene expression in liver and heart with combined N-Mgb/SnPP treatment. The degrees of increase with treatment,

expressed as a fold increase over control values are presented. Each was increased in both liver (top 2 panels) and heart (bottom 2 panels). Individual values are given in Tables 9 and 10.

[0029] FIG. 19 shows preconditioning with N-Mgb–SnPP mitigates postischemic liver injury and hepatotoxic injury. Degrees of hepatic ischemic-reperfusion (I/R) injury were judged by plasma lactate dehydrogenase (LDH) and alanine aminotransferase (ALT) levels. Pretreatment with N-Mgb–SnPP significantly decreased both LDH and ALT concentrations (left and middle panels). It also decreased the extent of hepatotoxic injury induced by intraperitoneal glycerol injection (right panel).

[0030] FIG. 20 shows gross appearance of liver sections obtained at 18-hour postischemia without (top) and with (bottom) N-Mgb–SnPP pretreatment. Liver ischemia evoked extensive gross necrosis as evidenced by whitish- gray liver appearance (top). However, with N-Mgb–SnPP pretreatment, the liver retained a near normal appearance (bottom).

[0031] FIG. 21 shows vitamin B12 and Fe sucrose each induces marked HO-1 protein increases within 4 hrs and persists for 18 hrs of their IV injection.

[0032] FIG. 22 shows maleate injection caused severe AKI as denoted by marked BUN and PCr increases over maleate injected controls (C). Neither SnPP alone nor FeS alone significantly altered the severity of renal injury. However, combined FeS + SnPP conferred marked protection, as denoted by 75% reductions in BUN / PCr concentrations (the horizontal lines represent the means of BUN/ PCr levels in normal mice).

[0033] FIG. 23 shows that within 18 hrs of inducing IRI, 4 fold elevations in BUN and PCr concentrations resulted. Pre-treatment with FeS + SNPP conferred significant protection, lowering the BUN and PCr levels by 50%. The horizontal lines represent mean BUN / PCr levels in normal mice.

[0034] FIG. 24 shows that maleate injection induced severe AKI. Pre-treatment with FeS + B12 markedly mitigated this injury, as denoted by BUN/ PCr reductions. The horizontal lines represent mean BUN / PCr levels in normal mice.

[0035] FIG. 25 shows severe renal failure resulted within 18 hrs of glycerol injection. Pre-treatment with FeS + B12 conferred substantial functional protection, as denoted by marked reductions in both 18 hr BUN and PCr concentrations. The horizontal lines represent mean BUN / PCr levels for normal mice.

[0036] FIG. 26 shows marked and significant increases in HO-1 mRNA, as assessed 4 hr post injection. By 18 hrs, HO-1 mRNA levels returned to normal values.

[0037] FIG. 27 shows the 4 hr mRNA increases are correlated with a significant increase in HO-1 protein levels. These levels remained elevated at the 18 hr time point, particularly in the case of FeS administration.

DETAILED DESCRIPTION

[0038] Injury to a bodily organ can elicit protective responses by the organ such that it is able to better protect itself should injurious events (i.e., insults) continue or re-occur. This protective phenomenon is known in the art as “ischemic preconditioning” or “acquired cytoresistance.”

[0039] One thought has been to use the phenomenon of acquired cytoresistance to preemptively protect organs, especially when a known insult is imminent. For example, the phenomenon could be induced to protect organs before an insult, such as exposure to surgery, balloon angioplasty, induced cardiac or cerebral ischemic-reperfusion injury, or radiocontrast toxicity. Alternatively or additionally, the phenomenon could be induced in organ donors (e.g., kidney, liver) to prevent or reduce cold storage injury and/or reimplantation ischemic-reperfusion injury. These approaches have not been deployed into clinical use, however, because, until the current disclosure, there had not been a mechanism to successfully induce acquired cytoresistance in a controlled manner without causing an injury to the organ that is to be protected itself.

[0040] The current disclosure provides compositions, kits, and methods that allow the induction of acquired cytoresistance without injury to the organ that is to be protected. Because acquired cytoresistance can be induced without causing injury to the organ, the phenomenon can be used in a clinical setting to preemptively protect organs, especially when a known insult is approaching.

[0041] Without being bound by theory, the compositions, kits, and methods induce acquired cytoresistance by up-regulating expression of protective stress proteins. Acquired cytoresistance can be induced through administration of heme proteins at a level, or with an approach, such that the heme proteins do not cause an injury to the organ that is to be protected. In particular embodiments, induction of acquired cytoresistance can also be achieved by administering compounds that up-regulate stress proteins through the same or similar biological pathways utilized by heme proteins. Such compounds include, for example, iron and vitamin B12 and associated metabolites.

[0042] An “insult” is an occurrence that is likely to cause injury to an organ. Exemplary insults include shock (low blood pressure), kidney hypoperfusion, surgery, induced cardiac or cerebral ischemic-reperfusion, cardiopulmonary bypass, balloon angioplasty, radiocontrast toxicity

administrations, chemotherapy, drug administration, nephrotoxic drug administration, blunt force trauma, puncture, poison, smoking, etc.

[0043] An "injury" is a detrimental effect on an organ evidenced by cell death within the organ, cell damage within the organ, damaged structure within the organ and/or decreased function of the organ as compared to one or more relevant control groups, conditions or reference levels.

[0044] "Absence of injury" to an organ, "without causing an injury" to an organ, "does not injure the organ" and similar phrases mean that any effect on an organ is, within the scope of sound medical judgment, commensurate with a reasonable benefit/risk ratio of administration. In particular embodiments, absence of an injury can be demonstrated by showing that the function of an organ is not statistically significantly different from a relevant control group, condition, or reference level according to a known test of organ function at the time using appropriate statistical comparisons. Exemplary assays of organ function include measuring markers associated with organ function; measuring the output of an organ; and measuring a performance metric of the organ as compared to one or more relevant control groups, conditions or reference levels.

[0045] By inducing acquired cytoresistance, the compositions, kits, and methods disclosed herein protect organs from injury, such as insult-induced injury. "Protecting an organ from injury" and similar phrases include one or more of: up-regulating the expression of protective stress proteins; preserving organ function in whole or in part (e.g., measuring the output of an organ; measuring a performance metric of the organ); reducing organ cell injury (in particular embodiments, as manifested by decreased leakage of intracellular proteins into the circulation), and reducing cell death within the organ as compared to one or more relevant control groups, conditions, or reference levels.

[0046] Numerous assays that can be used to assess presence or absence of an injury and associated protection are disclosed herein and can be used in animal and human models of organ function. Lack of injury and/or protection of an organ can be confirmed by comparing a relevant measure from a subject with a reference level. Reference levels can include "normal" or "control" levels or values, defined according to, e.g., discrimination limits or risk defining thresholds, in order to define cut-off points and/or abnormal values for organ function. The reference level can be a level of an indicia typically found in a subject who is not suffering from organ injury. Other terms for "reference levels" include "index," "baseline," "standard," "healthy," "pre-injury," etc. Such normal levels can vary, based on whether an indicia is used alone or in a formula combined with other indicia to output a score. Alternatively, the reference level can be derived from a database of scores from previously tested subjects who did not develop organ injury over a clinically relevant time period. Reference levels can also be derived from, e.g., a control subject

or population whose organ injury status is known. In some embodiments, the reference level can be derived from one or more subjects who have been exposed to treatment for an organ injury, or from subjects who have shown improvements in organ function following injury as a result of exposure to treatment. In some embodiments the reference level can be derived from one or more subjects with organ injury who have not been exposed to treatment. A reference level can also be derived from injury severity algorithms or computed indices from population studies.

[0047] In particular embodiments, a "reference level" can refer to a standardized value for organ function which represents a level not associated with any injury; a level associated with a particular type of injury; a level associated with a severity of injury; or a level associated with a particular subject at the time of a diagnosis, at the beginning of a treatment, or at a time point during a treatment. The reference level can be a universal reference level which is useful across a variety of testing locations or can be a reference level specific for a testing location and specific assay used to measure the organ function. In certain embodiments, the reference level, is derived from (i) an individual who does not have organ injury or organ injury of a particular type; or (ii) a group of individuals who do not have organ injury or organ injury of a particular type. Reference levels for a subject can also be related to time points of the subject undergoing treatments to monitor the natural progression or regression of organ injury in the subject.

[0048] In particular embodiments, reference levels can be derived from a "dataset". A dataset represents a set of numerical values resulting from evaluation of a sample (or population of samples) under a desired condition. The values of the dataset can be obtained, for example, by experimentally obtaining measures from a sample and constructing a dataset from these measurements; or alternatively, by obtaining a dataset from a service provider such as a laboratory, or from a database or a server on which the dataset has been stored.

[0049] Up-Regulation of Protective Stress Proteins. Without being bound by theory, the up-regulation of a number of stress proteins leads to the induction of acquired cytoresistance. "Up-regulation" includes an increase in expression of a gene or nucleic acid molecule of interest or the activity of a protein, e.g., an increase in gene expression or protein activity as compared to the expression or activity in an otherwise identical or comparable gene or protein that has not been up-regulated.

[0050] Up-regulation of the following exemplary stress proteins can lead to the induction of acquired cytoresistance: heme oxygenase (HO), haptoglobin, hemopexin, hepcidin, alpha-1 antitrypsin (AAT), interleukin-10 (IL-10), heat-shock proteins, neutrophil gelatinase-associated lipocalin (NGAL), and HMG CoA reductase.

[0051] Heme oxygenase (HO) is the rate-limiting enzyme in heme catabolism. There are three distinct HO isozymes: HO-1 (e.g., SEQ ID NO:1), HO-2 (isoform A; e.g., SEQ ID NO:2; isoform B; e.g., SEQ ID NO. 3; isoform C; e.g., SEQ ID NO: 4), and HO-3 (e.g., SEQ ID NO:5). HO-1 is an isozyme whose expression is up-regulated following diverse forms of tissue stress, such as induced by heme proteins, heavy metals, hypoxia, and various redox sensitive pathways. In contrast, HO-2 is an isozyme expressed constitutively. HO-3 is a recently identified isozyme whose functions are currently unknown.

[0052] Haptoglobin (e.g., SEQ ID NO:6) is a blood plasma protein having a molecular weight of 86,000 to 400,000 and plays an important role in the metabolism of hemoglobin liberated into the blood stream. When liberated excessively in the blood the hemoglobin is excreted into the urine through the renal tubules, resulting in not only an iron loss but also disorders of the renal tubules. Because haptoglobin binds selectively and firmly to hemoglobin in vivo and thereby forms a hemoglobin-haptoglobin complex, it has important functions in the recovery of iron and in the prevention of renal disorders.

[0053] Hemopexin (Hpx; e.g., SEQ ID NO:7) is a 60 kDa protein which is present in the plasma in high amounts being second to only albumin, immunoglobulins, and the plasma proteases. Hemopexin is often also referred to as beta-1B-glycoprotein. Hemopexin has a high affinity to heme ($K_D < 10^{-12}$ M), and it is believed that the biological role of Hpx is related to the transportation of heme thus preventing heme induced oxidative damages and heme bound iron loss. Hemopexin sequesters free heme from the plasma which induces a structural change whereby the heme-Hpx complex gains increased affinity to receptors in the liver, where it is engulfed by receptor-mediated endocytosis and heme is released at the low pH in the endosomes. After that, Hpx is returned to the circulation and can undergo further rounds of transportation.

[0054] Hemopexin is folded in two homologous domains, each of 200 amino acids, joined by a 20 amino acid residue linker. There is 25% sequence identity between the two domains. Two histidines coordinate the heme iron, namely His213 from the linker peptide and His270 from a loop of the C-terminal domain, giving a stable bis-histidyl Fe(III) complex. The numbering is with respect to the mature protein. Clin. Chim. Acta, 312, 2001, 13-23 and DNA Cell Biol., 21, 2002, 297-304 provide reviews of Hpx chemistry.

[0055] Hepcidin (prepropeptide; e.g., SEQ ID NO:8) is the key signal regulating iron homeostasis (Philpott, Hepatology 35:993 (2002); Nicolas et al., Proc. Natl. Acad. Sci. USA 99:4396 (2002)). High levels of human hepcidin result in reduced iron levels, and vice versa. Mutations in the hepcidin gene which result in lack of hepcidin activity are associated with juvenile hemochromatosis, a severe iron overload disease (Roetto et al., Nat. Genet., 33:21-22, 2003).

Studies in mice have demonstrated a role of hepcidin in control of normal iron homeostasis (Nicolas et al., Nat. Genet., 34:97-101, 2003; Nicolas et al., Proc. Natl. Acad. Sci. USA, 99:4596-4601, 2002; Nicolas et al., Proc. Natl. Acad. Sci. USA, 98:8780-8785, 2001).

[0056] In addition, data is accumulating implicating hepcidin in iron sequestration during inflammation (See, e.g., Weinstein et al., Blood, 100:3776-36781, 2002; Kemna et al., Blood, 106:1864-1866, 2005; Nicolas et al., J. Clin. Invest., 110:1037-1044, 2002; Nemeth et al., J. Clin. Invest., 113:1271-1276, 2004; Nemeth et al., Blood, 101:2461-2463, 2003 and Rivera et al., Blood, 105:1797-1802, 2005). Hepcidin gene expression has been observed to be robustly up-regulated after inflammatory stimuli, such as infections, which induce the acute phase response of the innate immune systems of vertebrates. In mice, hepcidin gene expression was shown to be up-regulated by lipopolysaccharide (LPS), turpentine, Freund's complete adjuvant, and adenoviral infections. Hepcidin expression is induced by the inflammatory cytokine IL-6. A strong correlation between hepcidin expression and anemia of inflammation was also found in patients with chronic inflammatory diseases, including bacterial, fungal, and viral infections.

[0057] Human hepcidin, a 25 amino acid peptide (e.g., SEQ ID NO:9) with anti-microbial and iron-regulating activity, was discovered independently by two groups investigating novel anti-microbial peptides. (Krause et al., FEBS Lett. 480:147 (2000); Park et al., J. Biol. Chem. 276:7806 (2001)). It has also been referred to as LEAP-1 (liver-expressed antimicrobial peptide). A hepcidin cDNA encoding an 83 amino acid pre-propeptide in mice and an 84 amino acid pre-propeptide in rat and human were subsequently identified in a search for liver specific genes that were regulated by iron (Pigeon et al., J. Biol. Chem. 276:7811 (2001)). The 24 residue N-terminal signal peptide is first cleaved to produce pro-hepcidin, which is then further processed to produce mature hepcidin, found in both blood and urine. In human urine, the predominant form contains 25 amino acids, although shorter 22 and 20 amino acid peptides are also present.

[0058] The mature peptide is notable for containing eight cysteine residues linked as four disulfide bridges. The structure of hepcidin was studied by Hunter et al., J. Biol. Chem., 277:37597-37603 (2002), by NMR using chemically synthesized hepcidin with an identical HPLC retention time to that of native hepcidin purified from urine. Hunter et al. reported their determination that hepcidin folded into a hairpin loop structure containing a vicinal disulfide bond (C1-C8, C2-C7, C3-C6, C4-C5).

[0059] Alpha-1 antitrypsin (AAT; e.g., SEQ ID NO:10) is a glycoprotein secreted by hepatocytes and normally present in the serum and in the majority of tissues in high concentrations, where it acts as an inhibitor of serine proteases. Protease inhibition by AAT is an essential component of the regulation of tissue proteolysis, and AAT deficiency is implicated in

the pathology of several diseases. Apart from its activity as an antiprotease, AAT could have an important anti-inflammatory biological function because it has an outstanding inhibitory capacity in respect of many inflammation mediators and in respect of oxidant radicals (Brantly M. *Am J Respir Cell Mol. Biol.*, 2002; 27: 652-654).

[0060] Interleukin-10 (IL-10; e.g., SEQ ID NO. 11) is a pleiotropic cytokine produced by several cell types such as macrophages, monocytes, Th2 type and regulatory T-cells and B-cells. IL-10 is a cytokine with immunosuppressive and anti-inflammatory properties; it regulates a number of cellular myeloid and lymphoid activities and directly inhibits the production of several inflammatory cytokines by T-cells and Natural Killer (NK) cells. IL-10 is known as a B-cell proliferation factor and is active in autoimmunity, antibody production, tumorigenesis and transplant tolerance. *Eur. J. Immunogenet.* 1997 24(I): 1-8. IL-10 also alters macrophage response to infection yet stimulates Fc receptors on the same cells. *Annals Allergy Asthma Immunol.* 1997 79:469-483; *J. Immunol.* 1993 151: 1224-1234; and *J. Immunol.* 1992 149:4048-4052.

[0061] Heat shock proteins were originally observed to be expressed in increased amounts in mammalian cells which were exposed to sudden elevations of temperature, while the expression of most cellular proteins is significantly reduced. It has since been determined that such proteins are produced in response to various types of stress, including glucose deprivation.

[0062] Heat shock proteins have the ability to bind other proteins in their non-native states, and in particular to bind nascent peptides emerging from ribosomes or extruded into the endoplasmic reticulum. Hendrick and Hartl., *Ann. Rev. Biochem.* 62:349-384 (1993); Hartl., *Nature* 381:571-580 (1996). Further, heat shock proteins have been shown to play an important role in the proper folding and assembly of proteins in the cytosol, endoplasmic reticulum, and mitochondria; in view of this function, they are referred to as "molecular chaperones". Frydman et al., *Nature* 370: 111-117 (1994); Hendrick and Hartl., *Ann. Rev. Biochem.* 62:349-384 (1993); Hartl, *Nature* 381:571-580 (1996).

[0063] Examples of heat shock proteins include BiP (also referred to as grp78 (e.g., SEQ ID NO:12)), hsp/hsc70 (e.g., SEQ ID NO:13), gp96 (grp94) (e.g., SEQ ID NO:14), hsp60 (e.g., SEQ ID NO:15), hsp40 (e.g., SEQ ID NO:16), hsp70/72 (e.g., SEQ ID NO:17), and hsp90 (isoform 1; e.g., SEQ ID NO:18; isoform 2; e.g., SEQ ID NO. 19).

[0064] Lipocalins are a family of extracellular ligand-binding proteins that are found in a variety of organisms from bacteria to humans. Lipocalins possess many different functions, such as the binding and transport of small hydrophobic molecules, nutrient transport, cell growth regulation, modulation of the immune response, inflammation, and prostaglandin synthesis.

[0065] Neutrophil gelatinase-associated lipocalin (NGAL; e.g., SEQ ID NO: 20), which is also known as human neutrophil lipocalin (HNL), N-formyl peptide binding protein, and 25 kDa α 2-microglobulin-related protein, is a 24 kDa protein, which can exist as a monomer, a homodimer, or a heterodimer with proteins, such as gelatinase B or matrix metalloproteinase-9 (MMP-9). A trimeric form of NGAL also has been identified. NGAL is secreted from specific granules of activated human neutrophils. Homologous proteins have been identified in mouse (24p3/uterocalin) and rat (α 2-microglobulin-related protein/neu-related lipocalin). Structural data have confirmed NGAL has an eight-stranded β -barrel structure, which is characteristic of lipocalins; however, NGAL has an unusually large cavity lined with more polar and positively charged amino acid residues than normally seen in lipocalins. NGAL is believed to bind small lipophilic substances, such as bacteria-derived lipopolysaccharides and formyl peptides, and may function as a modulator of inflammation.

[0066] NGAL is an early marker for acute renal injury or disease. In addition to being secreted by specific granules of activated human neutrophils, NGAL is also produced by nephrons in response to tubular epithelial damage and is a marker of tubulointerstitial (TI) injury. NGAL levels rise in acute tubular necrosis (ATN) from ischemia or nephrotoxicity, even after mild “subclinical” renal ischemia. Moreover, NGAL is known to be expressed by the kidney in cases of chronic kidney disease (CKD) and acute kidney injury ((AKI); see, e.g., Devarajan et al., *Amer. J. Kidney Diseases* 52(3): 395-399 (September 2008); and Bolignano et al., *Amer. J. Kidney Diseases* 52(3): 595-605 (September 2008)). Elevated urinary NGAL levels have been suggested as predictive of progressive kidney failure. It has been previously demonstrated that NGAL is markedly expressed by kidney tubules very early after ischemic or nephrotoxic injury in both animal and human models. NGAL is rapidly secreted into the urine, where it can be easily detected and measured. NGAL is resistant to proteases, suggesting that it can be recovered in the urine as a faithful marker of NGAL expression in kidney tubules.

[0067] The HMG-CoA reductase enzyme plays a central role in the production of cholesterol and other isoprenoids in the liver and other tissues via the mevalonate pathway. The conversion of 3-hydroxy-3-methylglutaryl-coenzyme A (HMG-CoA) to mevalonate is catalyzed by HMG-CoA reductase, and is an early and rate-limiting step in the cholesterol biosynthetic pathway in the liver and other tissues. Stress-induced increases in HMG CoA reductase mediate cholesterol synthesis leading to increased plasma membrane cholesterol.

[0068] Expression of protective stress proteins is up-regulated by administration of heme proteins. Heme proteins are metalloproteins that contain a heme prosthetic group (a protoporphyrin ring with a central Fe; a protoporphyrin ring includes four pyrrole rings linked by

methine bridges. Four methyl, two vinyl, and two propionate side chains can also be attached). In particular embodiments, the heme proteins are low molecular weight heme proteins. "Low molecular weight heme proteins" include those with a molecular weight of 25 kDa or less; 24 kDa or less; 23 kDa or less; 22 kDa or less; 21 kDa or less; 20 kDa or less; 19 kDa or less; 18 kDa or less; 17 kDa or less; 16 kDa or less; 15 kDa or less; 14 kDa or less; 13 kDa or less; 12 kDa or less; 11 kDa or less; or 10 kDa or less. In another embodiment, heme proteins are rapidly cleared when administered intravenously. "Rapidly cleared" means a urinary excretion rate that has a urinary clearance rate of >50% of serum creatinine or urea. In another embodiment the heme proteins are low molecular weight heme proteins that are rapidly cleared when administered intravenously. Myoglobin (e.g., SEQ ID NO:21) is one heme protein that can be used with the compositions, kits, and methods disclosed herein. References to heme proteins include modified heme proteins, variant heme proteins and D-substituted analog heme proteins. References to myoglobin include modified myoglobin, variant myoglobin and D-substituted analog myoglobin as described elsewhere herein.

[0069] Myoglobin is present in striated muscle tissue and functions to store and deliver oxygen by reversibly binding O₂ at myoglobin's open binding site. Through this reversible binding, myoglobin creates an intracellular source of oxygen for cellular mitochondria. Unlike hemoglobin, another heme protein, myoglobin naturally exists only as a monomer.

[0070] When muscle tissue is damaged, myoglobin is released into the bloodstream. Large amounts of myoglobin in the blood can cause renal injury by provoking constriction of renal vessels, forming obstructing casts in the lumina of renal tubules, and initiating interstitial inflammation, as described in Zager, R. A., Ren. Fail., 14, 341-344 (1992). Moreover, Nath et al. state that heme proteins, such as hemoglobin, when released into the extracellular space, can instigate tissue toxicity and that myoglobin is directly implicated in the pathogenesis of renal failure in rhabdomyolysis. J. Clin. Invest., 1992 Jul. (90)1: 267-70. Accordingly, heme proteins and myoglobin in particular can damage the renal system.

[0071] Based on these known detrimental effects of heme proteins, including myoglobin, it was not expected that heme proteins such as myoglobin could play a role in inducing acquired cytoresistance without causing an organ injury. Thus, one aspect of the current disclosure includes identifying compositions, kits, and methods to administer myoglobin in a manner that induces acquired cytoresistance without causing an injury to the organ that it is administered to protect.

[0072] Approaches that allow heme protein administration to induce acquired cytoresistance without causing an organ injury include selecting a therapeutically effective amount of the heme

protein; increasing the biological half-life of the heme protein; potentiating the action of the heme protein; and reducing toxicity associated with heme protein administration.

[0073] One embodiment disclosed herein includes selecting a therapeutically effective amount of a heme protein, such as myoglobin. Therapeutically effective amounts, methods to identify therapeutically effective amounts and exemplary therapeutically effective amounts are described more fully below.

[0074] The biological half-life of a heme protein can be extended by administering the heme protein in combination with a heme protein degradation inhibitor. In particular embodiments, heme protein degradation inhibitors can reduce or eliminate the cleavage of the heme protein's porphyrin ring by HO, reducing or eliminating release of the heme protein's toxic Fe content. In particular embodiments, administration of a heme protein degradation inhibitor in combination with a heme protein can allow for administration of lower doses of the heme protein.

[0075] In particular embodiments, any compound that blocks binding of heme to HO can function as a heme protein degradation inhibitor. For example, a number of synthetic analogs of iron protoporphyrin IX are known. These compounds are commercially available and/or can be readily synthesized by known methods. They include, for example, platinum, zinc, nickel, cobalt, copper, silver, manganese, chromium, and tin protoporphyrin IX. For convenience, these compounds can be referred to generically as Me-protoporphyrin or MePP, where Me stands for metal, and specifically by utilizing the chemical symbol for the metal such as Cr-protoporphyrin (CrPP), Sn-protoporphyrin (SnPP), Zn-protoporphyrin (ZnPP) for the chromium, tin, and zinc protoporphyrin compounds respectively.

[0076] Hemin and/or hematin can also be used as competitive HO-1 inhibitors. In some instances, hemin and hematin are used interchangeably and refer to protoporphyrin IX containing a ferric iron ion attached to a chloride ligand. Others distinguish hemin and hematin, referring to the Cl ligand form as hemin and referring to hematin as the same compound with hydroxide attached to the iron ion rather than chloride. Both can be used as competitive HO-1 inhibitors within the teachings of the current disclosure. Indeed, and as stated, any compound that blocks binding of heme to HO can function as a heme protein degradation inhibitor.

[0077] That blocking the action of HO could beneficially assist in the induction of acquired cytoresistance without causing an injury was unexpected. For example, Nath et al., showed that knocking out the HO-1 gene in mice worsened renal injury in the glycerol model of heme protein toxicity. The authors stated that HO-1 is a critical *protectant* against acute heme protein-induced toxicity in vivo. Am. J. of Path., 2000 May 156(5): 1527-1535.

[0078] Moreover, that Me-protoporphyrins could be used in combination with a heme protein to induce acquired cytoresistance without causing an injury was unexpected. This is because Me-protoporphyrins are generally thought to adversely affect organs in various models of organ injury. For example, Agarwal et al. found that pretreatment with Sn-protoporphyrin exacerbated renal injury in a HO-based in vivo model of heme protein mediated renal injury. Particularly, pretreatment with Sn-protoporphyrin led to higher serum creatinine values on days 3 through 5 and lower inulin clearances on day 5. Renal hemodynamics studied at day 2 after cisplatin demonstrated reduced renal blood flow rates, increased renal vascular resistance and increased fractional excretion of sodium in rats treated with Sn-protoporphyrin. *Kidney Int.* 1995 Oct. 48(4): 1298-307. In the glycerol model rhabdomyolysis, Nath et al., found that the kidney responds to high amounts of heme proteins by inducing HO and that blocking the action of HO with a competitive inhibitor (here, Sn-protoporphyrin) exacerbated kidney dysfunction. *J. Clin. Invest.* 1992 Jul; 90(1): 267-70. Ferenbach et al., and Goodman et al., have similarly shown that inhibition of HO using Me-protoporphyrins worsens renal damage. See *Nephron. Exp. Nephrol.* 2010 Apr. 115(3): e33-7 and *Kidney Int.* 2007 Oct. 72(8): 945-53 respectively. Based on these teachings of the art, one of ordinary skill in the art would not have expected the beneficial effects of HO-1 inhibition currently disclosed.

[0079] Without being bound by theory, heme proteins activate redox sensitive transcription factors, leading to the up-regulation of redox sensitive cytoprotective proteins. This pathway is initiated by Mgb's iron content. Thus, as demonstrated herein alternative approaches for inducing iron-mediated renal tubular cytoprotective gene signaling are also effective. These alternative approaches include administration of iron and/or vitamin B12. The rationale for B12 is that both cobalt and cyanide can independently induce HO-1. Thus, B12 represents a safe method to administer both cyanide and cobalt as a single agent, as both are integral parts of the B12 molecule.

[0080] Modified heme proteins and heme protein degradation inhibitors (e.g., protoporphyrins, hemin, hematin) can include those with (a) increased protein serum half-life and/or functional in vivo half-life, (b) reduced protein antigenicity, (c) increased protein storage stability, (d) increased protein solubility, (e) prolonged circulating time, and/or (f) increased bioavailability, e.g. increased area under the curve (AUC).

[0081] In particular embodiments, modified heme proteins and heme protein degradation inhibitors ("modifications") include those wherein one or more amino acids have been replaced with a non-amino acid component, or where the amino acid has been conjugated to a functional group or a functional group has been otherwise associated with an amino acid. The modified

amino acid may be, e.g., a glycosylated amino acid, a PEGylated amino acid, a farnesylated amino acid, an acetylated amino acid, a biotinylated amino acid, an amino acid conjugated to a lipid moiety, or an amino acid conjugated to an organic derivatizing agent. Amino acid(s) can be modified, for example, co-translationally or post-translationally during recombinant production (e.g., N-linked glycosylation at N-X-S/T motifs during expression in mammalian cells) or modified by synthetic means. The modified amino acid can be within the sequence or at the terminal end of a sequence. Modifications also include nitrated heme proteins, such as nitrated myoglobin.

[0082] In its native state, myoglobin is 17 kDa and thus is rapidly filtered and excreted by the kidney. By increasing myoglobin's size, its excretion can be slowed, thus, allowing for a more prolonged and durable protective effect. In one embodiment, the modified protein is a PEGylated heme protein or heme protein degradation inhibitor.

[0083] PEGylation is one method that can be used to increase the size of myoglobin and other low molecular weight proteins. PEGylation is a process by which polyethylene glycol (PEG) polymer chains are covalently conjugated to other molecules such as drugs or proteins. Several methods of PEGylating proteins have been reported in the literature. For example, N-hydroxy succinimide (NHS)-PEG was used to PEGylate the free amine groups of lysine residues and N-terminus of proteins; PEGs bearing aldehyde groups have been used to PEGylate the amino-termini of proteins in the presence of a reducing reagent; PEGs with maleimide functional groups have been used for selectively PEGylating the free thiol groups of cysteine residues in proteins; and site-specific PEGylation of acetyl-phenylalanine residues can be performed.

[0084] Covalent attachment of proteins or peptides to PEG has proven to be a useful method to increase the circulating half-lives of proteins and peptides in the body (Abuchowski, A. et al., *Cancer Biochem. Biophys.*, 1984, 7:175-186; Hershfield, M. S. et al., *N. Engl. J. Medicine*, 1987, 316:589-596; and Meyers, F. J. et al., *Clin. Pharmacol. Ther.*, 1991, 49:307-313). The attachment of PEG to proteins and peptides not only protects the molecules against enzymatic degradation, but also reduces their clearance rate from the body. The size of PEG attached to a protein has significant impact on the circulating half-life of the protein. The ability of PEGylation to decrease clearance is generally not a function of how many PEG groups are attached to the protein, but the overall molecular weight of the altered protein. PEGylation decreases the rate of clearance from the bloodstream by increasing the apparent molecular weight of the molecule. Up to a certain size, the rate of glomerular filtration of proteins is inversely proportional to the size of the protein. Usually the larger the PEG is, the longer the in vivo half-life of the attached protein is. In addition, PEGylation can also decrease protein aggregation (Suzuki et al., *Biochem. Bioph. Acta* vol. 788, pg. 248 (1984)), alter protein immunogenicity (Abuchowski et al.; *J. Biol. Chem.*

vol. 252 pg. 3582 (1977)), and increase protein solubility as described, for example, in PCT Publication No. WO 92/16221).

[0085] Several sizes of PEGs are commercially available (Nektar Advanced PEGylation Catalog 2005-2006; and NOF DDS Catalogue Ver 7.1), which are suitable for producing proteins with targeted circulating half-lives. A variety of active PEGs have been used including mPEG succinimidyl succinate, mPEG succinimidyl carbonate, and PEG aldehydes, such as mPEG-propionaldehyde.

[0086] In another embodiment, the modified protein is a nitrated heme protein or nitrated heme protein degradation inhibitor. Nitrite is involved in regulating production of nitric oxide (NO) from nitric oxide synthase (NOS) independent pathways. Inorganic nitrite can undergo a one electron reduction back to NO through various mechanisms with oxygen-binding heme proteins (hemoglobin and myoglobin), deoxyhemoglobin, deoxymyoglobin, xanthine oxidoreductase, endothelial NOS, acidic disproportionation, and members of the mitochondrial electron transport chain, e.g., mitochondrial heme proteins all being potential electron donors.

[0087] Nitrite binding to heme iron, such as in myoglobin, can increase the heme protein's ability to up-regulate expression of stress proteins, such as, heat shock proteins (e.g., HSP 72); HO-1; haptoglobin; hemopexin, hepcidin, IL-10, AAT, NGAL and/or HMG CoA reductase. Nitrite – Fe binding disclosed herein can also decrease toxicity associated with heme protein administration. Without being bound by theory, up-regulated expression of stress proteins serves to promote acquired cytoresistance.

[0088] Nitrated forms of active ingredients are used in particular embodiments because, without being bound by theory, the current disclosure suggests that following glomerular filtration, N-Mgb and SnPP undergo proximal tubule uptake where they activate redox sensitive transcription factors, leading to the up-regulation of redox sensitive cytoprotective proteins. Again without being bound by theory, this pathway is initiated by Mgb's iron (Fe) content. Nitrite binding to Mgb Fe facilitates Fe signaling while reducing potential Fe toxicity. Concomitant administration of SnPP also facilitates Fe signaling. These same pathways can be activated in extra-renal organs via SnPP tissue binding sites/signaling and Mgb uptake via scavenger receptors.

[0089] Reference to proteins including heme proteins, heme protein degradation inhibitors, and protective stress proteins described herein also include variants and D-substituted analogs thereof.

[0090] "Variants" of proteins disclosed herein include proteins having one or more amino acid additions, deletions, stop positions, or substitutions, as compared to a protein disclosed herein.

[0091] An amino acid substitution can be a conservative or a non-conservative substitution. Variants of proteins disclosed herein can include those having one or more conservative amino acid substitutions. A “conservative substitution” involves a substitution found in one of the following conservative substitutions groups: Group 1: alanine (Ala or A), glycine (Gly or G), Ser, Thr; Group 2: aspartic acid (Asp or D), Glu; Group 3: asparagine (Asn or N), glutamine (Gln or Q); Group 4: Arg, lysine (Lys or K), histidine (His or H); Group 5: Ile, leucine (Leu or L), methionine (Met or M), valine (Val or V); and Group 6: Phe, Tyr, Trp.

[0092] Additionally, amino acids can be grouped into conservative substitution groups by similar function, chemical structure, or composition (e.g., acidic, basic, aliphatic, aromatic, sulfur-containing). For example, an aliphatic grouping may include, for purposes of substitution, Gly, Ala, Val, Leu, and Ile. Other groups containing amino acids that are considered conservative substitutions for one another include: sulfur-containing: Met and Cys; acidic: Asp, Glu, Asn, and Gln; small aliphatic, nonpolar or slightly polar residues: Ala, Ser, Thr, Pro, and Gly; polar, negatively charged residues and their amides: Asp, Asn, Glu, and Gln; polar, positively charged residues: His, Arg, and Lys; large aliphatic, nonpolar residues: Met, Leu, Ile, Val, and Cys; and large aromatic residues: Phe, Tyr, and Trp. Additional information is found in Creighton (1984) *Proteins*, W.H. Freeman and Company.

[0093] Variants of proteins disclosed herein also include sequences with at least 70% sequence identity, at least 80% sequence identity, at least 85% sequence, at least 90% sequence identity, at least 95% sequence identity, at least 96% sequence identity, at least 97% sequence identity, at least 98% sequence identity, or at least 99% sequence identity to a protein disclosed herein. More particularly, variants of the proteins disclosed herein include proteins that share: 70% sequence identity with any of e.g., SEQ ID NO:1-29; 80% sequence identity with any of e.g., SEQ ID NO:1-29; 81% sequence identity with any of e.g., SEQ ID NO:1-29; 82% sequence identity with any of e.g., SEQ ID NO:1-29; 83% sequence identity with any of e.g., SEQ ID NO:1-29; 84% sequence identity with any of e.g., SEQ ID NO:1-29; 85% sequence identity with any of e.g., SEQ ID NO:1-29; 86% sequence identity with any of e.g., SEQ ID NO:1-29; 87% sequence identity with any of e.g., SEQ ID NO:1-29; 88% sequence identity with any of e.g., SEQ ID NO:1-29; 89% sequence identity with any of e.g., SEQ ID NO:1-29; 90% sequence identity with any of e.g., SEQ ID NO:1-29; 91% sequence identity with any of e.g., SEQ ID NO:1-29; 92% sequence identity with any of e.g., SEQ ID NO:1-29; 93% sequence identity with any of e.g., SEQ ID NO:1-29; 94% sequence identity with any of e.g., SEQ ID NO:1-29; 95% sequence identity with any of e.g., SEQ ID NO:1-29; 96% sequence identity with any of e.g., SEQ ID NO:1-29; 97% sequence

identity with any of e.g., SEQ ID NO:1-29; 98% sequence identity with any of e.g., SEQ ID NO:1-29; or 99% sequence identity with any of e.g., SEQ ID NO:1-29.

[0094] Variants of myoglobin can include myoglobin proteins that share: 70% sequence identity with e.g., SEQ ID NO:21; 80% sequence identity with e.g., SEQ ID NO:21; 81% sequence identity with e.g., SEQ ID NO:21; 82% sequence identity with e.g., SEQ ID NO:21; 83% sequence identity with e.g., SEQ ID NO:21; 84% sequence identity with e.g., SEQ ID NO:21; 85% sequence identity with e.g., SEQ ID NO:21; 86% sequence identity with e.g., SEQ ID NO:21; 87% sequence identity with e.g., SEQ ID NO:21; 88% sequence identity with e.g., SEQ ID NO:21; 89% sequence identity with e.g., SEQ ID NO:21; 90% sequence identity with e.g., SEQ ID NO:21; 91% sequence identity with e.g., SEQ ID NO:21; 92% sequence identity with e.g., SEQ ID NO:21; 93% sequence identity with e.g., SEQ ID NO:21; 94% sequence identity with e.g., SEQ ID NO:1; 95% sequence identity with e.g., SEQ ID NO:21; 96% sequence identity with e.g., SEQ ID NO:21; 97% sequence identity with e.g., SEQ ID NO:21; 98% sequence identity with e.g., SEQ ID NO:21; or 99% sequence identity with e.g., SEQ ID NO:21.

[0095] "% sequence identity" refers to a relationship between two or more sequences, as determined by comparing the sequences. In the art, "identity" also means the degree of sequence relatedness between protein sequences as determined by the match between strings of such sequences. "Identity" (often referred to as "similarity") can be readily calculated by known methods, including those described in: Computational Molecular Biology (Lesk, A. M., ed.) Oxford University Press, NY (1988); Biocomputing: Informatics and Genome Projects (Smith, D. W., ed.) Academic Press, NY (1994); Computer Analysis of Sequence Data, Part I (Griffin, A. M., and Griffin, H. G., eds.) Humana Press, NJ (1994); Sequence Analysis in Molecular Biology (Von Heijne, G., ed.) Academic Press (1987); and Sequence Analysis Primer (Gribskov, M. and Devereux, J., eds.) Oxford University Press, NY (1992). Preferred methods to determine sequence identity are designed to give the best match between the sequences tested. Methods to determine sequence identity and similarity are codified in publicly available computer programs. Sequence alignments and percent identity calculations may be performed using the Megalign program of the LASERGENE bioinformatics computing suite (DNASTAR, Inc., Madison, Wisconsin). Multiple alignment of the sequences can also be performed using the Clustal method of alignment (Higgins and Sharp CABIOS, 5, 151-153 (1989) with default parameters (GAP PENALTY=10, GAP LENGTH PENALTY=10). Relevant programs also include the GCG suite of programs (Wisconsin Package Version 9.0, Genetics Computer Group (GCG), Madison, Wisconsin); BLASTP, BLASTN, BLASTX (Altschul, et al., J. Mol. Biol. 215:403-410 (1990); DNASTAR (DNASTAR, Inc., Madison, Wisconsin); and the FASTA program incorporating the

Smith-Waterman algorithm (Pearson, Comput. Methods Genome Res., [Proc. Int. Symp.] (1994), Meeting Date 1992, 111-20. Editor(s): Suhai, Sandor. Publisher: Plenum, New York, N.Y.. Within the context of this disclosure it will be understood that where sequence analysis software is used for analysis, the results of the analysis are based on the "default values" of the program referenced. "Default values" mean any set of values or parameters which originally load with the software when first initialized.

[0096] "D-substituted analogs" include protein disclosed herein having one more L-amino acids substituted with one or more D-amino acids. The D-amino acid can be the same amino acid type as that found in the reference sequence or can be a different amino acid. Accordingly, D-analogs can also be variants.

[0097] While exemplary sequences are provided herein, sequence information provided by public databases can be used to identify additional related and relevant protein sequences and associated nucleic acid sequences encoding such proteins.

[0098] Iron. Reference to iron can include iron molecules or iron in an iron-containing complex. "Iron-containing complexes" or "iron complexes" are compounds that contain iron in the (II) or (III) oxidation state, complexed with an organic compound. Iron complexes include iron polymer complexes, iron carbohydrate complexes, and iron aminoglycosan complexes. These complexes are commercially available and/or can be synthesized by methods known in the art.

[0099] Examples of iron carbohydrate complexes include iron simple saccharide complexes, iron oligosaccharide complexes, and iron polysaccharide complexes, such as: iron carboxymaltose, iron sucrose, iron polyisomaltose (iron dextran), iron polymaltose (iron dextrin), iron gluconate, iron sorbitol, iron hydrogenated dextran, which may be further complexed with other compounds, such as sorbitol, citric acid and gluconic acid (for example iron dextrin-sorbitol-citric acid complex and iron sucrose-gluconic acid complex), and mixtures thereof.

[0100] Examples of iron aminoglycosan complexes include iron chondroitin sulfate, iron dermatin sulfate, iron keratan sulfate, which may be further complexed with other compounds and mixtures thereof.

[0101] Examples of iron polymer complexes include iron hyaluronic acid complex, iron protein complexes, and mixtures thereof. Iron protein complexes include ferritin, transferritin, as well as ferritin or transferritin with amino acid substitutions, and mixtures thereof.

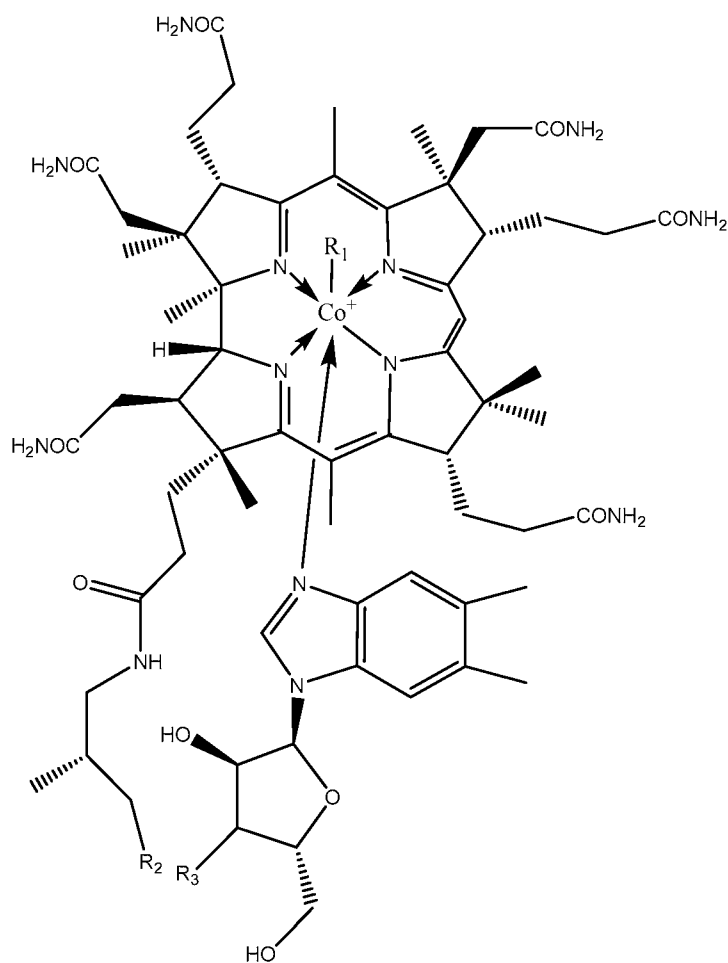
[0102] Particular embodiments utilize low molecular weight iron complexes (e.g., low molecular weight iron sucrose complexes). The molecular weight of the complex can be less than 25,000 and non-polymeric. In additional embodiments, the molecular weight of the complex can be less than 12,000 or less than 5000 or less than 2500. It is to be understood that the lower the

molecular weight of the iron complex and, correspondingly, the smaller the iron complex, the faster the iron complex may be incorporated into a patient's blood.

[0103] In particular embodiments, iron within the claims and exemplary embodiments refers to iron sucrose.

[0104] Vitamin B12 & Metabolites. Vitamin B12 is unique among vitamins in that it contains a metal ion, cobalt. Particular embodiments include the water soluble cyanocobalamin which is an organometallic compound with a trivalent cobalt ion bound inside a corrin ring. Methylcobalamin and 5-deoxyadenosyl cobalamin are forms of vitamin B12 primarily used by the human body. Additional forms include adenosyl cobalamin and hydroxyl cobalamin. Vitamin B12 may be obtained from any appropriate synthetic or natural source, and all analogues, derivatives, salts, and prodrugs, as well as mixtures thereof.

[0105] In embodiments, a derivative of vitamin B12 that can be utilized is produced by cleaving at least a portion of the PO_4^- group of vitamin B12. For example, the PO_4^- group of vitamin B12 can be cleaved using a nuclease, or removed with a nuclease in combination with a phosphatase. A derivative of vitamin B12 can have a structure



where R₁ can be 5'-deoxyadenosyl, CH₃, OH, or CN; R₂ can be OH or H; and R₃ can be OH or H.

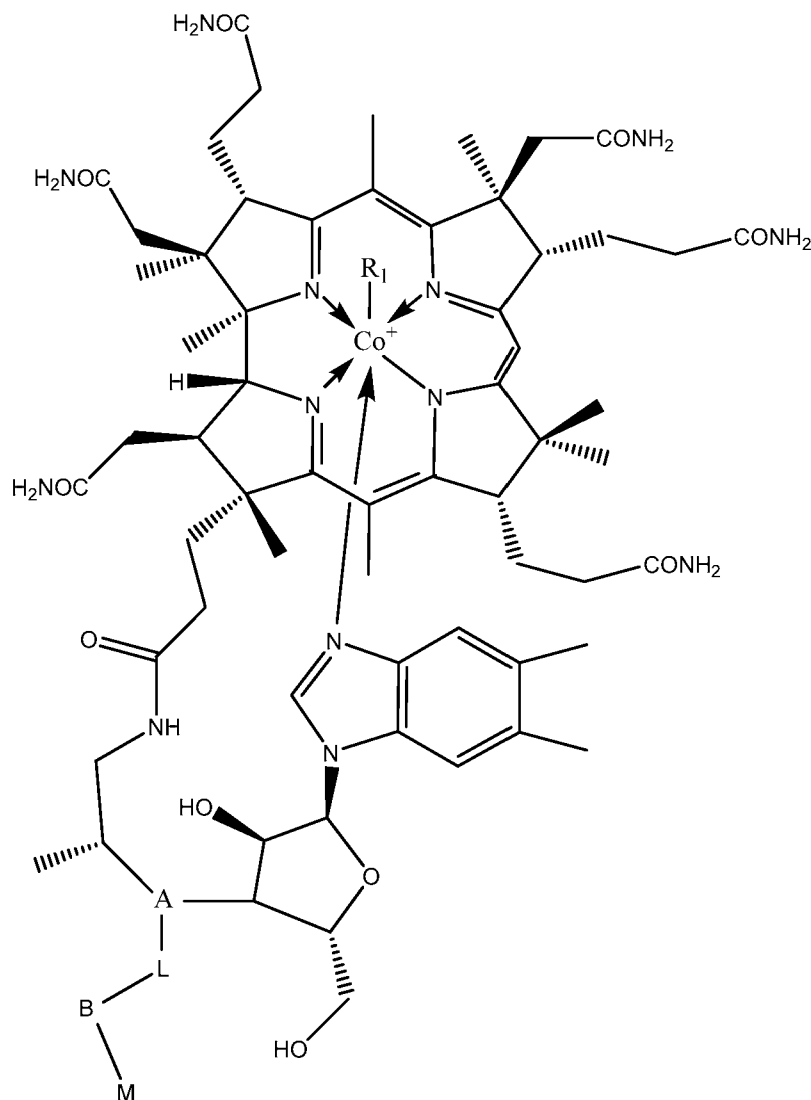
[0106] In embodiments, vitamin B12 can be coupled with a saccharide-metal complex. Additionally, a derivative of vitamin B12 can be coupled with a saccharide-metal complex. In some embodiments, a saccharide-metal complex can be derived from a disaccharide. For example a saccharide-metal complex can be derived from sucrose. In other examples, a saccharide-metal complex can be derived from lactose. In illustrative examples, the saccharide-metal complex can be iron sucrose. By coupling vitamin B12 with iron sucrose, iron and vitamin B12 can be delivered to an organ using a single structure.

[0107] The linkage between a saccharide-metal complex and vitamin B12 or a derivative of vitamin B12 can be formed using an acid-labile hydrazine linker. Additionally, the linkage between a saccharide-metal complex and vitamin B12 or a derivative of vitamin B12 can be formed using an acid labile hydrazone linker. Examples of a hydrazone linker used in conjunction with vitamin B12 is discussed in Bagnato JD, Eilers AL, Horton RA, Grisson CB: Synthesis and characterization of a cobalamin-colchicine conjugate as a novel tumor-targeted cytotoxid. *J. Org. Chem.* 2004: 69, 8987-8996. In other embodiments, the linkage between a saccharide-metal complex and vitamin B12 or a derivative of vitamin B12 can be formed using a polyether. To illustrate, polyethylene glycol can be used to link a saccharide-metal complex to vitamin B12 or a derivative of vitamin B12. In additional embodiments, the linkage between a saccharide-metal complex and vitamin B12 or a derivative of vitamin B12 can be formed using a peptide linker. In illustrative examples, a poly-glycine-serine linker can be used to couple a saccharide-metal complex to vitamin B12 or a derivative of vitamin B12. In further embodiments, the linkage between a saccharide-metal complex and vitamin B12 or a derivative of vitamin B12 can be formed using one or more peptides. In other illustrative examples, a polyamide can be used to link a saccharide-metal complex with vitamin B12 or a derivative of vitamin B12. In particular illustrative examples, a protease resistant polyamide can be used to link a saccharide-metal complex with vitamin B12 or a derivative of vitamin B12.

[0108] In some cases, the linkage between a saccharide-metal complex and vitamin B12 or a derivative of vitamin B12 can be formed at multiple sites of the saccharide-metal complex. For example, the linkage between a saccharide-metal complex and vitamin B12 or a derivative of vitamin B12 can be at multiple hydroxyl sites of the saccharide-metal complex. In other embodiments, the linkage between a saccharide-metal complex and vitamin B12 or a derivative of vitamin B12 can be at a single site of the saccharide-metal complex. To illustrate, the linkage between a saccharide-metal complex and vitamin B12 or a derivative of vitamin B12 can be at a single hydroxyl site of the saccharide-metal complex. Additionally, the linkage between a

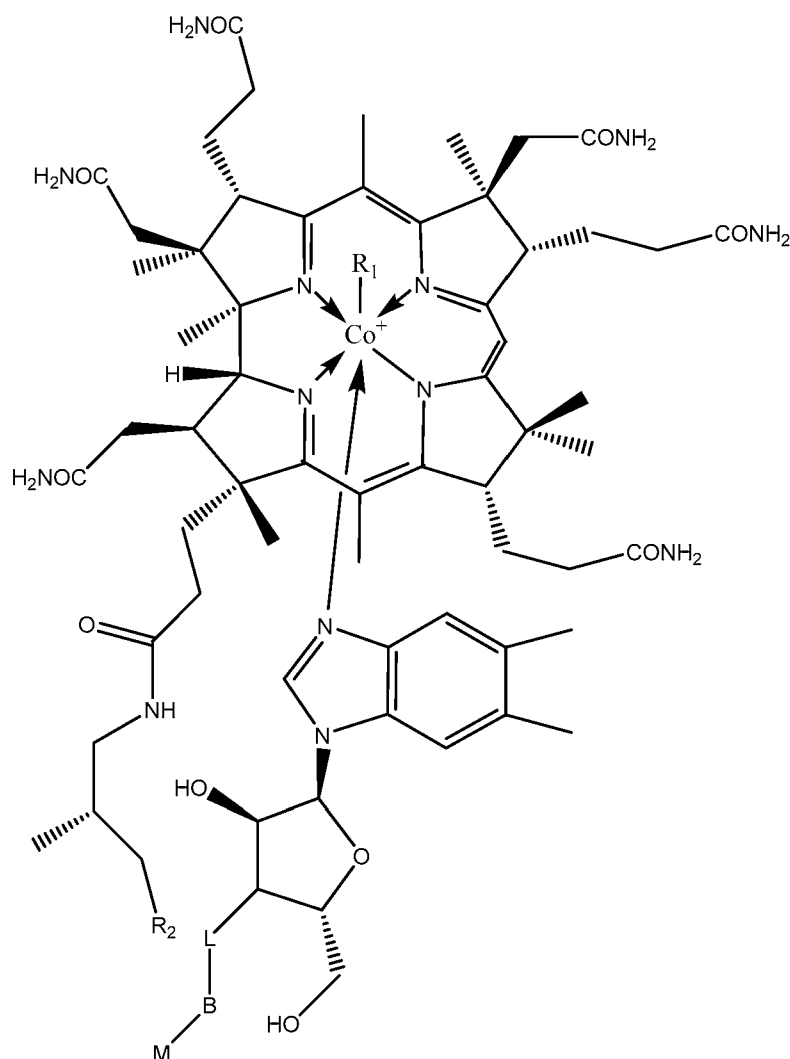
saccharide-metal complex and vitamin B12 can be with the phosphate group of vitamin B12 and a hydroxyl group of the saccharide-metal complex. Further, the linkage between a saccharide-metal complex and a derivative of vitamin B12 can be between a hydroxyl group of the saccharide-metal complex and a site resulting from cleaving the phosphate group from vitamin B12.

[0109] Example structures having a linkage between a saccharide-metal complex and vitamin B12 can have the following form:



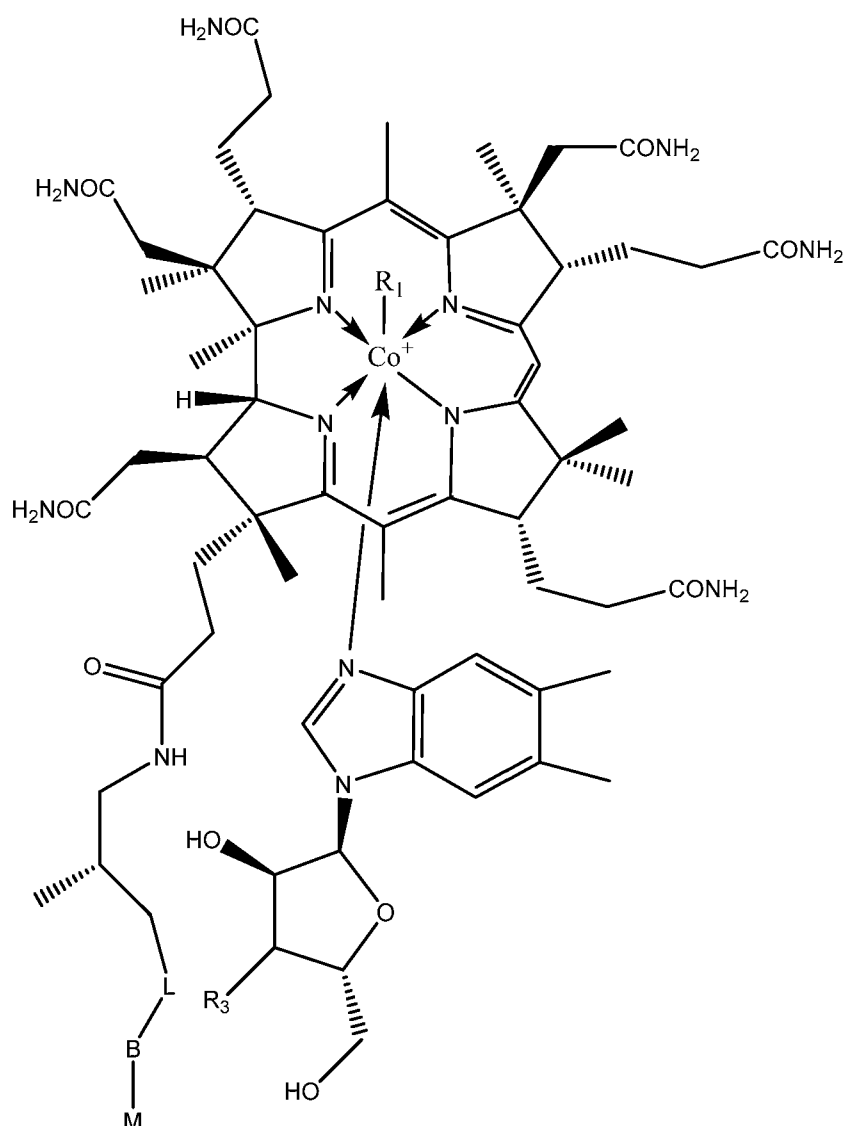
where R_1 can be 5'-deoxyadenosyl, CH_3 , OH , or CN ; A is a phosphate group, L is a linker, B is a saccharide-based structure, and M is a metal complexed with the saccharide-based structure. In illustrative embodiments, A can be PO_4 , L can be a hydrazone linker, B can be a saccharide-based structure, and M can be Fe . In embodiments, B can include 10-16 carbon atoms, 9-15 oxygen atoms, and 16-28 hydrogen atoms. In particular embodiments, B can be derived from sucrose.

[0110] Example structures having a linkage between a saccharide-metal complex and a derivative of vitamin B12 can have the following form:



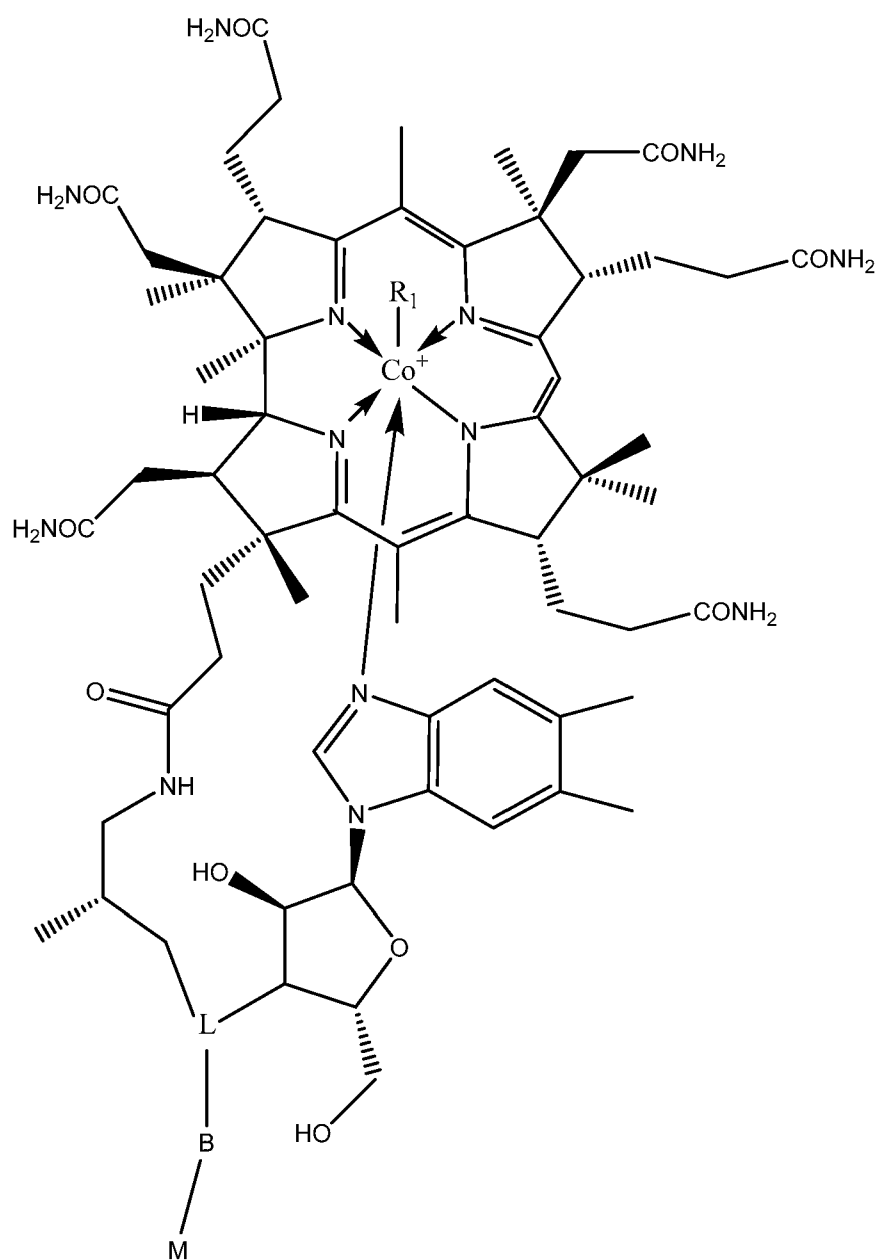
where R₁ can be 5'-deoxyadenosyl, CH₃, OH, or CN; R₂ can be OH or H; L is a linker, B is a saccharide-based structure, and M is a metal complexed with the saccharide-based structure. In illustrative embodiments, L can be a hydrazone linker and M can be Fe. In embodiments, B can include 10-16 carbon atoms, 9-15 oxygen atoms, and 16-28 hydrogen atoms. In particular embodiments, B can be derived from sucrose.

[0111] Additional example structures having a linkage between a saccharide-metal complex and a derivative of vitamin B12 can have the following form:



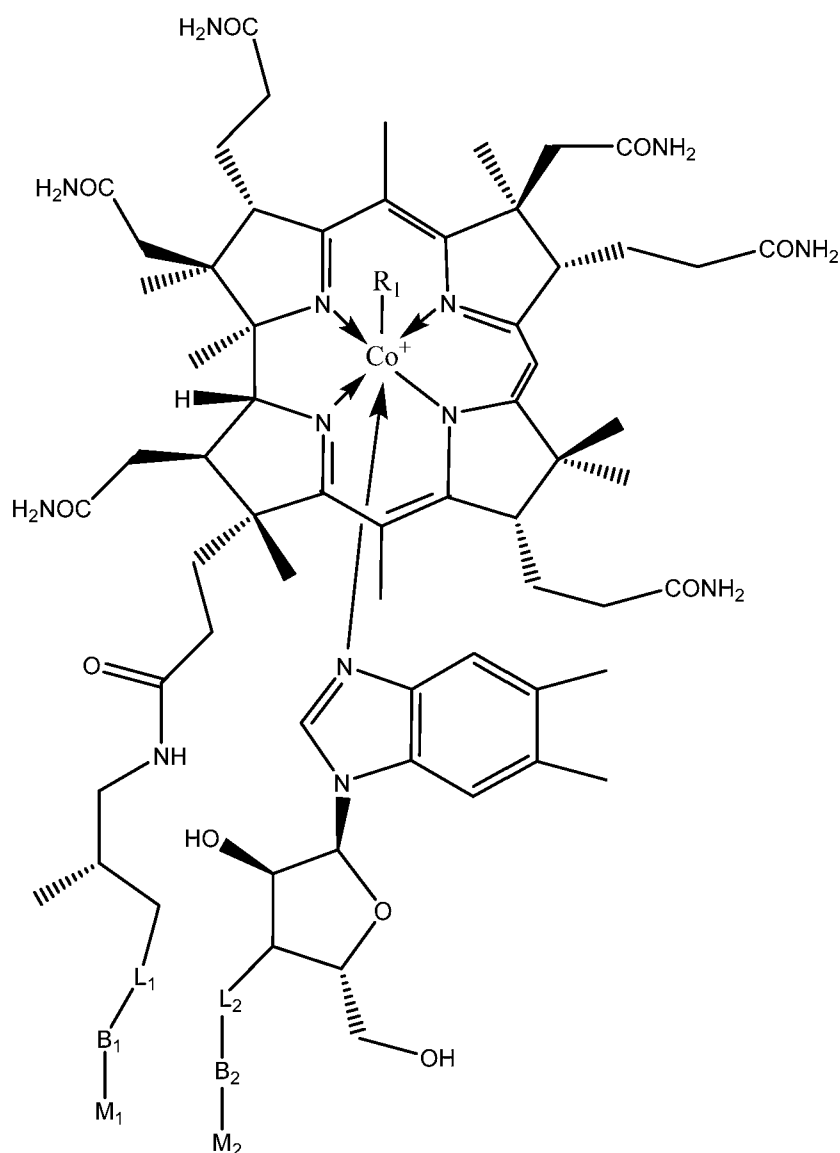
where R₁ can be 5'-deoxyadenosyl, CH₃, OH, or CN; R₃ can be OH or H; L is a linker, B is a saccharide-based structure, and M is a metal complexed with the saccharide-based structure. In an illustrative embodiment, L can be a hydrazone linker and M can be Fe. In embodiments, B can include 10-16 carbon atoms, 9-15 oxygen atoms, and 16-28 hydrogen atoms. In particular embodiments, B can be derived from sucrose.

[0112] Other example structures having a linkage between a saccharide-metal complex and a derivative of vitamin B12 can have the following form:



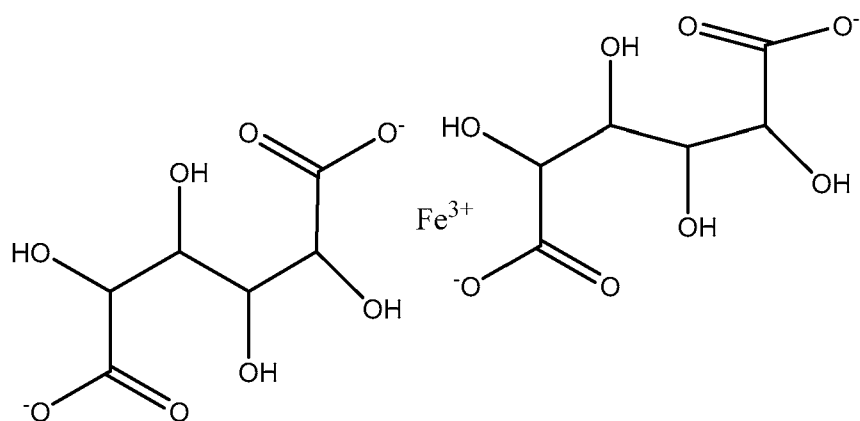
where R_1 can be 5'-deoxyadenosyl, CH_3 , OH , or CN ; L is a linker, B is a saccharide-based structure, and M is a metal complexed with the saccharide-based structure. In illustrative embodiments, L can be a hydrazone linker and M can be Fe . In embodiments, B can include 10-16 carbon atoms, 9-15 oxygen atoms, and 16-28 hydrogen atoms. In particular embodiments, B can be derived from sucrose.

[0113] Example structures having a linkage between multiple saccharide-metal complexes and a derivative of vitamin B12 can have the following form:



where R_1 can be 5'-deoxyadenosyl, CH_3 , OH , or CN ; L_1 is a first linker, L_2 is a second linker, B_1 is a first saccharide-based structure, B_2 is a second saccharide-based structure, M_1 is a first metal, and M_2 is a second metal complexed with the saccharide-based structure. In illustrative embodiments, L_1 and L_2 can be hydrazone linkers and M_1 and M_2 can be Fe . In embodiments, B_1 and B_2 can include 10-16 carbon atoms, 9-15 oxygen atoms, and 16-28 hydrogen atoms. In particular embodiments, B_1 and B_2 can be derived from sucrose.

[0114] In embodiments, a saccharide-metal complex can be derived from a disaccharide. For example a saccharide-metal complex can be derived from sucrose. In other examples, a saccharide-metal complex can be derived from lactose. Example structures of a saccharide-metal complex can have the following form:



It is to be understood that although the above structure indicates a single Fe atom complexed with a sucrose derived compound, one or more Fe atoms can be complexed with one or more repeating units of the sucrose derived compound to balance the charges of the groups as needed.

[0115] Compositions. Heme proteins (including modifications, variants and D-substituted analogs thereof), heme protein degradation inhibitors (e.g., HO-1 inhibitors, protoporphyrins, hemin and/or hematin), iron and vitamin B12 (individually and collectively, “active ingredients”) can be provided alone or in combination within a composition. In particular embodiments, composition includes at least one heme protein and/or at least one heme protein degradation inhibitor and at least one pharmaceutically acceptable carrier. Salts and/or pro-drugs of active ingredients can also be used.

[0116] A pharmaceutically acceptable salt includes any salt that retains the activity of the active ingredient and is acceptable for pharmaceutical use. A pharmaceutically acceptable salt also refers to any salt which may form in vivo as a result of administration of an acid, another salt, or a prodrug which is converted into an acid or salt.

[0117] Suitable pharmaceutically acceptable acid addition salts can be prepared from an inorganic acid or an organic acid. Examples of such inorganic acids are hydrochloric, hydrobromic, hydroiodic, nitric, carbonic, sulfuric and phosphoric acid. Appropriate organic acids can be selected from aliphatic, cycloaliphatic, aromatic, arylaliphatic, heterocyclic, carboxylic and sulfonic classes of organic acids.

[0118] Suitable pharmaceutically acceptable base addition salts include metallic salts made from aluminum, calcium, lithium, magnesium, potassium, sodium and zinc or organic salts made from N,N'-dibenzylethylene-diamine, chlorprocaine, choline, diethanolamine, ethylenediamine, N-methylglucamine, lysine, arginine and procaine.

[0119] A prodrug includes an active ingredient which is converted to a therapeutically active compound after administration, such as by cleavage of a protein or by hydrolysis of a biologically labile group.

[0120] In some embodiments, the compositions include active ingredients of at least 0.1% w/v of the composition; at least 1% w/v of composition; at least 10% w/v of composition; at least 20% w/v of composition; at least 30% w/v of composition; at least 40% w/v of composition; at least 50% w/v of composition; at least 60% w/v of composition; at least 70% w/v of composition; at least 80% w/v of composition; at least 90% w/v of composition; at least 95% w/v of composition; or at least 99% w/v of composition.

[0121] In other embodiments, active ingredients can be provided as part of a composition that can include, for example, at least 0.1% w/w of composition; at least 1% w/w of composition; at least 10% w/w of composition; at least 20% w/w of composition; at least 30% w/w of composition; at least 40% w/w of composition; at least 50% w/w of composition; at least 60% w/w of composition; at least 70% w/w of composition; at least 80% w/w of composition; at least 90% w/w of composition; at least 95% w/w of composition; or at least 99% w/w of composition.

[0122] Particular embodiments include a nitrated heme protein degradation inhibitor with a nitrated heme protein. Particular embodiments include a nitrated protoporphyrin with a nitrated heme protein. Particular embodiments include a nitrated metal protoporphyrin with a nitrated heme protein. Particular embodiments include a nitrated SnPP with a nitrated heme protein. Particular embodiments include a nitrated hemin with a nitrated heme protein. Particular embodiments include a nitrated hematin with a nitrated heme protein. In particular forms of these exemplary embodiments, the nitrated heme protein is myoglobin. Particular embodiments also include more than one nitrated heme protein degradation inhibitor (e.g. a nitrated protoporphyrin, nitrated hemin and/or nitrated hematin) with a heme protein (e.g., myoglobin or nitrated myoglobin). In further particular embodiments, a combination of heme protein degradation inhibitor is provided wherein not all constituents of the combination are nitrated.

[0123] Particular embodiments include iron, optionally in combination with a metal protoporphyrin, SnPP and/or vitamin B12. The iron can be iron sucrose. These embodiments can additionally include heme proteins (e.g., myoglobin or nitrated myoglobin) and/or heme protein degradation inhibitor (e.g., protoporphyrins, hemin and/or hematin and/or their nitrated forms). When embodiments utilize iron in combination with vitamin B12, the iron and B12 can be complexed or cross-linked into a single unit.

[0124] Exemplary generally used pharmaceutically acceptable carriers include any and all absorption delaying agents, antioxidants, binders, buffering agents, bulking agents or fillers,

chelating agents, coatings, disintegration agents, dispersion media, gels, isotonic agents, lubricants, preservatives, salts, solvents or co-solvents, stabilizers, surfactants, and/or delivery vehicles.

[0125] Exemplary antioxidants include ascorbic acid, methionine, and vitamin E.

[0126] Exemplary buffering agents include citrate buffers, succinate buffers, tartrate buffers, fumarate buffers, gluconate buffers, oxalate buffers, lactate buffers, acetate buffers, phosphate buffers, histidine buffers, and/or trimethylamine salts.

[0127] An exemplary chelating agent is EDTA.

[0128] Exemplary isotonic agents include polyhydric sugar alcohols including trihydric or higher sugar alcohols, such as glycerin, erythritol, arabitol, xylitol, sorbitol, or mannitol.

[0129] Exemplary preservatives include phenol, benzyl alcohol, meta-cresol, methyl paraben, propyl paraben, octadecyldimethylbenzyl ammonium chloride, benzalkonium halides, hexamethonium chloride, alkyl parabens such as methyl or propyl paraben, catechol, resorcinol, cyclohexanol, and 3-pentanol.

[0130] Stabilizers refer to a broad category of excipients which can range in function from a bulking agent to an additive which solubilizes the active ingredient or helps to prevent denaturation or adherence to the container wall. Typical stabilizers can include polyhydric sugar alcohols; amino acids, such as arginine, lysine, glycine, glutamine, asparagine, histidine, alanine, ornithine, L-leucine, 2-phenylalanine, glutamic acid, and threonine; organic sugars or sugar alcohols, such as lactose, trehalose, stachyose, mannitol, sorbitol, xylitol, ribitol, myoinisitol, galactitol, glycerol, and cyclitols, such as inositol; PEG; amino acid polymers; sulfur-containing reducing agents, such as urea, glutathione, thiocetic acid, sodium thioglycolate, thioglycerol, alpha-monothioglycerol, and sodium thiosulfate; low molecular weight polypeptides (i.e., <10 residues); proteins such as human serum albumin, bovine serum albumin, gelatin or immunoglobulins; hydrophilic polymers such as polyvinylpyrrolidone; monosaccharides such as xylose, mannose, fructose and glucose; disaccharides such as lactose, maltose and sucrose; trisaccharides such as raffinose, and polysaccharides such as dextran. Stabilizers are typically present in the range of from 0.1 to 10,000 parts by weight based on active ingredient weight.

[0131] The compositions disclosed herein can be formulated for administration by, for example, injection, inhalation, infusion, perfusion, lavage, or ingestion. The compositions disclosed herein can further be formulated for intravenous, intradermal, intraarterial, intranodal, intralymphatic, intraperitoneal, intralesional, intraprostatic, intravaginal, intrarectal, topical, intrathecal, intratumoral, intramuscular, intravesicular, oral and/or subcutaneous administration and more particularly by intravenous, intradermal, intraarterial, intranodal, intralymphatic,

intraperitoneal, intralesional, intraprostatic, intravaginal, intrarectal, intrathecal, intratumoral, intramuscular, intravesicular, and/or subcutaneous injection.

[0132] For injection, compositions can be formulated as aqueous solutions, such as in buffers including Hanks' solution, Ringer's solution, or physiological saline. The aqueous solutions can contain formulatory agents such as suspending, stabilizing, and/or dispersing agents. Alternatively, the formulation can be in lyophilized and/or powder form for constitution with a suitable vehicle, e.g., sterile pyrogen-free water, before use. Particular embodiments are formulated for intravenous administration.

[0133] For oral administration, the compositions can be formulated as tablets, pills, dragees, capsules, liquids, gels, syrups, slurries, suspensions and the like. For oral solid formulations such as, for example, powders, capsules and tablets, suitable excipients include binders (gum tragacanth, acacia, cornstarch, gelatin), fillers such as sugars, e.g. lactose, sucrose, mannitol and sorbitol; dicalcium phosphate, starch, magnesium stearate, sodium saccharine, cellulose, magnesium carbonate; cellulose preparations such as maize starch, wheat starch, rice starch, potato starch, gelatin, gum tragacanth, methyl cellulose, hydroxypropylmethyl-cellulose, sodium carboxy- methylcellulose, and/or polyvinylpyrrolidone (PVP); granulating agents; and binding agents. If desired, disintegrating agents can be added, such as corn starch, potato starch, alginic acid, cross-linked polyvinylpyrrolidone, agar, or alginic acid or a salt thereof such as sodium alginate. If desired, solid dosage forms can be sugar-coated or enteric-coated using standard techniques. Flavoring agents, such as peppermint, oil of wintergreen, cherry flavoring, orange flavoring, etc. can also be used.

[0134] Compositions can be formulated as an aerosol. In one embodiment, the aerosol is provided as part of an anhydrous, liquid or dry powder inhaler. Aerosol sprays from pressurized packs or nebulizers can also be used with a suitable propellant, e.g., dichlorodifluoromethane, trichlorofluoromethane, dichlorotetrafluoroethane, carbon dioxide or other suitable gas. In the case of a pressurized aerosol, a dosage unit may be determined by providing a valve to deliver a metered amount. Capsules and cartridges of gelatin for use in an inhaler or insufflator may also be formulated containing a powder mix of heme protein and a suitable powder base such as lactose or starch.

[0135] Compositions can also be formulated as depot preparations. Depot preparations can be formulated with suitable polymeric or hydrophobic materials (for example as an emulsion in an acceptable oil) or ion exchange resins, or as sparingly soluble derivatives, for example, as a sparingly soluble salts.

[0136] Additionally, compositions can be formulated as sustained-release systems utilizing semipermeable matrices of solid polymers containing at least one active ingredient. Various sustained-release materials have been established and are well known by those of ordinary skill in the art. Sustained-release systems may, depending on their chemical nature, release active ingredients following administration for a few weeks up to over 100 days. Depot preparations can be administered by injection; parenteral injection; instillation; or implantation into soft tissues, a body cavity, or occasionally into a blood vessel with injection through fine needles.

[0137] Depot formulations can include a variety of bioerodible polymers including poly(lactide), poly(glycolide), poly(caprolactone) and poly(lactide)-co(glycolide) (PLG) of desirable lactide:glycolide ratios, average molecular weights, polydispersities, and terminal group chemistries. Blending different polymer types in different ratios using various grades can result in characteristics that borrow from each of the contributing polymers.

[0138] The use of different solvents (for example, dichloromethane, chloroform, ethyl acetate, triacetin, N-methyl pyrrolidone, tetrahydrofuran, phenol, or combinations thereof) can alter microparticle size and structure in order to modulate release characteristics. Other useful solvents include water, ethanol, dimethyl sulfoxide (DMSO), N-methyl-2-pyrrolidone (NMP), acetone, methanol, isopropyl alcohol (IPA), ethyl benzoate, and benzyl benzoate.

[0139] Exemplary release modifiers can include surfactants, detergents, internal phase viscosity enhancers, complexing agents, surface active molecules, co-solvents, chelators, stabilizers, derivatives of cellulose, (hydroxypropyl)methyl cellulose (HPMC), HPMC acetate, cellulose acetate, pluronics (e.g., F68/F127), polysorbates, Span® (Croda Americas, Wilmington, Delaware), poly(vinyl alcohol) (PVA), Brij® (Croda Americas, Wilmington, Delaware), sucrose acetate isobutyrate (SAIB), salts, and buffers.

[0140] Excipients that partition into the external phase boundary of microparticles such as surfactants including polysorbates, dioctylsulfosuccinates, poloxamers, PVA, can also alter properties including particle stability and erosion rates, hydration and channel structure, interfacial transport, and kinetics in a favorable manner.

[0141] Additional processing of the disclosed sustained release depot formulations can utilize stabilizing excipients including mannitol, sucrose, trehalose, and glycine with other components such as polysorbates, PVAs, and dioctylsulfosuccinates in buffers such as Tris, citrate, or histidine. A freeze-dry cycle can also be used to produce very low moisture powders that reconstitute to similar size and performance characteristics of the original suspension.

[0142] Any composition disclosed herein can advantageously include any other pharmaceutically acceptable carriers which include those that do not produce significantly

adverse, allergic, or other untoward reactions that outweigh the benefit of administration. Exemplary pharmaceutically acceptable carriers and formulations are disclosed in Remington's Pharmaceutical Sciences, 18th Ed. Mack Printing Company, 1990. Moreover, formulations can be prepared to meet sterility, pyrogenicity, general safety, and purity standards as required by U.S. FDA Office of Biological Standards and/or other relevant foreign regulatory agencies.

[0143] Kits. Also disclosed herein are kits including one or more containers including one or more of the active ingredients and/or compositions described herein. In various embodiments, the kits may include one or more containers containing one or more active ingredients and/or compositions to be used in combination with the active ingredients and/or compositions described herein. Associated with such container(s) can be a notice in the form prescribed by a governmental agency regulating the manufacture, use, or sale of pharmaceuticals or biological products, which notice reflects approval by the agency of manufacture, use, or sale for human administration.

[0144] Optionally, the kits described herein further include instructions for using the kit in the methods disclosed herein. In various embodiments, the kit may include instructions regarding preparation of the active ingredients and/or compositions for administration; administration of the active ingredients and/or compositions; appropriate reference levels to interpret results associated with using the kit; proper disposal of the related waste; and the like. The instructions can be in the form of printed instructions provided within the kit or the instructions can be printed on a portion of the kit itself. Instructions may be in the form of a sheet, pamphlet, brochure, CD-Rom, or computer-readable device, or can provide directions to instructions at a remote location, such as a website. The instructions may be in English and/or in any national or regional language. In various embodiments, possible side effects and contraindications to further use of components of the kit based on a subject's symptoms can be included. The kits and instructions can also be tailored according to the type of organ to be protected and the type of insult the organ may encounter.

[0145] In various embodiments, the packaging, active ingredients and/or compositions, and instructions are combined into a small, compact kit with printed instructions for use of each of the active ingredients and/or compositions. In various embodiments in which more than one active ingredient and/or composition is provided, the sequencing of use of the active ingredients and/or compositions can be labeled in the kit.

[0146] In various embodiments, the kits described herein include some or all of the necessary medical supplies needed to use the kit effectively, thereby eliminating the need to locate and gather such medical supplies. Such medical supplies can include syringes, ampules,

tubing, facemask, a needleless fluid transfer device, an injection cap, sponges, sterile adhesive strips, Chloraprep, gloves, and the like. Variations in contents of any of the kits described herein can be made. Particular kits provide materials to administer compositions through intravenous administration.

[0147] Methods of Use. As stated, the compositions, kits, and methods disclosed herein can be used to protect organs from injury by inducing acquired cytoresistance in the absence of an injury. There are numerous potential uses for the compositions, kits, and methods, some of which are described herein.

[0148] Methods disclosed herein include treating organs with active ingredients disclosed herein including salts and prodrugs thereof. Treating organs includes delivering therapeutically effective amounts. Therapeutically effective amounts include those that provide effective amounts, prophylactic treatments, and/or therapeutic treatments.

[0149] An organ is a part of a subject that is typically self-contained and has a specific vital function. Examples of organs include the heart, liver, kidneys, spleen, pancreas, brain, lungs, intestines, stomach, etc. In particular embodiments, therapeutically effective amounts can be administered directly to organs.

[0150] Therapeutically effective amounts can also be administered to organs by administering the therapeutically effective amount to the subject in which the organ resides. Subjects include humans, veterinary animals (dogs, cats, reptiles, birds, etc.), livestock (horses, cattle, goats, pigs, chickens, etc.), and research animals (monkeys, rats, mice, fish, etc.). Treating subjects includes delivering therapeutically effective amounts. Thus, unless stated otherwise, administration to an organ can be by administration to a subject, resulting in physiological delivery to the organ or can be by administration directly to the organ.

[0151] An "effective amount" is the amount of an active ingredient or composition necessary to result in a desired physiological change in an organ or subject. Effective amounts are often administered for research purposes. Effective amounts disclosed herein protect organs from injury by inducing acquired cytoresistance in the absence of an injury.

[0152] A "prophylactic treatment" includes a treatment administered to an organ that does not display signs or symptoms of organ injury or displays only early signs or symptoms of organ injury such that treatment is administered for the purpose of diminishing, preventing, or decreasing the risk of developing further organ injury. Thus, a prophylactic treatment functions as a preventative treatment against organ injury.

[0153] A "therapeutic treatment" includes a treatment administered to an organ that displays symptoms or signs of organ injury and is administered to the organ for the purpose of reducing the worsening of organ injury.

[0154] The actual dose amount administered to a particular organ (or subject) can be determined by a physician, veterinarian, or researcher taking into account parameters such as physical and physiological factors including target; body weight; severity of condition; upcoming insult, when known; type of organ requiring protection; previous or concurrent therapeutic interventions; idiopathy of the subject; and route of administration.

[0155] The amount and concentration of active ingredient in a composition, as well as the quantity of the composition administered, can be selected based on clinically relevant factors, the solubility of the active ingredient in the composition, the potency and activity of the active ingredient, and the manner of administration of the composition, as well as whether the active ingredient is modified (e.g., nitrated, PEGylated) or administered in combination with a heme protein degradation inhibitor (e.g., an HO-1 inhibitor) among other considerations.

[0156] A composition including a therapeutically effective amount of an active ingredient(s) disclosed herein can be administered intravenously to a subject for protection of organs in a clinically safe and effective manner, including one or more separate administrations of the composition. For example, 0.05 mg/kg to 5.0 mg/kg can be administered to a subject per day in one or more doses (e.g., doses of 0.05 mg/kg QD, 0.10 mg/kg QD, 0.50 mg/kg QD, 1.0 mg/kg QD, 1.5 mg/kg QD, 2.0 mg/kg QD, 2.5 mg/kg QD, 3.0 mg/kg QD, 0.75 mg/kg BID, 1.5 mg/kg BID, or 2.0 mg/kg BID). For certain organs and indications, the total daily dose of an active ingredient can be 0.05 mg/kg to 3.0 mg/kg administered intravenously to a subject one to three times a day, including administration of total daily doses of 0.05-3.0, 0.1-3.0, 0.5-3.0, 1.0-3.0, 1.5-3.0, 2.0-3.0, 2.5-3.0, and 0.5-3.0 mg/kg/day of composition using 60-minute QD, BID, or TID intravenous infusion dosing. In one particular example, compositions can be intravenously administered QD or BID to a subject with, e.g., total daily doses of 1.5 mg/kg, 3.0 mg/kg, 4.0 mg/kg of a composition with up to 92-98% wt/wt of a heme protein.

[0157] Additional useful doses can often range from 0.1 to 5 µg/kg or from 0.5 to 1 µg /kg. In other examples, a dose can include 1 µg /kg, 5 µg /kg, 10 µg /kg, 15 µg /kg, 20 µg /kg, 25 µg /kg, 30 µg /kg, 35 µg/kg, 40 µg/kg, 45 µg/kg, 50 µg/kg, 55 µg/kg, 60 µg/kg, 65 µg/kg, 70 µg/kg, 75 µg/kg, 80 µg/kg, 85 µg/kg, 90 µg/kg, 95 µg/kg, 100 µg/kg, 150 µg/kg, 200 µg/kg, 250 µg/kg, 350 µg/kg, 400 µg/kg, 450 µg/kg, 500 µg/kg, 550 µg/kg, 600 µg/kg, 650 µg/kg, 700 µg/kg, 750 µg/kg, 800 µg/kg, 850 µg/kg, 900 µg/kg, 950 µg/kg, 1000 µg/kg, 0.1 to 5 mg/kg, or from 0.5 to 1 mg/kg. In other examples, a dose can include 1 mg/kg, 5 mg/kg, 10 mg/kg, 15 mg/kg, 20 mg/kg, 25

mg/kg, 30 mg/kg, 35 mg/kg, 40 mg/kg, 45 mg/kg, 50 mg/kg, 55 mg/kg, 60 mg/kg, 65 mg/kg, 70 mg/kg, 75 mg/kg, 80 mg/kg, 85 mg/kg, 90 mg/kg, 95 mg/kg, 100 mg/kg, 150 mg/kg, 200 mg/kg, 250 mg/kg, 350 mg/kg, 400 mg/kg, 450 mg/kg, 500 mg/kg, 550 mg/kg, 600 mg/kg, 650 mg/kg, 700 mg/kg, 750 mg/kg, 800 mg/kg, 850 mg/kg, 900 mg/kg, 950 mg/kg, 1000 mg/kg, or more.

[0158] Each of the described doses of active ingredients can be a heme protein alone, heme proteins in combination, a heme protein degradation inhibitor alone, heme protein degradation inhibitors in combination or a combination of one or more heme proteins and one or more heme protein degradation inhibitors, iron, and/or vitamin B12. In particular embodiments, when included in combinations to produce a dose, such as a dose stated herein, the substituents in the combination can be provided in exemplary ratios such as: 1:1; 1:1.25; 1:1.5; 1:1.75; 1:8; 1:1.2; 1:1.25; 1:1.3; 1:1.35; 1:1.4; 1:1.5; 1:1.75; 1:2; 1:3; 1:4; 1:5; 1:6; 1:7; 1:8; 1:9; 1:10; 1:15; 1:20; 1:30; 1:40; 1:50; 1:60; 1:70; 1:80; 1:90; 1:100; 1:200; 1:300; 1:400; 1:500; 1:600; 1:700; 1:800; 1:900; 1:1000; 1:1:1; 1:2:1; 1:3:1; 1:4:1; 1:5:1; 1:10:1; 1:2:2; 1:2:3; 1:3:4; 1:4:2; 1:5:3; 1:10:20; 1:2:1:2; 1:4:1:3; 1:100:1:1000; 1:25:30:10; 1:4:16:3; 1:1000:5:15; 1:2:3:10; 1:5:15:45; 1:50:90:135; 1:1.5:1.8:2.3; 1:10:100:1000 or additional beneficial ratios depending on the number and identity of substituents in a combination to reach the stated dosage. The substituents in a combination can be provided within the same composition or within different compositions.

[0159] Therapeutically effective amounts can be achieved by administering single or multiple doses during the course of a treatment regimen (e.g., QID, TID, BID, daily, every other day, every 3 days, every 4 days, every 5 days, every 6 days, weekly, every 2 weeks, every 3 weeks, monthly, every 2 months, every 3 months, every 4 months, every 5 months, every 6 months, every 7 months, every 8 months, every 9 months, every 10 months, every 11 months, or yearly).

[0160] In particular embodiments, compositions are administered within 48 hours of an upcoming insult, within 46 hours of an upcoming insult, within 44 hours of an upcoming insult, within 42 hours of an upcoming insult, within 40 hours of an upcoming insult, within 38 hours of an upcoming insult, within 36 hours of an upcoming insult, within 34 hours of an upcoming insult, within 32 hours of an upcoming insult, within 30 hours of an upcoming insult, within 28 hours of an upcoming insult, within 26 hours of an upcoming insult, within 24 hours of an upcoming insult, within 22 hours of an upcoming insult, within 20 hours of an upcoming insult, within 18 hours of an upcoming insult, within 16 hours of an upcoming insult, within 14 hours of an upcoming insult, within 12 hours of an upcoming insult, within 10 hours of an upcoming insult, within 8 hours of an upcoming insult, within 6 hours of an upcoming insult, within 4 hours of an upcoming insult, or within 2 hours of an upcoming insult. In one particular embodiment, compositions are administered within 18 hours of an upcoming insult.

[0161] In additional particular embodiments, compositions are administered at least 48 hours before an upcoming insult, at least 46 hours before an upcoming insult, at least 44 hours before an upcoming insult, at least 42 hours before an upcoming insult, at least 40 hours before an upcoming insult, at least 38 hours before an upcoming insult, at least 36 hours before an upcoming insult, at least 34 hours before an upcoming insult, at least 32 hours before an upcoming insult, at least 30 hours before an upcoming insult, at least 28 hours before an upcoming insult, at least 26 hours before an upcoming insult, at least 24 hours before an upcoming insult, at least 22 hours before an upcoming insult, at least 20 hours before an upcoming insult, at least 18 hours before an upcoming insult, at least 16 hours before an upcoming insult, at least 14 hours before an upcoming insult, at least 12 hours before an upcoming insult, at least 10 hours before an upcoming insult, at least 8 hours before an upcoming insult, at least 6 hours before an upcoming insult, at least 4 hours before an upcoming insult, or at least 2 hours before an upcoming insult. In one particular embodiment, compositions are administered at least 18 hours before an upcoming insult.

[0162] Transplant Protection. In particular embodiments, organs are protected from injury during transplant. The compositions can be administered (i) to an organ donor before organ isolation from the donor; (ii) to the isolated organ before transplantation, and/or (iii) to the organ transplant recipient. This method of use can apply to any organ capable of transplant from one individual subject to a second individual subject. In particular embodiments, therapeutically effective amounts can be delivered directly to an organ following removal from a subject or prior to implantation in a second subject.

[0163] Renal System Protection. Until the current disclosure, there were no agents able to prevent or mitigate the occurrence of AKI in patients at high risk, such as individuals undergoing surgery, cardiopulmonary bypass, or radiocontrast toxicity. It is noteworthy that acute kidney failure is a major risk factor for both morbidity and mortality as well as the need for long term kidney dialysis. The latter costs the Federal Government billions of dollars in its end stage kidney disease/Medicare program. Thus, prevention of AKI/ acute kidney failure presented a critical and completely unmet clinical need.

[0164] “Acute kidney injury”, (AKI) also known as “acute renal failure” (ARF) or “acute kidney failure”, refers to a disease or condition where a rapid loss of renal function occurs due to damage to the kidneys, resulting in retention of nitrogenous (urea and creatinine) and non-nitrogenous waste products that are normally excreted by the kidney. Depending on the severity and duration of the renal dysfunction, this accumulation is accompanied by metabolic disturbances, such as metabolic acidosis (acidification of the blood) and hyperkalaemia (elevated

potassium levels), changes in body fluid balance, effects on many other organ systems/organ system failure, intravascular volume overload, coma and death. It can be characterized by oliguria or anuria (decrease or cessation of urine production), although nonoliguric ARF may occur. AKI is a serious complication in hospitals, resulting in a prolonged hospital stay and high mortality. Cardiac disease and cardiac surgery are both common causes of AKI. Once patients have AKI, the mortality thereof is high.

[0165] AKI may be a consequence of various causes including a) pre-renal (causes in the blood supply), which includes, hypovolemia or decreased blood volume, usually from shock or dehydration and fluid loss or excessive diuretics use; hepatorenal syndrome, in which renal perfusion is compromised due to liver failure; vascular problems, such as atheroembolic disease and renal vein thrombosis, which can occur as a complication of nephrotic syndrome; infection, usually sepsis, and systemic inflammation due to infection; severe burns; sequestration due to pericarditis and pancreatitis; and hypotension due to antihypertensives and vasodilators; b) intrinsic renal damage, which includes renal ischemia (transient blood flow reductions or interruption) toxins or medication (e.g. some NSAIDs, aminoglycoside antibiotics, iodinated contrast, lithium, phosphate nephropathy due to bowel preparation for colonoscopy with sodium phosphates); rhabdomyolysis or breakdown of muscle tissue, where the resultant release of myoglobin in the blood affects the kidney, which can also be caused by injury (especially crush injury or extensive blunt trauma), statins, stimulants and some other drugs; hemolysis or breakdown of red blood cells, which can be caused by various conditions such as sickle-cell disease, and lupus erythematosus; multiple myeloma, either due to hypercalcemia or “cast nephropathy”; acute glomerulonephritis which may be due to a variety of causes, such as anti-glomerular basement membrane disease/Goodpasture's syndrome, Wegener's granulomatosis, or acute lupus nephritis with systemic lupus erythematosus; and c) post-renal causes (obstructive causes in the urinary tract) which include, medication interfering with normal bladder emptying (e.g. anticholinergics); benign prostatic hypertrophy or prostate cancer; kidney stones; abdominal malignancy (e.g. ovarian cancer, colorectal cancer); obstructed urinary catheter; or drugs that can cause crystalluria and drugs that can lead to myoglobinuria & cystitis.

[0166] Methods of the current disclosure include protecting the kidney by inducing acquired cytoresistance. As stated, appropriate therapeutically effective amounts can initially be determined using animal models to identify dose ranges. Particular exemplary therapeutically effective amounts of active ingredient include 10 mg/kg; 20 mg/kg; 30 mg/kg; 40 mg/kg; 50 mg/kg; 60 mg/kg; 70 mg/kg; 80 mg/kg; 90 mg/kg, and 100 mg/kg.

[0167] Exemplary animal models of kidney injury include: glycerol-induced renal failure (mimics rhabdomyolysis); ischemia-reperfusion-induced ARF (simulates the changes induced by reduced kidney blood flow, resulting in tissue ischemia and cell tubule cell death); drug-induced models such as gentamicin, cisplatin, NSAID, ifosfamide-induced ARF (mimics the renal failure due to clinical administration of respective drugs); uranium, potassium dichromate-induced ARF (mimics the occupational hazard); S-(1,2-dichlorovinyl)-L-cysteine-induced ARF (simulates contaminated water-induced renal dysfunction); sepsis-induced ARF (mimics the infection-induced renal failure); and radiocontrast-induced ARF (mimics renal failure in patients during use of radiocontrast media at the time of cardiac catheterization). For more information regarding these models, see Singh et al., *Pharmacol. Rep.* 2012, 64(1): 31-44.

[0168] Known tests of kidney function include ultrasound; CT scan; and measuring lactate dehydrogenase (LDH), blood urea nitrogen (BUN), creatinine, creatinine clearance, iothalamate clearance, glomerular filtration rate, and inulin clearance.

[0169] Hepatic Protection. Exemplary animal models of liver injury include: ischemic reperfusion injury; chemically-induced liver fibrosis using hepatotoxins (carbon tetrachloride, thioacetamide, dimethyl, or diethyl nitrosamine); bile duct ligation; the Schistosomiasis model; the Concanavalin A hepatitis model; inducible HCV transgenic mice; various genetic models; the Enteral ethanol infusion model (Tsukamoto-French model); and the methionine and choline deficiency model.

[0170] Further, a number of hepatotoxic compounds, including certain therapeutics, induce cytotoxicity. Hepatotoxic compounds can produce liver cytotoxicity by direct chemical attack or by the production of a toxic metabolite. Cytotoxicity can be induced by direct chemical attack using the following drugs: Anesthetics, such as, Enflurane, Fluroxene, Halothane, and Methoxyflurane; Neuropsychotropics, such as, Cocaine, Hydrazides, Methylphenidate, and Tricyclics; Anticonvulsants, such as, Phenyloin and Valproic acid; Analgesics, such as, Acetaminophen, Chlorzoxazone, Dantrolene, Diclofenac, Ibuprofen, Indomethacin, Salicylates, Tolmetin, and Zoxazolamine; Hormones, such as, Acetohexamide, Carbutamide, Glipizide, Metahexamide, Propylthiouracil, Tamoxifen, Diethylstilbestrol; Antimicrobials, such as, Amphotericin B, Clindamycin, Ketoconazole, Mebendazole, Metronidazole, Oxacillin, Paraaminosalicylic acid, Penicillin, Rifampicin, Sulfonamides, Tetracycline, and Zidovudine; Cardiovascular drugs, such as, Amiodarone, Diltiazem, a-Methyldopa, Mexiletine, Hydrazaline, Nicotinic acid, Papaverine, Perhexiline, Procainamide, Quinidine, and Tocainamide; and Immunosuppressives and Antineoplastics, such as, Asparaginase, Cisplatin, Cyclophosphamide, Dacarbazine, Doxorubicin, Fluorouracil, Methotrexate, Mithramycin, 6-MP, Nitrosoureas, Tamoxifen,

Thioguanine, and Vincristine; and Miscellaneous drugs, such as, Disulfiram, Iodide ion, Oxyphenisatin, Vitamin A, and Paraaminobenzoic acid.

[0171] Hepatotoxic compounds inducing cholestasis, an arrest in the flow of bile, may take several forms. Centribular cholestasis is accompanied by portal inflammatory changes. Bile duct changes have been reported with some drugs such as erythromycin, while pure canalicular cholestasis is characteristic of other drugs such as the anabolic steroids. Chronic cholestasis has been linked to such drugs as methyltestosterone and estradiol. Cholestatic disease can be induced using hepatotoxic compounds including the following: contraceptive steroids, androgenic steroids, anabolic steroids, Acetylsalicylic acid, Azathioprine, Benzodiazepine, Chenodeoxycholic acid, Chlordiazepoxide, Erythromycin estolate, Fluphenazine, Furosemide, Griseofulvin, Haloperidol, Imipramine, 6-Mercaptopurine, Methimazole, Methotrexate, Methyl dopa, Methylenediamine, Methyltestosterone, Naproxen, Nitrofurantoin, Penicillamine, Perphenazine, Prochlorperazine, Promazine, Thiobendazole, Thioridazine, Tolbutamide, Trimethoprim sulfamethoxazole, Arsenic, Copper, and Paraquat.

[0172] Some drugs, although primarily cholestatic, can also produce hepatotoxicity, and therefore the liver injury they cause is mixed. Drugs causing mixed liver injury include, for example, the following: Chlorpromazine, Phenylbutazone, Halothane, Chlordiazepoxide, Diazepam, Allopurinol, Phenobarbital, Naproxen, Propylthiouracil, Chloramphenicol, Trimethoprim sulfamethoxazole, Aminone, Disopyramide, Azathioprine, Cimetidine, and Ranitidine.

[0173] Detection of one or more enzymes of the arginine/urea/NO cycle, sulfuration enzymes, and/or spectrin breakdown related products is diagnostic of liver injury. Examples of these markers include: argininosuccinate synthetase (ASS) and argininosuccinate lyase (ASL), sulfuration (estrogen sulfotransferase (EST)), squalene synthase (SQS), liver glycogen phosphorylase (GP), carbamoyl-phosphate synthetase (CPS-1), α -enolase 1, glucose-regulated protein (GRP), and spectrin breakdown products.

[0174] In other embodiments, the detection of biomarkers as a diagnostic of liver injury, such as injury due to ischemia, can be correlated with existing tests. These can include: alkaline phosphatase (AP); 5'-nucleotidase (5'-ND); α -glutamyl transpeptidase (G-GT); leucine aminopeptidase (LAP); aspartate transaminase (AST); alanine transaminase (ALT); fructose-1,6-diphosphate aldolase (ALD); LDH; isocitrate dehydrogenase (ICDH); ornithine carbamoyltransferase (OCT); sorbitol dehydrogenase (SDH) arginase; guanase; creatine phosphokinase (CPK); cholinesterase (ChE); procollagen type III peptide levels (PIIP); ammonia blood levels in hepatoencephalopathies; ligand in levels in necrosis and hepatoma; hyaluronate

levels due to hepatic endothelial cell damage; α -1-fetoprotein (AFP) levels to detect hepatoma; carcinoembryonic antigen (CEA) levels to detect cancer metastasis to the liver; elevations of antibodies against a variety of cellular components, such as, mitochondrial, and nuclear and specific liver membrane protein; and detection of proteins, such as, albumin, globin, amino acids, cholesterol, and other lipids. Also, biochemical analysis of a variety of minerals, metabolites, and enzymes obtained from liver biopsies can be useful in identifying further biomarkers in inherited, acquired, and experimentally induced liver disorders.

[0175] In other embodiments, the amount of detected biomarkers can be correlated to liver function tests to further assess liver injury. As is understood by one of skill in the art, liver function tests include the following: assessment of hepatic clearance of organic anions, such as, bilirubin, indocyanine green (ICG), sulfobromophthalein (BSP) and bile acids; assessment of hepatic blood flow by measurements of galactose and ICG clearance; and assessment of hepatic microsomal function, through the use of the aminopyrine breath test and caffeine clearance test. For example, serum bilirubin can be measured to confirm the presence and severity of jaundice and to determine the extent of hyperbilirubinemia, as seen in parenchymal liver disease. Aminotransferase (transaminase) elevations reflect the severity of active hepatocellular damage, while alkaline phosphatase elevations are found with cholestasis and hepatic infiltrates (Isselbacher, K. and Podolsky, D. in Hartison's Principles of Internal Medicine, 12th edition. Wilson et al. eds., 2: 1301-1308 (1991)).

[0176] Additional scoring systems and parameters used to assess liver function include the Child-Pugh scoring system as follows:

Child-Pugh scoring system			
Measure	1 point	2 points	3 points
Bilirubin (total) $\mu\text{mol/l}$ (mg/dl)	<34 (<2)	34-50 (2-3)	>50 (>3)
Serum albumin g/l	>35	28-35	<28
INR	<1.7	1.71-2.20	>2.20
Ascites	None	Mild	Severe
Hepatic encephalopathy	None	Grade I-II (or suppressed with medication)	Grade III-IV (or refractory)

[0177] The indocyanine plasma clearance test using a fingertip light sensor can be used as well as a postoperative liver function scoring system developed by Schindl et al (Schindl M et al. 2005, Archives of Surgery 140(2):183-189). This system grades liver dysfunction according to the levels of lactic acid, total bilirubin, INR, and encephalopathy postoperatively. Total scores of 0, 1-

2, 3-4, or >4 are used to classify liver dysfunction as absent, mild, moderate, or severe, respectively. Further, the bile salt to phospholipid ratio can be evaluated.

[0178] Cardiac Protection. Exemplary animal models of cardiac injury include: myocardial infarction (MI) models, post-MI remodeling models, gene therapy models, cell therapy models, transverse aortic constriction (TAC) models, acute ischemic stroke models, renal and limb ischemia models, the Langendorff perfusion model, and the doxorubicin-induced cardiomyopathy model. See also, for example, cardiac injury animal models practiced by the Cardiovascular Research Laboratory, Baltimore, MD.

[0179] Various methods of detecting cardiac injury may be used, including non-invasive imaging, such as Magnetic Resonance Imaging (MRI), ultrasound, X-ray Computed Tomography (CT), single photon emission computed tomography (SPECT) and/or positron emission tomography (PET). Additional measures can include echocardiography, electrocardiogram, Mikro-tip pressure catheter, telemetry, immunohistochemistry, and molecular biological studies. U.S. Patent No. 2002/0115936 describes a method and apparatus for assessment of cardiac function by monitoring movement of the trachea.

[0180] Known tests of cardiac function include measuring PDH levels, plasma lactate levels, and/or cardiac carbohydrate oxidation. Markers associated with non-ischemic heart injury include: Alpha-2-HS-glycoprotein precursor (e.g., SEQ ID NO:22); Asporin; ATP synthase subunit delta (mitochondrial); Blood vessel epicardial substance (e.g., SEQ ID NO:23); C6ORF142; Carbonic anhydrase 1; Carbonic anhydrase 3; Ceruloplasmin; Coagulation factor IX; Collagen alpha-3(VI) chain; Dermatopectin; EGF-containing fibulin-like extracellular matrix protein 1; Fibrinogen gamma chain; Fibulin-1; Fibulin-2; Heat shock protein HSP 90-beta (e.g., SEQ ID NO:24); Hemoglobin subunit alpha; Hemoglobin subunit beta; Ig alpha-1 chain C region; Ig alpha-2 chain C region; Ig gamma-2 chain C region; Ig lambda chain C regions; Ig mu chain C region; Latent-transforming growth factor β -binding protein 2; Microfibril-associated glycoprotein 4; Myosin-2; Serum amyloid A protein; Sorbin and SH3 domain-containing protein 2 (e.g., SEQ ID NO:25); and Sorbin and SH3 domain-containing protein 2 (e.g., SEQ ID NO:26).

[0181] Markers associated with ischemic heart injury include: Alpha-2-HS-glycoprotein precursor (e.g., SEQ ID NO:22); Alpha-2-macroglobulin; Carbonic anhydrase 1; Hemoglobin subunit alpha; Hemoglobin subunit beta; Ig alpha-1 chain C region; Ig alpha-2 chain C region; Ig mu chain C region; Leiomodulin-1 (e.g., SEQ ID NO:27); Myosin regulatory light chain MRLC2 (e.g., SEQ ID NO:28); Nexilin (e.g., SEQ ID NO:29); Pyruvate dehydrogenase E1 component subunit α ; serum amyloid A protein; and somatic form.

[0182] Pulmonary Protection. Animal models of lung injury, including acute lung injury include injury inducement by intratracheal instillation of endotoxin (LPS), mechanical ventilation, hypoxemia, live bacteria (*E. coli*), hyperoxia, bleomycin, oleic acid, cecal ligation and puncture, and acid aspiration. For more information regarding lung injury models, see Assay Depot, described as the World's Largest On-Line Marketplace for Pharmaceutical Research Services.

[0183] Symptoms of lung injury include labored, rapid breathing, low blood pressure, and shortness of breath. Any type of pulmonary function testing can be used. Pulmonary function testing generally can be divided into three main areas. The first type of pulmonary testing is generally referred to as spirometry which provides measurements in terms of volume and breathing rates of different patient inspiratory and expiratory efforts. In addition, various flow rates at various stages of a test are also the type of data generated from spirometry testing. A second area of pulmonary testing is a set of procedures designed to determine the uniformity of the distribution of inspired air throughout the lungs of a patient. By virtue of such tests, pulmonary insufficiency can be determined even though the alveolar ventilation of a patient is normal. A third type of pulmonary testing concerns the ability of the lungs to diffuse inspired air through alveolar membranes and such tests provide an indication of the ability of the lung to arterialize venous blood by exchanging oxygen for carbon dioxide.

[0184] Breathing volume can be assessed using a volume flow-sensing device connected to a subject's airway (e.g. by use of a spirometer or tachymeter) or by measuring the mechanical excursions of the chest and abdominal walls. Techniques that rely on recordings of chest and abdominal wall movements that are either strain gauge based (recording of changes in body circumference length), or based on elastic inductive electrical conductor loops arranged around the chest and abdomen of the patient can also be used. Recordings of the inductance of the loops can then be used to estimate the magnitude of cross sectional area variations of the chest and abdominal compartments. U.S. Pat. No. 4,308,872 is an example of this self-inductance loop estimation technology. Such methods can be used for quantitative measurements of respiratory volumes after a calibration procedure.

[0185] In particular embodiments, tests of pulmonary function include measuring breathing volume, arterial blood gases, and/or the A-a O₂ gradient.

[0186] Protection Against Sepsis. Sepsis, or Systemic Inflammatory Response Syndrome (SIRS), is characterized by a whole-body inflammatory state with the presence of infection. Sepsis can lead to fever, rapid breathing and low blood pressure and can injure all organs including organs of the cardiovascular system, the immunological system and the endocrine system.

[0187] Animal models of sepsis include cecal ligation and puncture (CLP)-induced sepsis alone or in combination with instillation of bacteria (e.g., *Pseudomonas aeruginosa* or *Streptococcus pneumoniae*). Sepsis animal models also include intravenous or intraperitoneal administration of a toll-like receptor (TLR) agent such as lipopolysaccharide (LPS or endotoxin) or zymosan. Other sepsis models include ascending colon stent peritonitis and late-stage immunostimulatory models. For more information regarding sepsis models, see Assay Depot, described as the World's Largest On-Line Marketplace for Pharmaceutical Research Services.

[0188] Protection against sepsis can be confirmed by measuring blood pressure, blood gasses, cytokine measurements, and secondary organ function as described elsewhere herein (e.g., lung, liver, heart, kidney function).

[0189] The Examples below are included to demonstrate particular embodiments of the disclosure. Those of ordinary skill in the art should recognize in light of the present disclosure that many changes can be made to the specific embodiments disclosed herein and still obtain a like or similar result without departing from the spirit and scope of the disclosure.

[0190] Exemplary Embodiments.

1. A kit for protecting a subject's organ(s) from injury, the kit including a therapeutically effective amount of myoglobin, iron, and/or vitamin B12 wherein administration of the therapeutically effective amount of myoglobin, iron, and/or vitamin B12 to the subject protects the subject's organ(s) from injury without causing organ injury.
2. A kit for protecting a subject's organ(s) from injury, the kit including a therapeutically effective amount of a heme protein, iron, and/or vitamin B12 wherein administration of the therapeutically effective amount of heme protein, iron, and/or vitamin B12 to the subject protects the subject's organ(s) from injury without causing organ injury.
3. A kit of embodiment 2 wherein the heme protein, iron, and/or vitamin B12 is formulated within a composition.
4. A kit of any one of embodiments 2 or 3 wherein the heme protein is a heme protein variant, a heme protein d-substituted analog, a heme protein modification, or combination thereof.
5. A kit of any one of embodiments 2-4 wherein the heme protein is a modified heme protein.
6. A kit of embodiment 5 wherein the modified heme protein is a nitrated heme protein or a PEGylated heme protein.
7. A kit of any one of embodiments 2-6 wherein the heme protein is myoglobin.
8. A kit of any one of embodiments 2-7 wherein the heme protein is a myoglobin variant and/or a myoglobin modification.

9. A kit of embodiment 8 wherein the modified myoglobin is a nitrated myoglobin or a PEGylated myoglobin.
10. A kit of any one of embodiments 2-9 further including a heme protein degradation inhibitor, optionally, a nitrated heme protein degradation inhibitor.
11. A kit of embodiment 10 wherein the heme protein degradation inhibitor is formulated within a composition.
12. A kit of any one of embodiments 10 or 11 wherein the heme protein degradation inhibitor and the heme protein, iron, and/or vitamin B12 are formulated within the same composition.
13. A kit of any one of embodiments 10-12 wherein the heme protein degradation inhibitor is a heme oxygenase inhibitor.
14. A kit of embodiment 13 wherein the heme oxygenase inhibitor is a protoporphyrin, hemin, and/or hematin, optionally, a nitrated protoporphyrin, hemin, and/or hematin.
15. A kit of any one of embodiments 13 or 14 wherein the heme oxygenase inhibitor is a metal protoporphyrin, optionally, a nitrated metal protoporphyrin.
16. A kit of embodiment 15 wherein the metal protoporphyrin is Sn-protoporphyrin.
17. A kit of any one of embodiments 2-16 further including administration instructions.
18. A kit of any one of embodiments 2-17 wherein absence of organ injury caused by the administration is confirmed by comparison to a reference level.
19. A kit of any one of embodiments 2-18 wherein protection is evidenced by comparison to a reference level.
20. A kit of any one of embodiments 18 or 19 wherein the reference level is provided within the kit.
21. A kit of any one of embodiments 2-20 wherein the organ is protected from an injury based on an insult.
22. A kit of embodiment 21 wherein the insult is scheduled.
23. A kit of embodiment 22 wherein the administration occurs at least 8 hours before the scheduled insult.
24. A kit of any one of embodiments 22 or 23 wherein the scheduled insult is surgery, induced cardiac/cerebral ischemic reperfusion, cardiovascular surgery, balloon angioplasty, chemotherapy, nephrotoxic drug administration, and/or radiocontrast toxicity.
25. A kit of embodiment 24 wherein the surgery is an organ transplant surgery.
26. A kit of embodiment 21 wherein the insult is sepsis.
27. A kit of any one of embodiments 2-26 wherein the organ is a transplanted organ.
28. A kit of any one of embodiments 2-27 wherein the organ is a heart, kidney, liver, or lung.

29. A kit of any one of embodiments 2-28 wherein the organ is a heart and protection is evidenced by improvement of cardiac function, and/or reduction in cardiac enzyme release.
30. A kit of embodiment 29 wherein the cardiac enzyme is troponin.
31. A kit of any one of embodiments 2-30 wherein the organ is a kidney and protection is evidenced by prevention or reduction in blood urea nitrogen (BUN) or serum creatinine increases.
32. A kit of any one of embodiments 2-31 wherein the organ is a liver and protection is evidenced by prevention or reduction in liver enzyme increases.
33. A kit of any one of embodiments 2-32 wherein the organ is a lung and protection is evidenced by reduction in blood gas deterioration, reduction in need for supplemental oxygen, and/or reduced ventilator requirements.
34. A kit for generating acquired cytoresistance in a subject's organ(s), the kit including a therapeutically effective amount of a heme protein, iron, and/or vitamin B12 wherein administration of the therapeutically effective amount of heme protein, iron, and/or vitamin B12 to the subject generates acquired cytoresistance in the subject's organ(s) without causing organ injury.
35. A kit of embodiment 34 wherein the heme protein, iron, and/or vitamin B12 is formulated within a composition.
36. A kit of any one of embodiments 34 or 35 wherein the heme protein is a heme protein variant, a heme protein d-substituted analog, a heme protein modification, or a combination thereof.
37. A kit of any one of embodiments 34-36 wherein the heme protein is a modified heme protein.
38. A kit of embodiment 37 wherein the modified heme protein is a nitrated heme protein or a PEGylated heme protein.
39. A kit of any one of embodiments 34-38 wherein the heme protein is myoglobin.
40. A kit of embodiment 34-39 wherein the heme protein is a myoglobin variant and/or a myoglobin modification.
41. A kit of embodiment 40 wherein the modified myoglobin is a nitrated myoglobin or a PEGylated myoglobin.
42. A kit of any one of embodiments 34-41 further including a heme protein degradation inhibitor, optionally a nitrated heme protein degradation inhibitor.
43. A kit of embodiment 42 wherein the heme protein degradation inhibitor is formulated within a composition.

44. A kit of any one of embodiments 42 or 43 wherein the heme protein degradation inhibitor and the heme protein are formulated within the same composition.
45. A kit of any one of embodiments 42-44 wherein the heme protein degradation inhibitor is a heme oxygenase inhibitor.
46. A kit of embodiment 45 wherein the heme oxygenase inhibitor is a protoporphyrin, hemin, and/or hematin, optionally a nitrited protoporphyrin, hemin, and/or hematin.
47. A kit of any one of embodiments 45 or 46 wherein the heme oxygenase inhibitor is a metal protoporphyrin.
48. A kit of embodiment 47 wherein the metal protoporphyrin is Sn-protoporphyrin.
49. A kit of any one of embodiments 34-48 further including administration instructions.
50. A kit of any one of embodiments 34-49 wherein absence of organ injury caused by the administration is confirmed by comparison to a reference level.
51. A kit of any one of embodiments 34-50 wherein the acquired cytoresistance protects the organ from an injury.
52. A kit of embodiment 51 wherein protection is evidenced by comparison to a reference level.
53. A kit of any one of embodiments 50 or 52 wherein the reference level is provided within the kit.
54. A kit of any one of embodiments 51-53 wherein the organ is protected from an injury based on an insult.
55. A kit of embodiment 54 wherein the insult is scheduled.
56. A kit of embodiment 55 wherein the administration occurs at least 8 hours before the scheduled insult.
57. A kit of any one of embodiments 55 or 56 wherein the scheduled insult is surgery, chemotherapy, or radiocontrast toxicity.
58. A kit of embodiment 57 wherein the surgery is an organ transplant surgery.
59. A kit of embodiment 54 wherein the insult is sepsis.
60. A kit of any one of embodiments 34-59 wherein the organ is a transplanted organ.
61. A kit of any one of embodiments 34-60 wherein the organ is a heart, kidney, liver, or lung.
62. A kit of any one of embodiments 51-61 wherein the organ is a heart and protection is evidenced by improvement of cardiac function, and/or reduction in cardiac enzyme release.
63. A kit of embodiment 62 wherein the cardiac enzyme is troponin.
64. A kit of any one of embodiments 51-63 wherein the organ is a kidney and protection is evidenced by prevention or reduction in BUN or serum creatinine increases.

65. A kit of any one of embodiments 51-64 wherein the organ is a liver and protection is evidenced by prevention or reduction in liver enzyme increases.
66. A kit of any one of embodiments 51-65 wherein the organ is a lung and protection is evidenced by reduction in blood gas deterioration, reduction in need for supplemental oxygen, and/or reduced ventilator requirements.
67. A kit for up-regulating expression of protective stress proteins in a subject's organ(s), the kit including a therapeutically effective amount of a heme protein, iron and/or vitamin B12 wherein administration of the therapeutically effective amount of heme protein, iron and/or vitamin B12 to the subject up-regulates expression of protective stress proteins in the subject's organ(s) without causing organ injury.
68. A kit of embodiment 67 wherein the heme protein, iron and/or vitamin B12 is formulated within a composition.
69. A kit of any one of embodiments 67 or 68 wherein the heme protein is a heme protein variant, a heme protein d-substituted analog, a heme protein modification, or a combination thereof.
70. A kit of any one of embodiments 67-69 wherein the heme protein is a modified heme protein.
71. A kit of embodiment 70 wherein the modified heme protein is a nitrated heme protein or a PEGylated heme protein.
72. A kit of any one of embodiments 67-71 wherein the heme protein is myoglobin.
73. A kit of any one of embodiments 67-72 wherein the heme protein is a myoglobin variant and/or a myoglobin modification.
74. A kit of embodiment 73 wherein the modified myoglobin is a nitrated myoglobin or a PEGylated myoglobin.
75. A kit of any one of embodiments 67-74 wherein the protective stress proteins are selected from heme oxygenase, haptoglobin, hemopexin, hepcidin, alpha-1 antitrypsin, interleukin-10, heat-shock proteins, neutrophil gelatinase-associated lipocalin, and HMG CoA reductase.
76. A kit of any one of embodiments 67-75 further including a heme protein degradation inhibitor, optionally a nitrated heme protein degradation inhibitor.
77. A kit of embodiment 76 wherein the heme protein degradation inhibitor is formulated within a composition.
78. A kit of any one of embodiments 76 or 77 wherein the heme protein degradation inhibitor and the heme protein are formulated within the same composition.

79. A kit of any one of embodiments 76-78 wherein the heme protein degradation inhibitor is a heme oxygenase inhibitor.
80. A kit of embodiment 79 wherein the heme oxygenase inhibitor is a protoporphyrin, hemin, and/or hematin, optionally a nitrited protoporphyrin, hemin and/or hematin.
81. A kit of any one of embodiments 79 or 80 wherein the heme oxygenase inhibitor is a metal protoporphyrin.
82. A kit of embodiment 81 wherein the metal protoporphyrin is Sn-protoporphyrin.
83. A kit of any one of embodiments 67-82 further including administration instructions.
84. A kit of any one of embodiments 67-83 wherein absence of organ injury caused by the administration is confirmed by comparison to a reference level.
85. A kit of any one of embodiments 67-84 wherein the up-regulation of protective stress proteins protects the organ from an injury.
86. A kit of embodiment 85 wherein protection is evidenced by comparison to a reference level.
87. A kit of any one of embodiments 84 or 86 wherein the reference level is provided within the kit.
88. A kit of any one of embodiments 85-87 wherein the organ is protected from an injury based on an insult.
89. A kit of embodiment 88 wherein the insult is scheduled.
90. A kit of embodiment 89 wherein the administration occurs at least 8 hours before the scheduled insult.
91. A kit of any one of embodiments 89 or 90 wherein the scheduled insult is surgery, chemotherapy, or radiocontrast toxicity.
92. A kit of embodiment 91 wherein the surgery is an organ transplant surgery.
93. A kit of embodiment 88 wherein the insult is sepsis.
94. A kit of any one of embodiments 67-93 wherein the organ is a transplanted organ.
95. A kit of any one of embodiments 67-94 wherein the organ is a heart, kidney, liver, or lung.
96. A kit of any one of embodiments 85-95 wherein the organ is a heart and protection is evidenced by improvement of cardiac function, and/or reduction in cardiac enzyme release.
97. A kit of embodiment 96 wherein the cardiac enzyme is troponin.
98. A kit of any one of embodiments 85-97 wherein the organ is a kidney and protection is evidenced by prevention or reduction in BUN or serum creatinine increases.
99. A kit of any one of embodiments 85-98 wherein the organ is a liver and protection is evidenced by prevention or reduction in liver enzyme increases.

100. A kit of any one of embodiments 85-99 wherein the organ is a lung and protection is evidenced by reduction in blood gas deterioration, reduction in need for supplemental oxygen, and/or reduced ventilator requirements.
101. A composition including myoglobin, a myoglobin variant, a myoglobin d-substituted analog, a myoglobin modification, or a combination thereof, optionally iron and/or vitamin B12.
102. A composition of embodiment 101 wherein the myoglobin is a modified myoglobin.
103. A composition of embodiment 102 wherein the modified myoglobin is a nitrated myoglobin or a PEGylated myoglobin.
104. A composition of any one of embodiments 101-103 wherein the myoglobin is a myoglobin variant.
105. A composition of any one of embodiments 101-104 further including a heme protein degradation inhibitor, optionally a nitrated heme protein degradation inhibitor.
106. A composition of embodiment 105 wherein the heme protein degradation inhibitor is a heme oxygenase inhibitor.
107. A composition of embodiment 106 wherein the heme oxygenase inhibitor is a protoporphyrin, hemin, and/or hematin, optionally a nitrated protoporphyrin, hemin and/or hematin.
108. A composition of any one of embodiments 106 or 107 wherein the heme oxygenase inhibitor is a metal protoporphyrin.
109. A composition of embodiment 108 wherein the metal protoporphyrin is Sn-protoporphyrin.
110. A composition including a heme protein and a heme protein degradation inhibitor, optionally iron and/or vitamin B12.
111. A composition of embodiment 110 wherein the heme protein is a modified heme protein.
112. A composition of embodiment 111 wherein the modified heme protein is a nitrated heme protein or a PEGylated heme protein.
113. A composition of any one of embodiments 110-112 wherein the heme protein is myoglobin.
114. A composition of any one of embodiments 110-113 wherein the heme protein is a myoglobin variant and/or a myoglobin modification.
115. A composition of embodiment 114 wherein the modified myoglobin is a nitrated myoglobin or a PEGylated myoglobin.
116. A composition of any one of embodiments 110-115 wherein the heme protein degradation inhibitor is a heme oxygenase inhibitor.

117. A composition of embodiment 116 wherein the heme oxygenase inhibitor is a protoporphyrin, hemin, and/or hematin, optionally a nitrated protoporphyrin, hemin and/or hematin.
118. A composition of any one of embodiments 116 or 117 wherein the heme oxygenase inhibitor is a metal protoporphyrin.
119. A composition of embodiment 118 wherein the metal protoporphyrin is Sn-protoporphyrin.
120. A method of protecting a subject's organ(s) from injury including administering to the subject a therapeutically effective amount of a composition including a heme protein, iron and/or vitamin B12 before the injury to the organ occurs, wherein the administering protects the subject's organ(s) from the injury without causing organ injury.
121. A method of embodiment 120 wherein the composition includes a modified heme protein.
122. A method of embodiment 121 wherein the modified heme protein is a nitrated heme protein or a PEGylated heme protein.
123. A method of any one of embodiments 120-122 wherein the heme protein is myoglobin.
124. A method of any one of embodiments 120-123 wherein the heme protein is a myoglobin variant and/or a myoglobin modification.
125. A method of embodiment 124 wherein the modified myoglobin is a nitrated myoglobin or a PEGylated myoglobin
126. A method of any one of embodiments 120-125 wherein the composition further includes a heme protein degradation inhibitor, optionally a nitrated heme protein degradation inhibitor.
127. A method of any one of embodiments 120-126 further including administering to the subject a second composition including a heme protein degradation inhibitor, optionally a nitrated heme protein degradation inhibitor.
128. A method of any one of embodiments 126 or 127 wherein the heme protein degradation inhibitor is a heme oxygenase inhibitor.
129. A method of embodiment 128 wherein the heme oxygenase inhibitor is a protoporphyrin, hemin, and/or hematin, optionally a nitrated protoporphyrin, hemin and/or hematin.
130. A method of any one of embodiments 128 or 129 wherein the heme oxygenase inhibitor is a metal protoporphyrin.
131. A method of embodiment 130 wherein the metal protoporphyrin is Sn-protoporphyrin.
132. A method of any one of embodiments 120-131 wherein absence of organ injury caused by the administration is confirmed by comparison to a reference level.
133. A method of any one of embodiments 120-132 wherein protection is evidenced by comparison to a reference level.

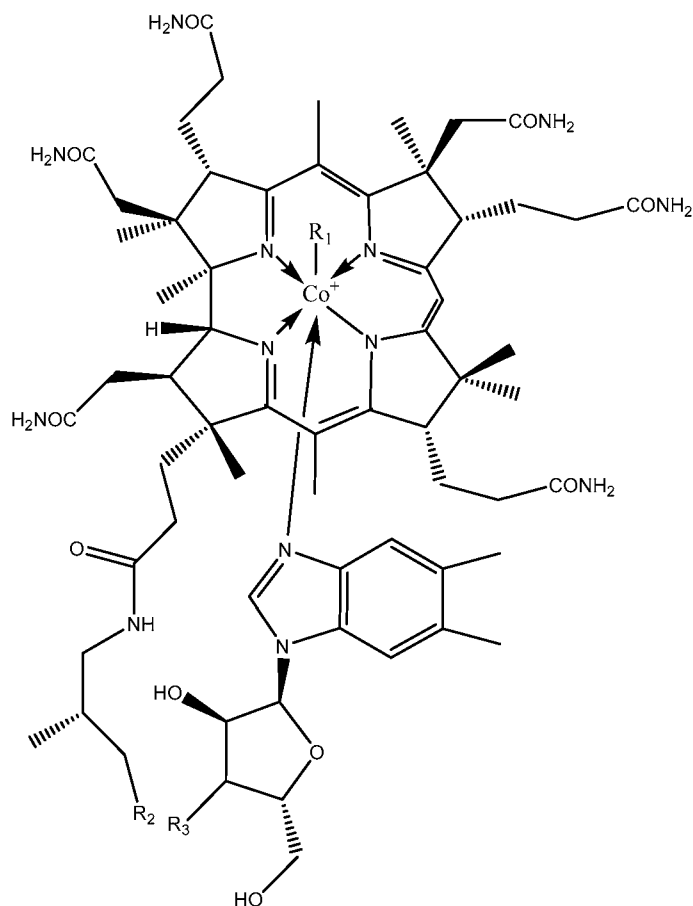
134. A method of any one of embodiments 120-133 wherein the injury is an injury based on an insult.
135. A method of embodiment 134 wherein the insult is scheduled.
136. A method of embodiment 135 wherein the administration occurs at least 8 hours before the scheduled insult.
137. A method of any one of embodiments 135 or 136 wherein the scheduled insult is surgery, chemotherapy, or radiocontrast toxicity.
138. A method of embodiment 137 wherein the surgery is an organ transplant surgery.
139. A method of embodiment 134 wherein the insult is sepsis.
140. A method of any one of embodiments 120-139 wherein the organ is a transplanted organ.
141. A method of any one of embodiments 120-140 wherein the organ is a heart, kidney, liver, or lung.
142. A method of any one of embodiments 120-141 wherein the organ is a heart and protection is evidenced by improvement of cardiac function, and/or reduction in cardiac enzyme release.
143. A method of embodiment 142 wherein the cardiac enzyme is troponin.
144. A method of any one of embodiments 120-143 wherein the organ is a kidney and protection is evidenced by prevention or reduction in BUN or serum creatinine increases.
145. A method of any one of embodiments 120-144 wherein the organ is a liver and protection is evidenced by prevention or reduction in liver enzyme increases.
146. A method of any one of embodiments 120-145 wherein the organ is a lung and protection is evidenced by reduction in blood gas deterioration, reduction in need for supplemental oxygen, and/or reduced ventilator requirements.
147. A method of generating acquired cytoresistance in a subject's organ(s) including administering to the subject a therapeutically effective amount of a composition including a heme protein, iron, and/or vitamin B12 wherein the administering generates acquired cytoresistance without causing organ injury.
148. A method of embodiment 147 wherein the composition includes a modified heme protein.
149. A method of embodiment 148 wherein the modified heme protein is a nitrated heme protein or a PEGylated heme protein.
150. A method of any one of embodiments 147-149 wherein the heme protein is myoglobin.
151. A method of any one of embodiments 147-150 wherein the heme protein is a myoglobin variant and/or a myoglobin modification.

152. A method of embodiment 151 wherein the modified myoglobin is a nitrated myoglobin or a PEGylated myoglobin
153. A method of any one of embodiments 147-152 wherein the composition further includes a heme protein degradation inhibitor.
154. A method of any one of embodiments 147-153 further including administering to the subject a second composition including a heme protein degradation inhibitor, optionally a nitrated heme protein degradation inhibitor.
155. A method of any one of embodiments 153 or 154 wherein the heme protein degradation inhibitor is a heme oxygenase inhibitor.
156. A method of embodiment 155 wherein the heme oxygenase inhibitor is a protoporphyrin, hemin, and/or hematin, optionally nitrated protoporphyrin, hemin and/or hematin.
157. A method of any one of embodiments 155 or 156 wherein the heme oxygenase inhibitor is a metal protoporphyrin.
158. A method of embodiment 157 wherein the metal protoporphyrin is Sn-protoporphyrin.
159. A method of any one of embodiments 147-158 wherein absence of organ injury caused by the administration is confirmed by comparison to a reference level.
160. A method of any one of embodiments 147-159 wherein the acquired cytoresistance protects an organ from injury.
161. A method of embodiment 160 wherein the protection is evidenced by comparison to a reference level.
162. A method of any one of embodiments 160 or 161 wherein the injury is injury based on an insult.
163. A method of embodiment 162 wherein the insult is scheduled.
164. A method of embodiment 163 wherein the administration occurs at least 8 hours before the scheduled insult.
165. A method of any one of embodiments 163 or 164 wherein the scheduled insult is surgery, chemotherapy, or radiocontrast toxicity.
166. A method of embodiment 165 wherein the surgery is an organ transplant surgery.
167. A method of embodiment 162 wherein the insult is sepsis.
168. A method of any one of embodiments 147-167 wherein the organ is a transplanted organ.
169. A method of any one of embodiments 147-168 wherein the organ is a heart, kidney, liver, or lung.

170. A method of any one of embodiments 160-169 wherein the organ is a heart and protection is evidenced by improvement of cardiac function, and/or reduction in cardiac enzyme release.
171. A method of embodiment 170 wherein the cardiac enzyme is troponin.
172. A method of any one of embodiments 160-171 wherein the organ is a kidney and protection is evidenced by prevention or reduction in BUN or serum creatinine increases.
173. A method of any one of embodiments 160-172 wherein the organ is a liver and protection is evidenced by prevention or reduction in liver enzyme increases.
174. A method of any one of embodiments 160-173 wherein the organ is a lung and protection is evidenced by reduction in blood gas deterioration, reduction in need for supplemental oxygen, and/or reduced ventilator requirements.
175. A method of up-regulating expression of protective stress proteins in a subject's organ(s) including administering to the subject a therapeutically effective amount of a composition including a heme protein, , iron and/or vitamin B12 wherein the administering up-regulates expression of protective stress proteins in the subject's organs without causing organ injury.
176. A method of embodiment 175 wherein the protective stress proteins are selected from heme oxygenase, haptoglobin, hemopexin, hepcidin, alpha-1 antitrypsin, interleukin-10, heat-shock proteins, neutrophil gelatinase-associated lipocalin, and/or HMG CoA reductase.
177. A method of any one of embodiments 175 or 176 wherein the composition includes a modified heme protein.
178. A method of embodiment 177 wherein the modified heme protein is a nitrated heme protein or a PEGylated heme protein.
179. A method of any one of embodiments 175-178 wherein the heme protein is myoglobin.
180. A method of any one of embodiments 175-179 wherein the heme protein is a myoglobin variant and/or a myoglobin modification.
181. A method of any one of embodiments 180 wherein the modified myoglobin is a nitrated myoglobin or a PEGylated myoglobin
182. A method of any one of embodiments 175-181 wherein the composition further includes a heme protein degradation inhibitor, optionally a nitrated heme protein degradation inhibitor.
183. A method of any one of embodiments 175-182 further including administering to the subject a second composition including a heme protein degradation inhibitor, optionally a nitrated heme protein degradation inhibitor.
184. A method of any one of embodiments 182 or 183 wherein the heme protein degradation inhibitor is a heme oxygenase inhibitor.

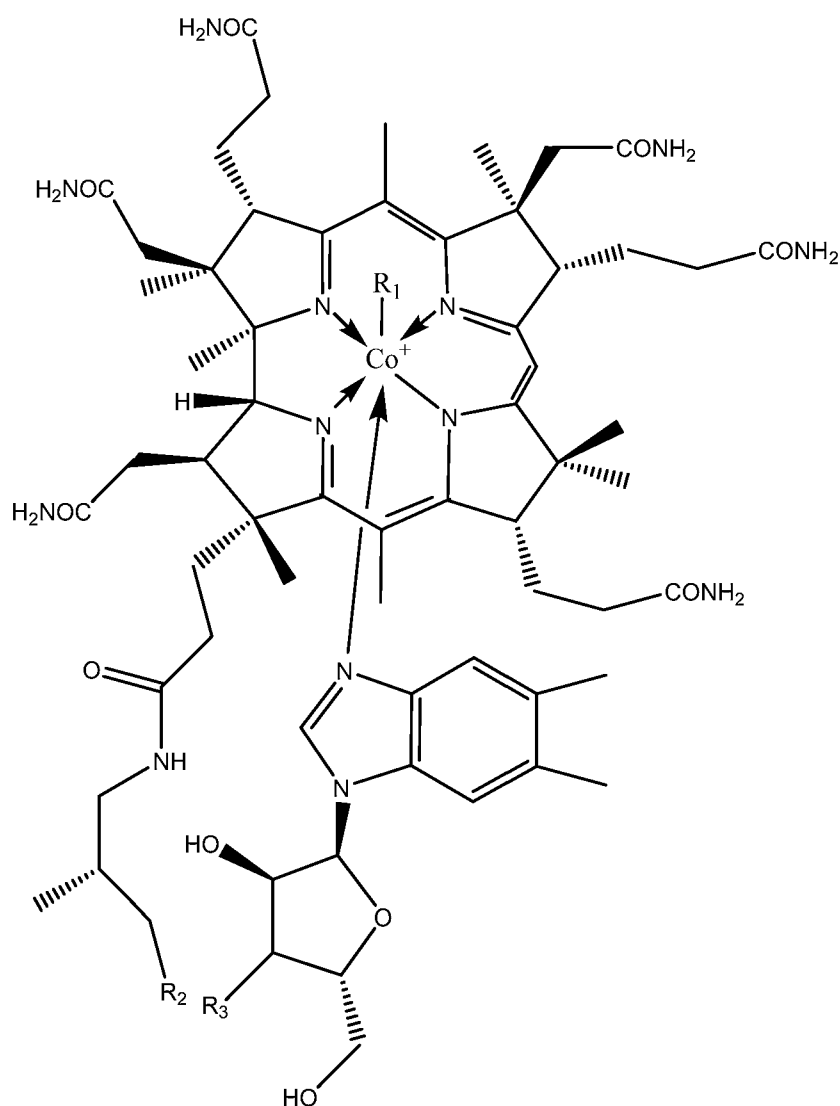
185. A method of embodiment 184 wherein the heme oxygenase inhibitor is a protoporphyrin, hemin, and/or hematin, optionally a nitrated protoporphyrin, hemin and/or hematin.
186. A method of any one of embodiments 184 or 185 wherein the heme oxygenase inhibitor is a metal protoporphyrin.
187. A method of embodiment 186 wherein the metal protoporphyrin is Sn-protoporphyrin.
188. A method of any one of embodiments 175-187 wherein absence of organ injury caused by the administration is confirmed by comparison to a reference level.
189. A method of any one of embodiments 175-188 wherein the up-regulated expression of protective stress proteins protects an organ from injury.
190. A method of embodiment 189 wherein protection is evidenced by comparison to a reference level.
191. A method of any one of embodiments 189 or 190 wherein the injury is an injury based on an insult.
192. A method of embodiment 191 wherein the insult is scheduled.
193. A method of embodiment 192 wherein the administration occurs at least 8 hours before the scheduled insult.
194. A method of any one of embodiments 192 or 193 wherein the scheduled insult is surgery, chemotherapy, or radiocontrast toxicity.
195. A method of embodiment 194 wherein the surgery is an organ transplant surgery.
196. A method of embodiment 191 wherein the insult is sepsis.
197. A method of any one of embodiments 175-196 wherein the organ is a transplanted organ.
198. A method of any one of embodiments 175-197 wherein the organ is a heart, kidney, liver, or lung.
199. A method of any one of embodiments 189-198 wherein the organ is a heart and protection is evidenced by improvement of cardiac function, and/or reduction in cardiac enzyme release.
200. A method of embodiment 199 wherein the cardiac enzyme is troponin.
201. A method of embodiment any one of embodiments 189-200 wherein the organ is a kidney and protection evidenced by prevention or reduction in BUN or serum creatinine increases.
202. A method of any one of embodiments 189-201 wherein the organ is a liver and protection evidenced by prevention or reduction in liver enzyme increases.
203. A method of any one of embodiments 189-202 wherein the organ is a lung and protection is evidenced by reduction in blood gas deterioration, reduction in need for supplemental oxygen, and/or reduced ventilator requirements.

204. An embodiment of any one of embodiments 1-203 wherein the composition is formulated for intravenous delivery, oral delivery, subcutaneous delivery, or intramuscular delivery.
205. An embodiment of any one of embodiments 1-204 wherein the composition is formulated within a slow-release depot.
206. A composition of matter comprising the structure



where R₁ is 5'-deoxyadenosyl, CH₃, OH, or CN; R₂ is OH or H; and R₃ is OH or H.

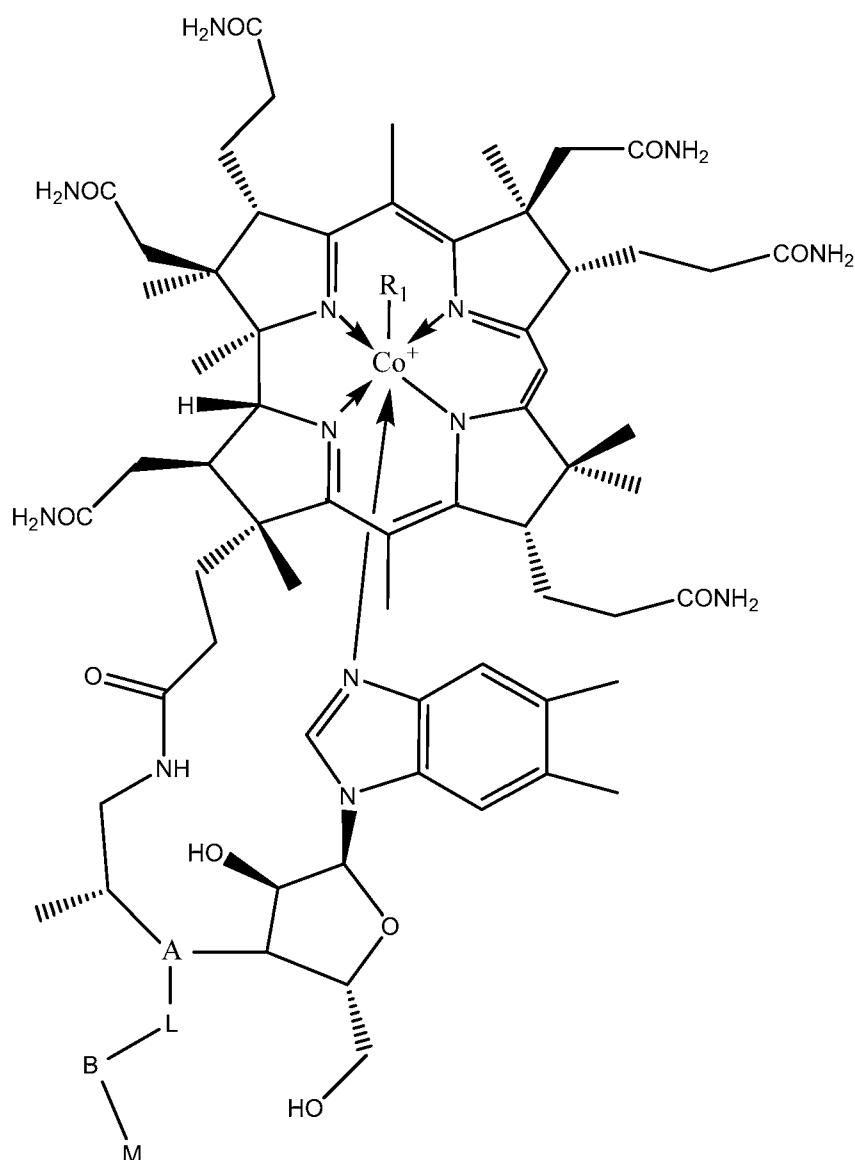
207. An embodiment of any one of embodiments 1-205, wherein the B12 has a structure



where R_1 is 5'-deoxyadenosyl, CH_3 , OH , or CN ; R_2 is OH or H ; and R_3 is OH or H .

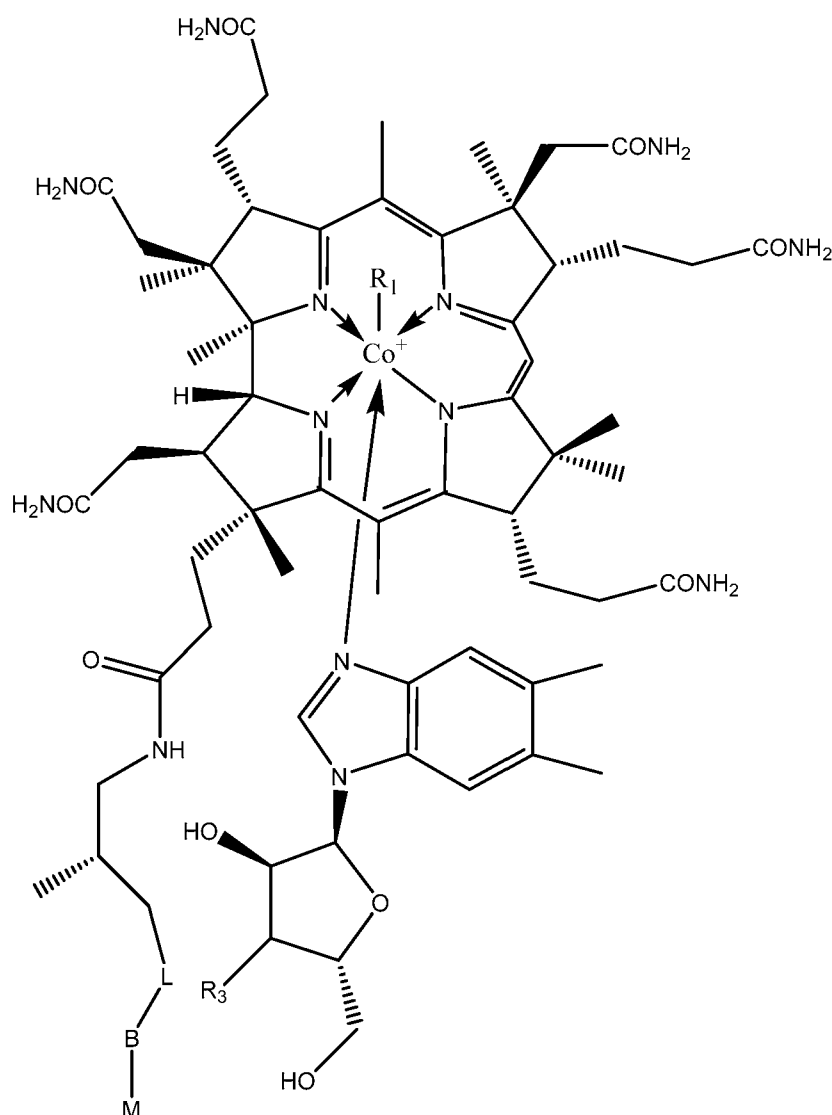
208. An embodiment of any of the preceding embodiments wherein rather than administration to an organ through administration to a subject, administration is directly to an organ.

209. A composition of matter comprising the structure



where R_1 is 5'-deoxyadenosyl, CH_3 , OH, or CN; A is a phosphate group, L is a linker, B is a saccharide-based structure, and M is a metal complexed with the saccharide-based structure.

210. A composition of matter of embodiment 209, wherein A is PO_4 , L is a hydrazone linker, B is a saccharide-based structure, and M is Fe.
211. A composition of matter of embodiment 209 or 210, wherein B has 10-16 carbon atoms, 9-15 oxygen atoms, and 16-28 hydrogen atoms.
212. A composition of matter of embodiment 209, 210, or 211, wherein B is derived from sucrose
213. A composition of matter comprising the structure



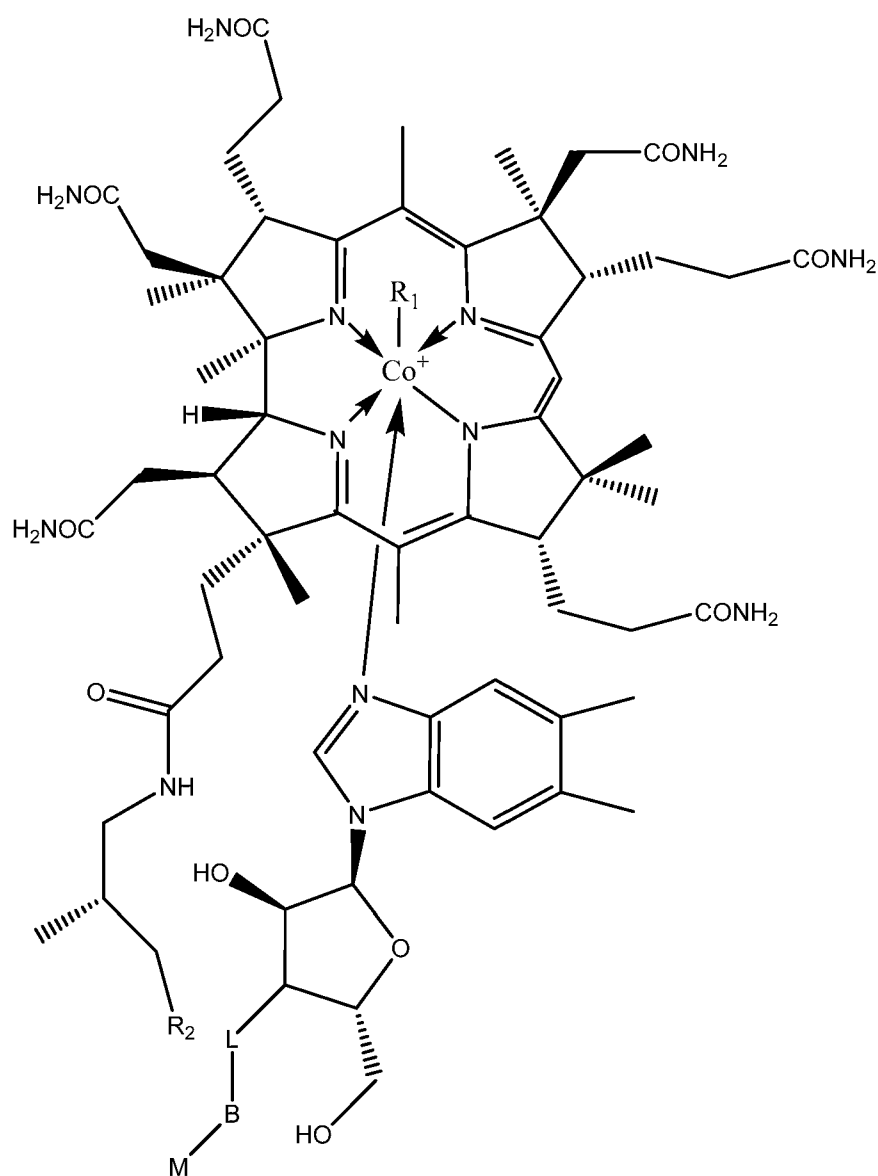
where R_1 is 5'-deoxyadenosyl, CH_3 , OH, or CN; R_3 is OH or H; L is a linker, B is a saccharide-based structure, and M is a metal complexed with the saccharide-based structure.

214. A composition of matter of embodiment 213, wherein L is a hydrazone linker and M is Fe.

215. A composition of matter of embodiment 213, or 214, wherein B includes 10-16 carbon atoms, 9-15 oxygen atoms, and 16-28 hydrogen atoms.

216. A composition of matter of embodiment 213, 214, or 215, wherein B is derived from sucrose.

217. A composition of matter comprising the structure:



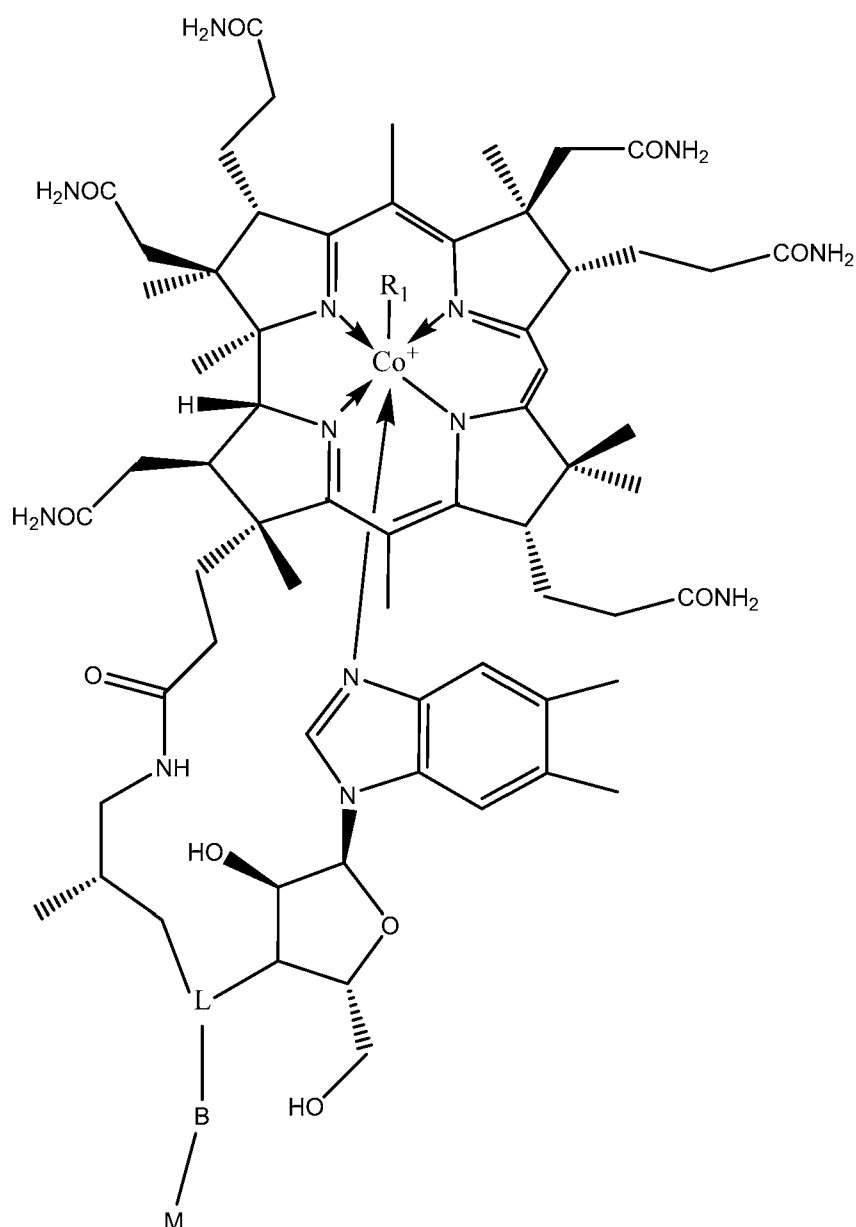
where R_1 is 5'-deoxyadenosyl, CH_3 , OH , or CN ; R_3 is OH or H ; L is a linker, B is a saccharide-based structure, and M is a metal complexed with the saccharide-based structure.

218. A composition of matter of embodiment 217, wherein L is a hydrazone linker and M is Fe .

219. A composition of matter of embodiment 217 or 218, wherein B includes 10-16 carbon atoms, 9-15 oxygen atoms, and 16-28 hydrogen atoms.

220. A composition of matter of embodiment 217, 218, or 219, wherein B is derived from sucrose.

221. A composition of matter comprising the structure:



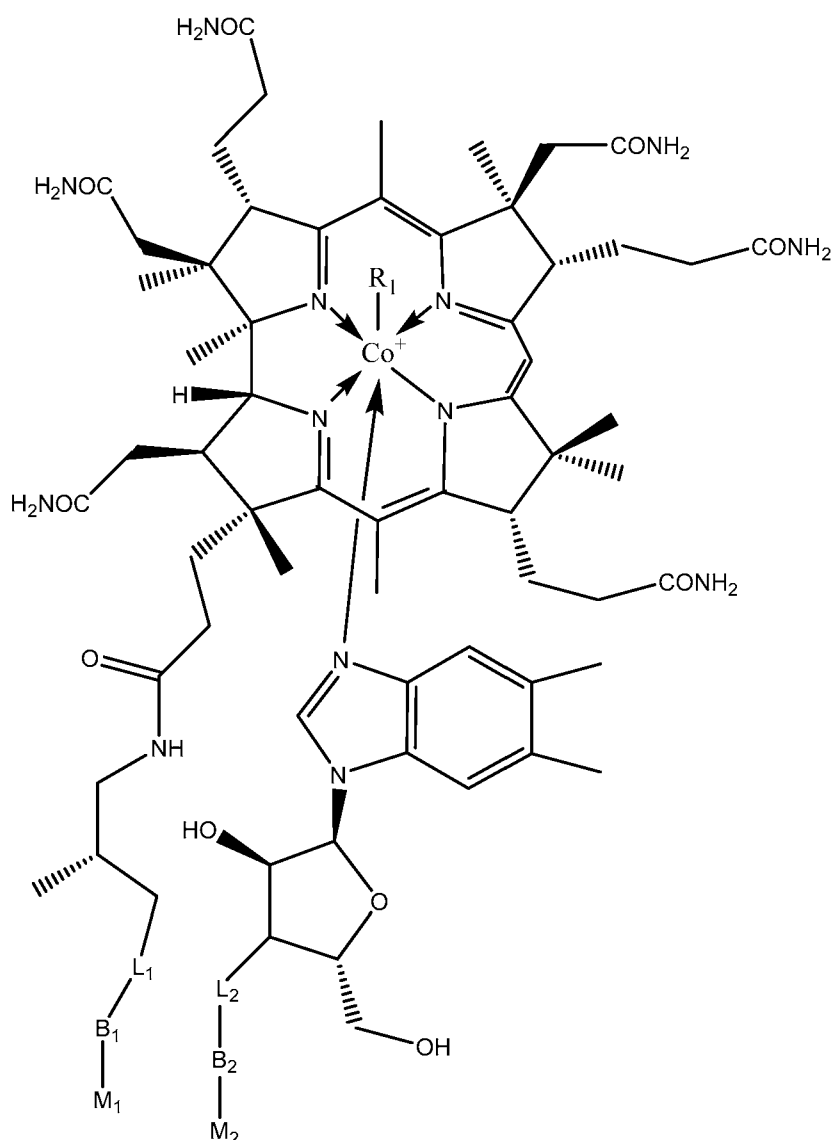
where R_1 is 5'-deoxyadenosyl, CH_3 , OH , or CN ; L is a linker, B is a saccharide-based structure, and M is a metal complexed with the saccharide-based structure.

222. A composition of matter of embodiment 221, wherein L is a hydrazone linker and M is Fe .

223. A composition of matter of embodiment 221 or 222, wherein B has 10-16 carbon atoms, 9-15 oxygen atoms, and 16-28 hydrogen atoms.

224. A composition of matter of embodiment 221, 222, or 223, wherein B is derived from sucrose.

225. A composition of matter comprising the structure:



where R_1 is 5'-deoxyadenosyl, CH_3 , OH , or CN ; L_1 is a first linker, L_2 is a second linker, B_1 is a first saccharide-based structure, B_2 is a second saccharide-based structure, M_1 is a first metal, and M_2 is a second metal complexed with the saccharide-based structure.

226. A composition of matter of embodiment 225, wherein L_1 and L_2 are each independently a hydrazone linker and M_1 and M_2 are each independently Fe.

227. A composition of matter of embodiment 225 or 226, wherein B_1 and B_2 each independently include 10-16 carbon atoms, 9-15 oxygen atoms, and 16-28 hydrogen atoms.

228. A composition of matter of embodiment 225, 226, or 227, wherein B_1 and B_2 are each independently derived from sucrose.

[0191] Example 1. Renal Protection. The data described in FIGs. 1-4 and Tables 1-7 was collected using the following protocols:

[0192] The Glycerol Model of AKI. This is a widely used model of rhabdomyolysis-induced AKI that has been employed worldwide for 50 years. The model was used to test whether prophylactic interventions confer protection against AKI. Basically, the protocol is as follows: Male CD-1 mice (35-45 grams), obtained from Charles River Laboratories, Wilmington, MA were studied. Mice were maintained under standard vivarium conditions and generally housed for 1-3 weeks prior to study. The mice were placed in a cylindrical restraining cage, and then were given a tail vein injection of the test substances (see below) or test substance vehicle. The mice were then returned to their cages. Eighteen hours (hrs) later, the mice were briefly anesthetized by isoflurane inhalation, and given an intramuscular injection of hypertonic (50%) glycerol in a dose of 9 ml/Kg body weight. The dose is divided in two, with half injected into the muscle of each of the hind limbs. The mice were then returned to their cages. Eighteen hrs later, the mice were deeply anesthetized with pentobarbital (50-100 mg/Kg), the abdominal cavity was opened through a midline abdominal incision, a blood sample was obtained from the abdominal vena cava and the kidneys were resected. A kidney cross section was obtained and fixed in formalin for subsequent histologic analysis. The terminal blood samples were analyzed for BUN and creatinine, using commercially available assay kits. The remaining kidney tissue was subjected to cortical dissection, and the cortical tissues were then extracted for protein and RNA. The protein samples were saved for analysis of HO-1 levels, and the RNA samples were subjected to RT-PCR to quantify HO-1 mRNA as well as levels of other stress gene mRNAs (e.g. NGAL, haptoglobin, hemopexin, hepcidin).

[0193] Test preparation: Lyophilized horse skeletal muscle (myoglobin) (Sigma Chemicals) was used as the test agent.

[0194] Myoglobin + SnPP: To 5 mg of dry myoglobin was added 0.9 ml of PBS + 0.1 ml of a stock SnPP solution (50 umole/ml). The resulting final concentrations were 5 mg/ml myoglobin + 5 umoles/ml of SnPP. The tail vein was injected with 200 ul of this solution, which equals 1 mg myoglobin + 1 umole SnPP.

[0195] Nitrited Myoglobin: Na nitrite was added to myoglobin to achieve a 1-5 mole / mole ratio to myoglobin (e.g. 1-5 umole of nitrite / 1 umole of myoglobin). The resulting final concentrations were 5-10 mg/ml myoglobin + 0.04-0.4 mg/ml nitrite. The tail vein was injected with 200 ul of this solution.

[0196] Myoglobin + PEG: To a stock solution of 20 mg/ml Mgb in PBS was added 100 mg/ml of PEG-6000; .250 ul. This was administered as a subcutaneous injection in the dorsal neck (250 ul total injection). For combined Mgb/PEG + SnPP, SnPP was added to the above in a concentration of 3 mg/ml.

[0197] These are the test materials administered to mice to assess protection against the glycerol AKI model, as noted above.

[0198] Independent effects of each test agent: To assess whether myoglobin + SnPP had a greater effect than either myoglobin alone or SnPP alone, the same solutions as noted above were created as follows: myoglobin +SnPP; SnPP alone, or myoglobin alone. These were used in the above noted glycerol model.

[0199] Four hr post myoglobin vs myoglobin +SnPP vs SnPP alone experiments. To confirm that the myoglobin +SnPP has a synergistic effect in inducing HO-1 mRNA and HO-1 protein levels, each of the above combinations have been administered alone via tail vein injection. Four hrs later, the mice were sacrificed as noted above and the kidneys were harvested for assessment of HO-1 mRNA and protein levels. For additional information regarding methods, see Zager et al., Am J Physiol Renal Physiol. 2014 Jul 30. Pii.

Table 1. SnPP quadruples the amount of HO-1 mRNA induction at 4 hrs post injection vs. myoglobin alone (HO-1 / GAPDH mRNA)

	4 hr IV Control	4 hr IV Myoglobin	4 hr IV SnPP	4 hr IV Myoglobin & SnPP
	1.80	2.58	6.95	13.80
	2.49	2.41	2.85	12.05
	1.50	7.78	9.72	13.51
		2.93	8.25	12.36
Average	1.93	3.93	6.94	12.93
Std Error	0.29	1.29	1.48	0.43
Unpaired p (vs Control)		0.25	0.036	0.000006
Unpaired p (vs Ovnt Myoglobin)			0.17	0.00057
Unpaired p (vs Ovnt SnPP)				0.0080

[0200] As shown in Table 2, at the 4 hr time point, there is a preferential increase in HO-1 protein expression (by ELISA). Given that it is just 4 hrs post injection, the mRNA increases are greater than the protein increases as protein synthesis must follow the mRNA induction- requiring more time.

Table 2. Preferential Increase in HO-1 Protein Expression (by ELISA) at the 4 Hr Time Point (Cortex: ng HO-1 / mg protein)

	4 Hr IV PBS	4 hr IV Carrier (0.01N NaOH)	4 hr IV 1mg Myoglobin	4 hr IV 1μmole SnPP	4 hr IV 1mg Myoglobin & 1μmole SnPP
	12.6	20.2	64.7	53.6	68.8

	12.9	22.8	36.0	32.2	41.7
	15.6		40.7	31.5	88.6
	13.1		40.2	20.5	86.4
Average	13.5	21.5	45.4	34.4	71.4
Std Error	0.7	1.3	6.5	6.9	10.8
Unpaired p (vs Control)		0.0037	0.0028	0.024	0.0018
Unpaired p (vs Carrier - 0.01N NaOH)			0.071	0.28	0.038
Unpaired p (vs IV myoglobin)				0.29	0.086
Unpaired p (vs IV SnPP)					0.028

[0201] Table 3 shows HO-1 mRNA induction roughly 18 hrs (overnight) post injection vs. myoglobin alone (HO-1 / GAPDH mRNA) vs. myoglobin in combination with SnPP.

Table 3. HO-1 mRNA induction overnight post injection with control (PBS), myoglobin alone (HO-1 / GAPDH mRNA), and myoglobin in combination with SnPP.

Subject	Ovnt IV Control (PBS)	Ovnt IV 1mg Myoglobin	Ovnt IV 1mg Myoglobin + 1μmole SnPP
1	0.28	0.51	0.75
2	0.47	0.71	2.26
3	0.62	0.53	6.76
Average	0.46	0.58	3.26
Std Error	0.10	0.06	1.81
unpaired p (vs Normal)		0.35	0.20
unpaired p (vs IV Myoglobin)			0.21

[0202] Table 4 shows HO-1 protein induction roughly 18 hrs (overnight) post control injection vs. myoglobin alone (HO-1 / GAPDH mRNA) vs. myoglobin in combination with SnPP.

Table 4. HO-1 protein induction overnight post control injection, myoglobin alone (HO-1 / GAPDH mRNA), and myoglobin in combination with SnPP.

Subject	Ovnt IV Control (PBS)	Ovnt IV 1mg Myoglobin	Ovnt IV 1mg Myoglobin + 1μmole SnPP
1	24.8	24.6	61.4
2	16.0	50.6	93.6
3	20.6	34.9	102.6
Average	20.5	36.7	85.9
Std Error	2.5	7.6	12.5

unpaired p (vs Control)	0.11	0.0068
unpaired p (vs Myoglobin)		0.028
Correlation protein vs mRNA r =		0.80

[0203] FIGs. 1A and 1B show HO mRNA expression (FIG. 1A) and protein expression (FIG. 1B) following vehicle (control), myoglobin (Mgb), or myoglobin in combination with SnPP (Mgb + SnPP) administration 18 hours before glycerol insult. The data indicate that there is a potentiation of myoglobin induced HO-1 induction with concomitant SnPP treatment.

[0204] Table 5 shows induction of haptoglobin protein expression following exposure to myoglobin alone or myoglobin in combination with PEG as compared to carrier control. The data demonstrate that myoglobin + PEG induce far greater increases in cytoprotective haptoglobin expression than myoglobin alone.

Table 5. Haptoglobin Protein Expression 4 hour time point after SQ injection.

Control	Myoglobin Alone	Myoglobin + PEG
9.5 ±2.9 ng/mg protein	32.7 ± 6.3 ng/mg protein	118.8 ±20 ng/mg protein
		p<001 vs control; p<0.025 vs Myoglobin alone

[0205] Table 6 shows plasma LDH levels – a sensitive marker of liver, kidney, lung, and heart injury. Myoglobin + SnPP did not cause an LDH increase at the 4 hr time point.

Table 6. Myoglobin + SnPP Does not cause an LDH increase at the 4 hr time point (Plasma: Absorbance U LDH/ml)

Subject	4 hr IV Carrier	4 hr IV Myoglobin	4 hr IV SnPP	4 hr IV Myoglobin & SnPP
1		4.54	4.54	5.06
2		4.91	5.29	5.63
3	5.36	4.54	5.00	5.78
4	3.49	3.90	3.23	3.30
Average	4.43	4.47	4.51	4.94
Std Error	0.94	0.21	0.46	0.57
Unpaired p (vs Carrier)		0.95	0.93	0.64
Unpaired p (vs Myoglobin)			0.94	0.47
Unpaired p (vs SnPP)				0.58

[0206] FIG. 2 left panels show cellular kidney damage following glycerol insult and the FIG. 2 right panels show the protective effect of pre-treatment with myoglobin in combination with SnPP.

[0207] FIG. 3 shows that N-Mgb + SnPP preferentially elevate the protective stress protein, interleukin-10 (IL-10).

[0208] FIG. 4 shows that N-Mgb + SnPP elevates the protective stress protein, haptoglobin.

[0209] Example 2. Hepatic Protection. Hepatotoxic injury was assessed by plasma LDH levels 24 hrs after insult. Liver insult included 9 ml/kg glycerol injection (this is the same model that is used to cause renal injury). Liver injury raised plasma LDH from 3.5 to 114 units/ml. With myoglobin/SnPP pre-treatment, plasma LDH levels were reduced by 75%.

Table 7. Hepatotoxic injury assessed by plasma LDH levels 24 hrs after insult.

Subject No.	Control	Hepatic Injury	Hepatic Injury + Myoglobin + SnPP
1	3.7	4.4	
2	2.1	130.1	10.4
3	3.9	69.5	20.9
4	4.1	87.5	60.2
5		128.3	38.9
6		155.4	61.3
Mean	3.5	114.2	32.7
Std Error	0.5	15.6	10.1
Unpaired t test (injury +/- myoglobin + SnPP)			p<0.0014

[0210] The data described in Examples 1 and 2 show that heme protein, modified heme protein, and heme protein in combination with a heme protein degradation inhibitor protect the kidney and liver from injury due to glycerol insult. The protection is evidenced through markers of injury (LDH), organ function (BUN and creatinine) and induction of protective stress proteins (HO-1 and haptoglobin).

[0211] Example 3. FIG. 5 shows assessment of the impact of equimolar nitrite binding to myoglobin Fe on the expression of myoglobin toxicity. HK-2 cells (a proximal tubule cell line derived from normal human kidney) were incubated in keratinocyte serum free medium either under normal (control) conditions or in the presence of 10 mg/mL horse skeletal muscle myoglobin or nitrated myoglobin (produced by equimolar Na nitrite addition to 10 mg/ml myoglobin). After 18 hr incubations, the severity of cell injury (% cell death) was assessed by MTT assay. Myoglobin induced 40% cell death (40% decrease in MTT cell uptake), compared to control incubated cells. Nitrite binding to myoglobin reduced cell death by 75%. Thus, nitrite binding is able to reduce myoglobin's cytotoxic effects.

[0212] FIG. 6 shows the dose-response relationship between plasma heme oxygenase 1 (HO-1) and administered N-myoglobin dose. Normal mice were injected IM with either 0, 1, 2, or

5 mg/Kg nitrated myoglobin +SnPP (constant dose of 1 μ mole). Eighteen hrs later, plasma HO-1 levels were assessed by ELISA. A steep dose - response relationship between the administered N-myoglobin dose and plasma HO-1 levels was observed. Thus, HO-1 assay has potential biomarker utility for N-Mgb/SnPP induced HO-1 induction.

[0213] FIG. 7 shows maintenance of normal serum creatinine levels over a 25 fold variation in N-myoglobin dose. Mice were subjected to a 2 hr subcutaneous infusion of 1, 3, 6, 12, or 25 mg/Kg of nitrated myoglobin (holding SnPP at a constant dose of 1 μ mole). Eighteen hrs later, potential renal injury was assessed by measuring serum creatinine concentrations. No significant increase was observed at any of the N -Mgb doses, indicating a lack of over toxicity (n, 2-4 mice/group).

[0214] Example 4. Introduction. Acute kidney injury (AKI) is a well-recognized risk factor for morbidity, mortality, and the initiation of chronic kidney disease (CKD; Ishani et al. J Am Soc Nephrol 2009;20:223–8; Xue et al. J Am Soc Nephrol 2006;17:1135–42; Liangos et al. Clin J Am Soc Nephrol 2006;1:43–51; Wald et al. JAMA 2009; 302:1179–85; Goldberg et al. Kidney Int 2009;76:900–6). However, no proven ways to prevent AKI currently exist. It is well established that after an initial bout of ischemic or toxic injury, the kidney develops marked resistance to subsequent damage (e.g., Honda et al. Kidney Int 1987;31:1233–8; Zager et al. Kidney Int 1984;26:689–700; Zager et al. Lab Invest 1995;72:592–600; Zager, Kidney Int 1995;47:1336–45; Zager, Kidney Int 1995;47:628–37). This phenomenon, which is mediated in part by an upregulation of cytoprotective and anti-inflammatory “stress” proteins (e.g., heme oxygenase 1 (HO-1), ferritin, haptoglobin, hemopexin, alpha 1 antitrypsin, interleukin 10 (IL-10) has been referred to as “ischemic preconditioning” or the “acquired cytoresistance” state. Zager et al. J Am Soc Nephrol 2014;25:998–1012; Deng et al. Kidney Int 2001;60: 2118–28; Zarjou et al. J Clin Invest 2013;123:4423–34; Nath et al. J Clin Invest 1992;90:267–70; Zager et al. Am J Physiol 2012;303:F1460–72; Fink, J Leukoc Biol 2009;86:203–4 Arredouani et al. Immunology 2005;114:263–71; Blum et al. J Am Coll Cardiol 2007; 49:82–7; Galicia et al. Eur J Immunol 2009;39:3404–12; Zager et al. Am J Physiol 2012;303:F139–48; Zager et al. PLoS One 2014;9:e9838; Hunt & Tuder, Curr Mol Med 2012;12:827–35; Janciauskiene et al. J Biol Chem 2007;282:8573–82.

[0215] Given the profound protective nature of acquired cytoresistance, investigators have sought ways to safely recapitulate it in humans. Notable in this regard is so-called “remote preconditioning,” whereby recurrent bouts of upper and lower limb ischemia are induced by recurrently inflating and deflating blood pressure cuffs. Yang et al. Am J Kidney Dis 2014;64:574–83; Mohd et al. J Surg Res 2014;186:207–16; Li et al. J Cardiothorac Surg 2013;8:43. The goal

is to release unknown tissue “conditioning factors” into the systemic circulation that will trigger protective tissue responses (e.g., in brain, heart, liver, and kidney). Despite its appeal, this approach has had only questionable success, likely because of the following reasons: (1) the “factors” released from postischemic limbs that might induce “preconditioning,” and how much factor release is required to induce this state, are unknown; (2) the cellular pathways by which such factors impact distant organs to induce cytoresistance have not been defined; and (3) it is impossible to judge whether the desired preconditioning actually develops in any given individual.

[0216] An alternative approach for inducing acquired cytoresistance was sought. To this end, a pharmacologic regimen including low dose nitrated myoglobin (N-Mgb) + tin protoporphyrin (SnPP), which markedly and synergistically upregulate a host of renal tubular cell cytoprotectants (e.g., HO-1, haptoglobin, and IL-10) in the absence of obvious renal or extrarenal toxicities was developed. Within 18 hours of agent administration, striking resistance to nephrotoxic AKI, adenosine triphosphate (ATP) depletion-induced AKI, and post-AKI progression to CKD result. In addition, hepatic protection against postischemic and toxic injury is expressed. Lastly, it was observed that the induction of this cytoresistant state can be gauged noninvasively by using plasma HO-1 and haptoglobin levels as “biomarkers” of its induction.

[0217] Methods. General approach. Animals. All experiments were conducted using male CD-1 mice (35–45 g; Charles River Laboratories, Wilmington, Massachusetts). They were housed under standard vivarium conditions with free food and water access throughout. The used protocols were approved by the Institution’s Institutional Animal Care and Utilization Committee (IACUC) according to the National Institutes of Health guidelines.

[0218] Cytoresistance-inducing reagents. Horse skeletal muscle (#Mb0360; Sigma) was used as the primary cytoresistance-inducing agent. However, because myoglobin (Mgb) has an inherent nephrotoxic potential (particularly under conditions of volume depletion and aciduria), two approaches were used to mitigate Mgb’s potential adverse effects. First, the Mgb was converted into a nitrated form by the addition of equimolar amount of sodium (Na) nitrite. In this regard, nitrite is an ambidentate molecule that directly binds 1:1 to myoglobin Fe either via its oxygen or nitrogen component. Cotton et al. *Advanced inorganic chemistry*. Hoboken, NJ: Wiley-Interscience, 1999:1355; Silaghi-Dumitrescu et al. *Nitric Oxide* 2014; 42C:32–9. Noteworthy is that Fe is the dominant mediator of Mgb’s cytotoxic effect, (Zager et al. *J Clin Invest* 1992;89:989–95; Zager & Burkhart, *Kidney Int* 1997;51:728–38) and this toxicity is substantially reduced by prior nitrite binding. Rassaf et al. *Circ Res* 2014;114:1601–10; Totzeck et al. *Circulation* 2012;126:325–34 [*J Clin Invest* 1992;89: 989–95]; Totzeck et al. *PLoS One* 2014;22:e105951; Hendgen-Cotta et al. *Proc Natl Acad Sci US A* 2008;105:10256–61.

[0219] In addition to its ability to decrease Fe-mediated toxicity, nitrite has been implicated as a mediator of “remote preconditioning,” possibly through nitric oxide (NO) generation. Rassaf, supra. In this regard, heme proteins directly reduce nitrite, with resultant NO production. Juncos et al. *Am J Pathol* 2006;169:21–31; Kellerman, *J Clin Invest* 1993;92:1940–9; Zager et al. *Am J Physiol* 2008;294:F187–97. Thus, by binding nitrite directly to Mgb, Mgb injection with subsequent proximal tubule endocytic uptake, results in direct proximal tubule nitrite and NO targeting.

[0220] Second, for heme Fe to induce most of its cytotoxicity, it must first be released from its sequestration site within the porphyrin ring. This Fe release is mediated via porphyrin ring cleavage via HO-1. Hence, to attenuate potential Mgb cytotoxicity, it was administered along with a transient HO-1 inhibitor, SnPP. In this regard, it has previously been reported that SnPP addition to Mgb-exposed cultured proximal tubule (HK-2) cells or to in vivo heme loaded mouse proximal tubule segments reduces Mgb toxicity by as much as 85%. Zager & Burkhart, *Kidney Int* 1997;51:728–38. This cytoprotective action is further indicated by observations that SnPP may mitigate postischemic acute renal failure (ARF). Juncos et al. *Am J Pathol* 2006;169:21–31; Kaizu et al. *Kidney Int* 2003;63:1393–403.

[0221] Impact of Mgb, SnPP, and Mgb 1 SnPP on renal cortical heme signaling. It was postulated that (1) N-Mgb would be a potent signaling molecule, leading to the upregulation of heme responsive element and redox sensitive genes, which evoke cytoprotective activities (e.g., HO-1, haptoglobin, hemopexin, and IL-10); (2) SnPP can independently upregulate such genes; and (3) when administered together, N-Mgb + SnPP coadministration can lead to additive or synergistic heme responsive element signaling. The following experiment tested these hypotheses.

[0222] Thirty-two mice were divided into 4 equal groups: (1) control mice; (2) mice treated with 1 mg of N-Mgb injection (as a bolus through the tail vein); (3) mice treated with 1 mmol of SnPP (via tail vein); and (4) mice treated with combined N-Mgb 1 SnPP. After either 4 hours (n = 16) or 18 hours (n = 16), the mice were deeply anesthetized with pentobarbital (50 mg/kg), the abdomen was opened through a midline abdominal incision, and the kidneys were removed. To determine potential effects on extrarenal organs, a liver lobe and the heart were also removed. The tissues were iced and then extracted for protein and RNA (RNeasy Plus Mini; Qiagen, Valencia, California) and subjected to enzyme linked immunosorbent assay (ELISA) and reverse transcriptase polymerase chain reaction (RT-PCR) for HO-1, haptoglobin, and IL-10 protein and messenger RNAs (mRNAs). Zager et al. *J Am Soc Nephrol* 2014;25:998–1012; Zager et al. *Am J Physiol* 2012;303:F139–48. As an assessment of renal function, control mice and the 18 hour after N-Mgb + SnPP–treated mice had blood urea nitrogen (BUN) and plasma creatinine levels

measured. Additionally, transverse 10% formalin fixed kidney sections (3 mM) were cut and stained with hematoxylin and eosin (H&E) and periodic acid Schiff (PAS) to further assess potential injury.

[0223] Assessments of cytoresistance. Glycerol model of rhabdomyolysis-induced AKI. Twenty mice were divided into 4 equal groups (controls, mice treated with N-Mgb, SnPP, and mice treated with N-Mgb + SnPP tail vein injections) as described previously. 18 hours later, the mice were briefly anesthetized with isoflurane and immediately injected with 9 mL/kg of 50% glycerol, administered in equally divided doses into each hind limb. At 18 hours after glycerol injection, the mice were anesthetized with pentobarbital, the abdomen was opened, a blood sample for BUN and creatinine assessments was obtained from the vena cava, and the kidneys were resected. The control post-glycerol group and the N-Mgb + SnPP-pretreated glycerol group had kidney sections stained with H&E.

[0224] Maleate model of AKI. When injected into rodents, maleate undergoes selective proximal tubule uptake via organic anion transporters and induces profound, proximal tubule-specific ATP depletion. Kellerman, J Clin Invest 1993;92:1940–9; Zager et al. Am J Physiol 2008;294:F187–97. This culminates in severe AKI. The following experiment assessed whether N-Mgb + SnPP pretreatment can protect against this form of renal damage. Twelve mice were divided into 2 equal groups, which received either N-Mgb–SnPP or vehicle injection. Eighteen hours later, they all received an intraperitoneal (IP) injection of Na maleate (600 mg/kg). Zager et al. Am J Physiol 2008;294:F187–97. 18 hours later, the mice were anesthetized, and terminal blood samples were obtained from the inferior vena cava for BUN and creatinine measurements.

[0225] Postischemic AKI progression to CKD. After 30 minutes of unilateral renal ischemia, the damaged kidney undergoes a transition to CKD, manifested by progressive tubular dropout, interstitial inflammation, and fibrosis, culminating in a 40% loss of renal mass (kidney weight). Zager et al. Am J Physiol 2011;301:F1334–45; Zager et al. Kidney Int 2013;84:703–12. To ascertain whether N-Mgb–SnPP treatment could mitigate postischemic disease progression, 6 mice were pretreated with these agents and 18 hours later they were anesthetized with pentobarbital and subjected to 30 minutes of left renal pedicle occlusion performed through a midline abdominal incision at a body temperature of 37°C.

[0226] The right kidney was left untouched. After the period of renal ischemia, the vascular clamp was removed and complete reperfusion was confirmed by loss of renal cyanosis. The mice were then sutured and allowed to recover from anesthesia. Six mice, subjected to the same surgical protocol, but without N-Mgb–SnPP pretreatment, served as controls. Two weeks later, the abdominal incision was reopened and the kidneys were resected. Relative degree of renal

injury between the 2 groups was assessed by loss of left renal mass (as determined by renal wet weight) vs weight of left kidneys from 6 normal mice. Renal cortical neutrophil gelatinase associated lipocalin (NGAL) mRNA and protein levels were also assessed as additional markers of renal damage.

[0227] Dose-response relationships after IP N-Mgb–SnPP injections. To assess whether a slower delivery rate of N-Mgb–SnPP (vs via intravenous [IV] bolus injection) also induces an upregulation of cytoprotective proteins and renal cytoresistance, mice were injected with 0, 1, 2.5, or 5 mg of N-Mgb 1 the standard SnPP dose (1 mmol) (3 mice each; 1 mL saline vehicle). Eighteen hours later, the mice were anesthetized with pentobarbital, a blood sample was obtained, and the kidneys were resected to determine HO-1 and haptoglobin mRNA and protein levels. To test whether plasma HO-1 and haptoglobin levels rose and reflected degrees of renal HO-1 and haptoglobin upregulation, plasma HO-1 and haptoglobin levels were also determined.

[0228] To assess whether the previously determined plasma and kidney HO-1 and haptoglobin levels correlated with degrees of cytoresistance, additional mice were injected with 0, 2.5, or 5 mg of N-Mgb 1 1 mmol of SnPP (n = 3 mice per group). Eighteen hours later, all mice were subjected to the glycerol AKI model as described previously. Severities of AKI were determined 18 hours after glycerol injection by BUN and plasma creatinine analyses.

[0229] Hepatic ischemia experiments. Fourteen mice were subjected to the previously published partial hepatic ischemia model, which is conducted by occluding blood flow (at the portal triad) to 3 of 5 hepatic lobes for 25 minutes. Zager et al. *Am J Physiol Renal Physiol* 2014;307:F856–68. Half of the mice were pretreated 18 hours earlier with 1 mg N-Mgb + 1 mmol SnPP as described previously. Reperfusion after the ischemic period was assessed by restoration of normal hepatic color in the 3 involved liver lobes. Eighteen hours later, the mice were reanesthetized, the abdominal cavity was reopened, and a terminal blood sample was obtained for plasma alanine aminotransferase (ALT) and lactate dehydrogenase (LDH) levels as markers of postischemic liver damage.

[0230] Hepatotoxic injury. To assess whether N-Mgb–SnPP can protect against a toxic form of liver injury, 12 anesthetized mice received injections of 50% glycerol. The glycerol (8 mg/kg) was given via an IP injection to favor hepatocellular uptake via the portal circulation. Half of the mice had been pretreated 18 hours earlier with N-Mgb–SnPP (1 mg Mgb/1mmol SnPP) as described previously. Four hours after IP glycerol injection, when the mice were still anesthetized, they were sacrificed via transection of the abdominal vena cava. The extent of acute hepatic injury was gauged by plasma ALT concentrations.

[0231] Calculations and statistics. All values are given as the mean $\pm$ standard error of the mean. Statistical comparisons were made by unpaired Student's *t* test. If multiple comparisons were made, the Bonferroni correction was applied. The severity of renal histologic injury in the glycerol AKI model was graded on a 11 to 41 scale (least to most severe tubular necrosis and cast formation observed). The histologic results were compared by Wilcoxon rank sum test. Statistical significance was taken as a *P* value of < 0.05 .

[0232] Results. Renal function and histology after IV N-Mgb + SnPP injection. Neither BUN nor plasma creatinine increases were observed at 18 hours after IV injection of 1 mg N-Mgb + SnPP (BUN, 22 ± 3 vs 25 ± 3 mg/dL; creatinine, 0.32 ± 0.03 vs 0.30 ± 0.04 mg dL; controls vs Mgb/SnPP treatment, respectively). Furthermore, there was no evidence of renal morphologic injury as evidenced by either PAS or H&E staining. In particular, no evidence of tubular necrosis or heme cast formation was apparent in the treatment group (see FIG. 8) The proximal tubular brush border as depicted by PAS staining, remained entirely intact (upper 2 panels). In this regard, brush border blebbing and swelling into proximal tubule lumina are judged to be highly sensitive light microscopic markers of tubular damage. Venkatachalam et al. *Kidney Int* 1978;14:31–49; Donohoe et al. *Kidney Int* 1978;13:208–22. Thus, these data indicated that the IV N-Mgb–SnPP treatment was well tolerated by the kidney.

[0233] Impact of IV N-Mgb and SnPP, alone and in combination on HO-1, IL-10, and haptoglobin expressions. Renal HO-1 assessments. As shown in FIG. 9, left panel, N-Mgb alone and SnPP alone caused only modest increases in 4 hour HO-1 mRNA levels. In contrast, a 20-fold increase in HO-1 mRNA was observed at 4 hours after combined N-Mgb + SnPP injection. By 18 hours post-treatment, these mRNA increases translated into marked HO-1 protein increases, being 7-fold higher than control values. In contrast, only relatively small HO-1 protein increases were observed with N-Mgb alone or SnPP alone at the 18-hour time point. To sum up, these 4 hour mRNA and 18 hour HO-1 protein increases indicate a synergistic effect of N-Mgb + SnPP on renal cortical HO-1 gene expression. (Additional HO-1 mRNA [18 hours] and protein data [4 hours] are presented in Table 8).

Table 8. Kidney mRNA and protein values 4 h (a) and 18 h (b) after Rx treatment

Measured substance	Control	N-Mgb	SnPP	SnPP 1 N-Mgb
(a) 4 h after Rx treatment				
Kidney mRNA				
HO-1	0.61 ± 0.1	3.38 ± 0.38	4.38 ± 0.28	10.5 ± 1.23 (<0.0001)
Haptoglobin	0.20 ± 0.06	1.94 ± 0.31	0.19 ± 0.01	5.45 ± 1.16 (<0.005)
IL-10	0.56 ± 0.20	1.45 ± 0.6	0.39 ± 0.15	5.18 ± 1.23 (<0.005)
HO-1 protein	13.3 ± 1.3	36.1 ± 2.9	22.9 ± 2.6	55.5 ± 3.7 (<0.001)
Haptoglobin	7.9 ± 1.9	17.6 ± 1	13.1 ± 1.3	18.9 ± 2.7 (<0.001)
IL-10	304 ± 29	265 ± 54	550 ± 86	838 ± 63 (<0.001)
(b) 18 h after Rx treatment				
Kidney mRNA cortex				
HO-1	0.61 ± 0.1	0.58 ± 0.18	0.63 ± 0.06	1.45 ± 0.61 (NS)
Haptoglobin	0.20 ± 0.06	0.24 ± 0.04	0.23 ± 0.08	0.4 ± 0.19 (NS)
IL-10	0.56 ± 0.20	0.43 ± 0.10	0.18 ± 0.09	0.57 ± 0.13 (NS)
Kidney protein				
HO-1	13.3 ± 1.3	30 ± 6	18 ± 2	71 ± 10 (<0.001)
Haptoglobin	10.3 ± 2.7	183.8 ± 20.4	53.5 ± 17.2	203 ± 8 (<0.0001)
IL-10	304 ± 29	292 ± 54	454 ± 51	840 ± 60 (<0.001)

Abbreviations: HO-1, heme oxygenase 1; IL-10, interleukin 10; mRNA, messenger RNA; N-Mgb, nitrited myoglobin; NS, not significant; Rx, treatment; SnPP, tin protoporphyrin. Individual renal cortical mRNA and protein levels induced by the test agents administered alone or in combination at 4 h (a) and 18 h (b) after injection.

[0234] Renal IL-10 assessments. As shown in FIG. 10, left panel, N-Mgb alone and SnPP alone had either minimal or no impact on IL-10 mRNA levels at the 4-hour time point. In contrast, combined N-Mgb + SnPP caused a 10-fold IL-10 mRNA increase at 4 hours after injection. Corresponding to these results was the absence of IL-10 protein increases at 18 hours after N-Mgb alone or SnPP injection alone. Conversely, a >2-fold increase in IL-10 protein was seen at 18 hours after combined N-Mgb–SnPP injection. (Additional IL-10 mRNA [18 hours] and protein data [4 hours] are presented in Table 8).

[0235] Renal cortical haptoglobin assessments. As with HO-1 and IL-10, the combination of N-Mgb + SnPP induced the greatest haptoglobin mRNA increases at 4 hours after agent injection (FIG. 11). At 18 hours after injections, a massive (20-fold) increase in renal cortical haptoglobin protein levels was observed in response to N-Mgb–SnPP injection. However, the haptoglobin protein levels were comparably increased with N-Mgb alone at the 18-hour time point. This implies that it was the N-Mgb component of the combined therapy that drove the 18-hour haptoglobin protein increases. (Given this massive increase, it is conceivable that no added increase could be induced by the combination therapy). Additional haptoglobin mRNA (18 hours) and protein data (4 hours) are presented in Table 8.

[0236] Impact of IV N-Mgb alone, SnPP alone, and N-Mgb + SnPP on the severity of the glycerol AKI model. As shown in FIG. 12, pretreatment with SnPP alone had virtually no effect on the severity of glycerol-induced AKI. N-Mgb alone induced modest protection as judged by BUN/creatinine levels. However, when N-Mgb + SnPP were used together, complete functional protection was observed (BUN/creatinine levels remained at normal values). Coinciding histologic protection was also observed (3.5 ± 0.25 vs 1.25 ± 0.25 histologic scores for the glycerol vs the N-Mgb + SnPP-treated group; $P < 0.05$). In this regard, the untreated glycerol group manifested widespread tubular necrosis and cast formation as previously depicted. Zager et al. *Am J Physiol Renal Physiol* 2014;307:F856–68. These changes were virtually absent in the N-Mgb + SnPP pretreatment group.

[0237] Maleate AKI model. As depicted in FIG. 13, maleate injection caused severe renal injury as denoted by marked BUN/creatinine increases. Pretreatment with N-Mgb + SnPP conferred almost complete protection against this injury as denoted by near normal BUN/creatinine levels.

[0238] FIG. 14 shows maleate- induced cardiotoxicity is reduced by pretreatment with N-Mgb + SnPP. Mice were treated with 1 mg/Kg N-myoglobin + 1 μ mole SnPP or IV vehicle injection). Eighteen hrs later, 800 mg/Kg maleate was administered IP. The extent of myocardial injury was determined 18 hrs post maleate injection by measuring plasma troponin I concentrations (by ELISA). Maleate injection caused a 10 fold increase in plasma troponin levels. Pre-treatment with N-Mgb+SnPP reduced the maleate induced troponin increase by 75%.

[0239] Postischemic AKI model. By 2 weeks postischemia, a 38% reduction in postischemic left renal mass was observed in the control unilateral ischemia mice (FIG. 15). In contrast, only a 12% reduction was seen in the mice that had received prophylactic N-Mgb + SnPP treatment ($P < 0.005$). This reduction in renal injury was also denoted by marked reductions in NGAL mRNA and protein levels in the N-Mgb– SnPP pretreatment group (FIG. 15).

[0240] Dose-response relationships between renal cortical and plasma HO-1/haptoglobin levels and degrees of protection against glycerol-induced AKI. As shown in FIG. 16, progressive increases in IP N-Mgb dosages into normal mice produced progressive increases in renal cortical and plasma HO-1 and haptoglobin levels. Significant correlations between plasma and renal cortical HO-1 and haptoglobin levels were observed (e.g., $r = 0.82$ between renal cortical and plasma haptoglobin levels). Furthermore, these increasing N-Mgb doses were associated with progressive (50%; 100%) protection against the glycerol AKI model (FIG. 17). Thus, these data imply that the degree of plasma HO-1 or haptoglobin increases can serve as biomarkers of N-Mgb-SnPP-induced renal gene induction and the degrees of resistance to subsequent ARF.

Despite administering 5 mg of N-Mgb (+standard SnPP dose), no evidence of renal injury (normal BUN, creatinine; see FIG. 17, right panel) was observed.

[0241] Liver assessments. Hepatic HO-1, IL-10, and haptoglobin expressions in liver in response to N-Mgb/SnPP injections. The fold increases over control values for HO-1, IL-10, and haptoglobin mRNAs (4 hours) and for protein levels (18 hours) are depicted in FIG. 18, top panels. Marked increases in each were observed. Individual values for each agent alone or in combination are given in Table 9.

Table 9. Liver mRNA and protein levels 4 h (a) and 18 h (b) after Rx treatment

Measured substance	Control	N-Mgb	SnPP	SnPP 1 N-Mgb
(a) 4 h after Rx treatment				
Liver mRNA				
HO-1	1.1 ± 0.12	1.83 ± 0.33	3.15 ± 0.25	5.66 ± 0.29 (<0.001)
Haptoglobin	0.5 ± 0.1	0.98 ± 0.1	0.32 ± 0.02	1.01 ± 0.12 (<0.01)
IL-10	0.06 ± 0.002	0.67 ± 0.46	0.14 ± 0.1	1.12 ± 0.64 (<0.001)
Liver protein				
HO-1 protein	10.2 ± 1.2	17 ± 2	7.4 ± 0.7	15.1 ± 1.4 (<0.025)
Haptoglobin	115.3 ± 9.6	359.5 ± 39.6	130.0 ± 8.9	351.0 ± 40.7 (<0.001)
IL-10	314 ± 36	286 ± 32	485 ± 47	412 ± 34 (=0.1)
(b) 18 h after Rx treatment				
Liver mRNA				
HO-1	1.1 ± 0.12	0.82 ± 0.07	2.56 ± 0.21	2.86 ± 0.4 (<0.001)
Haptoglobin	0.5 ± 0.1	0.91 ± 0.07	0.65 ± 0.17	1.19 ± 0.4 (<0.05)
IL-10	0.06 ± 0.02	0.06 ± 0.02	0.05 ± 0.01	0.06 ± 0.02 (NS)
Liver protein				
HO-1 protein	10.2 ± 1.2	14.9 ± 0.3	18 ± 2.5	22.9 ± 1.2 (<0.0001)
Haptoglobin	115.3 ± 9.6	358.8 ± 32.8	212.0 ± 63.6	410 ± 64.3 (<0.001)
IL-10	314 ± 36	5988 ± 549	8198 ± 725	8015 ± 225 (<0.001)

Abbreviations: HO-1, heme oxygenase 1; IL-10, interleukin 10; mRNA, messenger RNA; N-Mgb, nitrited myoglobin; NS, not significant; Rx, treatment; SnPP, tin protoporphyrin. Individual liver mRNA and protein levels induced by the test agents administered alone or in combination at 4 h (a) and 18 h (b) after injection.

[0242] At 4 hours after injection, hepatic HO-1, IL-10, and haptoglobin mRNA levels were significantly higher with combined N-Mgb + SnPP injection vs either agent alone (Table 9). This translated into greater hepatic HO-1, IL-10, and haptoglobin protein increases as assessed at the 18-hour time point ($P < 0.001$ for each protein vs control tissues).

[0243] Hepatic ischemic model. Hepatic ischemia induced marked increases in plasma ALT and LDH concentrations (see FIG. 19). The LDH and ALT increases were reduced by 75% and 50%, respectively, with N-Mgb + SnPP pretreatment (corresponding to the hepatic HO-1, haptoglobin, and IL-10 protein increases; Table 9). As shown in FIG. 20 (top), widespread necrosis was observed in gross sections of postischemic liver. Pretreatment with N-Mgb + SnPP led to a much more normal gross hepatic appearance (FIG. 20 (bottom)).

[0244] Hepatotoxic injury. As shown in the right panel of FIG. 19, N-Mgb + SnPP treatment also reduced the extent of IP glycerol-induced liver injury as assessed by plasma ALT levels.

[0245] Cardiac HO-1, IL-10, and haptoglobin mRNA and protein levels. As shown at the bottom of FIG. 18, combined N-Mgb + SnPP induced 3- to 4-fold increases in HO-1, haptoglobin, and IL-10 mRNAs at 4 hours, and up to 3- to 15-fold increases in their protein levels at the 18-hour time point. Individual values are given in Table 10.

Table 10. Cardiac mRNA and protein levels 4 h (a) and 18 h (b) after Rx treatment

Measured substance	Control	N-Mgb	SnPP	SnPP + N-Mgb
(a) 4 h after Rx treatment				
Cardiac mRNA				
HO-1	0.07 ± 0.01	0.09 ± 0.01	0.14 ± 0.01	0.3 ± 0.01 (<0.001)
Haptoglobin	0.31 ± 0.07	0.75 ± 0.10	0.52 ± 0.21	1.32 ± 0.22 (<0.002)
IL-10	0.36 ± 0.10	0.86 ± 0.11	0.58 ± 0.16	0.96 ± 0.22 (<0.04)
Cardiac Protein				
HO-1	1.50 ± 0.8	1.64 ± 0.19	1.310.13	1.54 ± 0.09 (NS)
Haptoglobin	15.6 ± 5.0	40.4 ± 8.6	19.1 ± 2.1	29.4 ± 4.1 (<0.1)
IL-10	8.1 ± 5	21 ± 12	15.8 ± 10	41 ± 14 (<0.035)
(b) 18 h after Rx treatment				
Cardiac mRNA				
HO-1	0.07 ± 0.01	0.08 ± 0.01	0.09 ± 0.03	0.24 ± 0.07 (<0.005)
Haptoglobin	0.31 ± 0.07	0.53 ± 0.21	0.59 ± 0.17	1.28 ± 0.2 (<0.002)
IL-10	0.36 ± 0.10	0.67 ± 0.10	0.53 ± 0.10	0.64 ± 0.14 (=0.1)
Cardiac protein				
HO-1	1.5 ± 0.08	1.9.7 ± 0.37	2.67 ± 0.4	4.2 ± 0.98 (<0.01)
Haptoglobin	15.6 ± 5.0	249.6 ± 15.0	96.1 ± 36.2	250.7 ± 37.8 (<0.001)
L-10	8 ± 5	14.5 ± 10	23.4 ± 14	51.4 ± 19 (<0.035)

Abbreviations: HO-1, heme oxygenase 1; IL-10, interleukin 10; mRNA, messenger RNA; N-Mgb, nitrited myoglobin; NS, not significant; Rx, treatment; SnPP, tin protoporphyrin. Individual cardiac mRNA and protein levels induced by the test agents administered alone or in combination at 4 h (a) and 18 h (b) after injection.

In general, far greater mRNA and protein increases were observed with combined agent administration vs either agent alone.

[0246] Discussion. In 1992, Nath et al. (J Clin Invest 90:267–70) demonstrated that hemoglobin administration in the rat can induce marked protection against subsequent (24 hours later) glycerol-mediated rhabdomyolysis-induced ARF. This protective response was ascribed to heme-mediated HO-1 upregulation, based on 2 pivotal observations: (1) heme pretreatment markedly increased renal HO-1 mRNA and protein levels, as well as HO-1 enzyme activity, and (2) the glycerol model was markedly worsened by administering the potent HO-1 inhibitor, SnPP, at the time of (and after) glycerol injection. From the time of these seminal observations, the role of HO-1 as a potent antioxidant and anti-inflammatory molecule has been well established in multiple models of AKI (e.g., cisplatin, renal ischemia, endotoxemia; reviewed in Nath, Curr Opin

Nephrol Hypertens 2014;23:17–24). Furthermore, its protective effects have been extensively described in diverse forms of extrarenal tissue damage (e.g., brain, liver, heart, organ transplantation). Kusmic et al. J Transl Med 2014;12:89; Czibik et al. Basic Res Cardiol 2014;109:450; Sharp et al. Transl Stroke Res 2013;6:685–92; Le et al. CNS Neurosci Ther 2013;12:963–8; Huang et al. World J Gastroenterol 2013;21:2937–48; Liu et al. Crit Care Med 2014; 42:e762–71; Wszola et al. Prog Transplant 2014;1: 19–26. However, less certain than the existence of HO's protective actions is the exact mechanism by which that protection is effected. Because HO-1 cleavage of the porphyrin ring releases highly toxic catalytic Fe (which exerts direct adverse effects; Zager & Burkhart, Kidney Int 1997;51:728–38) it is now believed that secondary consequences of increased HO-1 activity are involved. These include the generation of the antioxidants biliverdin and bilirubin, cytoprotective carbon monoxide production, and increased tissue (H) ferritin levels, with its great capacity for catalytic Fe binding. Zarjou et al. J Clin Invest 2013;123:4423–34; Nath, Curr Opin Nephrol Hypertens 2014;23:17–24. Additional complexities in interpreting HO-1 involvement in cytoprotection stem from the fact that HO-1 inducers (e.g., heme) also upregulate a number of other cytoprotective pathways, for example, haptoglobin (Zager et al. Am J Physiol 2012;303:F139–48), hemopexin (Zager et al. Am J Physiol 2012;303:F1460–72) alpha 1 antitrypsin (Zager et al. PLoS One 2014;9:e9838) and IL-10 (as shown in the present disclosure). This complicates interpretation of HO-1 effects on tissue injury given the presence of multiple upregulated tissue protective proteins.

[0247] The interplay of SnPP and HO-1 is also complex. First, as a competitive inhibitor of HO-1, SnPP administration can secondarily increase HO-1 mRNA and protein levels either by enzyme “feedback inhibition” or by the induction of a mild pro-oxidant state with counterbalancing HO-1 production (e.g., Kaizu et al. Kidney Int 2003;63:1393–403). Second, the Sn moiety of SnPP may independently upregulate HO-1 via direct pro-oxidant effects. Barrera-Oviedo et al. Ren Fail 2013;35:132–7. Third, whenever considering the effects of SnPP, it is important to recognize that secondary HO-1 induction could potentially be offset by SNPP-induced HO-1 inhibition. However, it is noteworthy that SnPP has a relatively short half-life (2–4 hours; Berglund et al. Hepatology 1988;8:625–31). Thus, delayed HO-1 increases (e.g., 18 hours after glycerol administration or N-Mgb–SnPP treatment) should be free to exert its biological effects because of prior SnPP elimination. This concept is supported by observations that at 24 hours after SnPP administration, upregulated HO-1 was able to exert a cytoprotective effect (e.g., against ischemic ARF; Juncos et al. Am J Pathol 2006;169:21–31; Kaizu et al. Kidney Int 2003;63:1393–403).

[0248] In light of the previously mentioned considerations, it was hypothesized that a combination of N-Mgb + SnPP might induce either additive or synergistic increases in HO-1 and in other redox sensitive cytoprotective proteins (e.g., haptoglobin and IL-10). This hypothesis was tested by measuring HO-1, haptoglobin, and IL-10 mRNA and protein levels at 4 and 18 hours after N-Mgb, SnPP, or N-Mgb + SnPP injection. As shown in FIGs. 7–9, combined therapy generally induced synergistic or additive responses. For example, at 4 hours after injection, a 20-fold increase in HO-1 mRNA was observed, more than doubling the increases seen with either N-Mgb or SnPP alone. At 18 hours, this early mRNA increase translated into 7-fold HO-1 protein increases. Qualitatively similar results were observed with IL-10. Particularly noteworthy was a massive (20-fold) increase in haptoglobin protein at 18 hours after N-Mgb–SnPP administration. However, in this case, it appeared that it was N-Mgb rather than an N-Mgb–SnPP interaction, which was largely responsible, given that N-Mgb alone vs N-Mgb + SnPP induced comparable renal haptoglobin increases. Clearly, additional cytoprotective redox sensitive proteins, other than HO-1, IL-10, and haptoglobin, may also have been induced by the N-Mgb–SnPP protocol (e.g., α_1 antitrypsin, hemopexin, hepcidin). Thus, it seems logical that multiple cytoprotective proteins could act in concert to mitigate cell injury responses.

[0249] Having observed dramatic renal cortical increases in cytoprotective proteins after N-Mgb–SnPP administration, the latter's effectiveness in protecting against 3 forms of AKI was tested. FIG. 12 depicts the results in the glycerol model. As shown, SnPP administration alone induced no significant reductions in BUN or creatinine levels. When N-Mgb alone was administered, a modest protective effect was observed. However, when administered together, N-Mgb + SnPP pretreatment evoked essentially complete functional protection as indicated by normal BUN and plasma creatinine concentrations at 18 hours after glycerol injection. Furthermore, near normal renal histology was observed. Thus, these findings underscore the principle that synergistic increases in cytoprotective proteins can translate into synergistic protection against ARF.

[0250] To further explore the scope of N-Mgb–SnPP-mediated protection, the maleate model of proximal tubular ATP depletion-mediated ARF was used. Again, dramatic or near complete protection was observed (FIG. 13). Because it is now well recognized that AKI can initiate the onset of progressive chronic renal disease, whether N-Mgb–SnPP pretreatment could abrogate this process in a previously published unilateral postischemic renal injury model (Zager et al. *Kidney Int* 2013;84:703–12; Zager et al. *Am J Physiol Renal Physiol* 2014;307:F856–68) in which a 40% loss of renal mass normally results in 2 weeks was assessed. As shown in FIG. 15, postischemic injury was markedly attenuated with N-Mgb–SnPP pretreatment as evidenced by a

reduction in renal mass loss from 38% to 12%, and marked reductions in NGAL mRNA and protein levels. Thus, in each of 3 heterogeneous AKI models, dramatic protection was observed. Although the kidney has the largest exposure to the 2 test agents (e.g., via rapid filtration, Mgb endocytosis), virtually all cells are transiently exposed to them after their IV injection. Furthermore, protoporphyrins can bind to and be taken up by a variety of cells. Anderson et al. *J Pharmacol Exp Ther* 1984;228:327–33. Thus, it was questioned whether the disclosed N-Mgb–SnPP regimen might also upregulate protective responses in extrarenal organs. Indeed, this was the case, given that both hepatic and cardiac tissues manifested HO-1, IL-10, and haptoglobin mRNA and protein increases at both 4 and 18 hours after N-Mgb–SnPP injection (as presented in Tables 9 and 10). That N-Mgb alone could induce a response in extrarenal tissues was surprising, given that megalin-cubilin-mediated endocytosis is thought to be a renal specific pathway. This either suggests potential extrarenal uptake, possibly via scavenger receptors, (Canton et al. *Nat Rev* 2013;13:621–34) or that when present in the microcirculation, N-Mgb and SnPP are able to activate intracellular cytoprotective genes. To test whether extrarenal protection might result, the impact of N-Mgb + SnPP pretreatment on the extent of postischemic hepatic injury was assessed. As presented in FIG. 18, marked reductions in both LDH and ALT plasma concentrations were observed. Furthermore, obvious protection was indicated by the gross appearance of postischemic hepatic tissues (FIG. 19). To further test hepatic resistance to injury, mice were subjected to an IP injection of glycerol, which on reaching the liver through the portal circulation induces modest hepatic damage. Within 4 hours of IP glycerol injection, increases in plasma ALT resulted, which were largely abrogated by prior N-Mgb–SnPP injection.

[0251] It has previously been demonstrated that plasma levels of either haptoglobin or HO-1 can serve as biomarkers of renal cortical haptoglobin and HO-1 increments in the setting of ARF. Z Zager et al. *Am J Physiol* 2012;303:F139–48; Zager et al. *J Am Soc Nephrol* 2012;23:1048–2057. Thus, it was questioned whether plasma haptoglobin and HO-1 might also serve as biomarkers for induction of these proteins in kidney after N-Mgb–SnPP administration and for the emergence of the cytoresistant state. This indeed was the case. As shown in FIG. 16, increasing doses of N-Mgb–SnPP induced dose-dependent increases in plasma haptoglobin and HO-1 levels, and these increases directly correlated with renal cortical haptoglobin and HO-1 content. Furthermore, striking inverse relationships between N-Mgb–SnPP-induced plasma HO-1 and plasma haptoglobin increases and postglycerol BUN concentrations were observed (r , -0.79/ r , -0.71 for BUN vs plasma HO-1 and haptoglobin levels, respectively). Thus, plasma HO-1/haptoglobin increments would likely confirm biological activity of N-Mgb–SnPP in clinical trials,

and the degrees of HO-1 and haptoglobin plasma increase might also be predictive of degrees of resistance to subsequent AKI.

[0252] An obvious concern by applying this prophylactic strategy to patients is potential renal and/or extrarenal toxicities. However, in this regard, it is noteworthy that SnPP has already been shown to be well tolerated in humans (e.g., Berglund et al. *Hepatology* 1988;8:625–31; Kappas et al. *Pediatrics* 1988;81:485–97; Reddy et al. *J Perinatol* 2003;23: 507–12). Furthermore, it was previously documented in a cell culture system that nitrite addition markedly reduces myoglobin's cytotoxic effects by 75% (unpublished data, 2014). To assess the potential in vivo margin of safety for N-Mgb + SnPP (see Supplemental FIGs.), the maximal amount of N-Mgb that could be given to mice before nephrotoxicity was observed was tested. Up to 25 times the employed N-Mgb dose (with a constant SnPP dose) could be administered (over 2 hours) without induction of nephrotoxicity (normal BUN and creatinine, 18 hours later). Finally, neither the standard N-Mgb–SnPP dosage (1 mg N-Mgb/1 mmol SnPP) nor 5 mg IP N-Mgb (FIG. 17) induced overt renal injury (18 hour BUN/creatinine, or histology), nor did it raise hepatic ALT or cardiac troponin levels. In concert, these data indicate usefulness in clinical application.

[0253] Conclusions. Administration of N-Mgb, along with an inhibitor of its degradation (SnPP), leads to dramatic increases in a number of cytoprotective proteins in kidney. The potency of this response is indicated by observations that the documented renal HO-1 protein increases were 15 times greater than that which has been achieved with bardoxolone methyl, a well recognized Nrf-2– mediated HO-1 inducer. Wu et al. *Am J Physiol* 2011;300: F1180–92. Within 18 hours of its administration, N-Mgb + SnPP evoked dramatic protection against 3 diverse models of AKI: glycerol-induced rhabdomyolysis, maleate-induced proximal tubule ATP depletion, and postischemic AKI progression to CKD. Surprisingly, N-Mgb + SnPP administration also induced synergistic increases in cytoprotective proteins in liver, leading to dramatic protection against hepatic ischemic-reperfusion injury and hepatotoxicity. Finally, N-Mgb + SnPP can upregulate cytoprotective proteins in heart, suggesting cardiac protection, and thus, broad ranging cytoprotective effects. Of note, each of these responses was induced in the absence of discernable renal, hepatic, or cardiac toxicity. Thus, these data suggest that N-Mgb + SnPP coadministration can provide a clinical prophylactic strategy for protecting against both renal and extrarenal injuries, such as may result during cardiopulmonary bypass, aortic aneurysm repair, or other complex, high-risk surgeries. Thus, this strategy could potentially meet a number of significant unmet clinical needs.

[0254] Example 5. Two mongrel dogs, one male, one female, had baseline blood drawn for measurement of plasma heme oxygenase 1 (HO-1; canine ELISA,) BUN, plasma creatinine, and

lactate dehydrogenase (LDH) levels. A baseline spot urine sample was also obtained for HO-1 assay. Dog 1 then received a 50 ml/50 min infusion of normal saline/40mM NaHCO₃ containing 5 mg/Kg of nitrated canine myoglobin + 3.75 mg/Kg of SnPP. Dog 2 received 2.5 mg/Kg canine N-myoglobin + 7.5 mg/Kg SnPP. Four and 26 hrs later, repeat blood samples were obtained. A second urine sample was collected at 26 hrs post infusion. As shown in Table 11, the infusion evoked massive increases in plasma and urinary HO-1 concentrations in the absence of renal injury (based on pre and BUN and plasma creatinine levels). LDH values remained unchanged, implying an absence of obvious renal /extrarenal tissue injury.

Table 11. HO-1 Induction in Dogs

	Dog 1 (male)	Dog 2 (female)
Baseline BUN (mg/dl)	20 →	28 →
26 hr BUN	28	23
Baseline Creatinine (mg/dl)	0.5 →	0.7 →
26 hr Creatinine	0.5	0.6
Baseline LDH (units/dl)	0.4 →	0.31 →
26 hr LDH	0.2	0.31
Baseline Plasma HO-1 (mg/ml)	1.3 →	4.0 →
4 hr Plasma HO-1	34 →	44.7 →
26 hr Plasma HO-1	155	90.6
Baseline Urine HO-1 (mg/mg cr)	2 →	0.8 →
26 hr Urine HO-1	18.8	11.1

[0255] Example 6. Effects of Fe sucrose and cyanocobalamin (Vitamin B₁₂) on heme oxygenase 1 induction in kidney. Heme oxygenase-1 (HO-1) upregulation is a critical mediator of N-myoglobin/SnPP's cytoprotective activity in kidney and extra-renal organs. Hence, additional agents were sought that can induce HO-1 up-regulation, and thus, contribute to the emergence of tissue protection against toxic and ischemic forms of injury. Because Fe is the critical mediator of N-Mgb's activity, the impact of an Fe-carbohydrate polymer (Fe sucrose; molecular weight ranging from 34-61 kDa) on HO-1 levels was assessed.

[0256] As an alternative and/or complementary strategy, the impact of cyanocobalamin (vitamin B12) on HO-1 induction in kidney was studied. The rationale for B12 testing is that both cobalt and cyanide can independently induce HO-1. Thus, B12 could represent a safe method to administer both cyanide and cobalt, and as a single agent, since both are integral parts of the B12 molecule.

[0257] Methods. Male CD-1 mice (25-40 grams) Charles River, Wilmington, MA) were used for all experiments. They were housed under standard vivarium conditions with free food and

water access. All experiments were approved by the Fred Hutchinson Cancer Research Center IACUC in accordance with NIH guidelines.

[0258] Effects of Fe sucrose (FeS) / tin protoporphyrin (SnPP) on AKI severity. Maleate model of AKI. When injected into rodents, maleate undergoes relatively selective proximal tubule cell uptake via organic anion transporters. Once intracellular accumulation occurs, maleate is a preferred substrate for succinyl-CoA:3-oxoacid CoA transferase. This results in the formation of maleyl-coenzyme A. With subsequent conversion of maleyl CoA into a stable thioether, severe coenzyme A (CoA) depletion results. Ample levels of CoA are essential for fatty acid “activation”, allowing for their subsequent metabolism through the Krebs cycle, yielding ATP. In the absence of this process, proximal tubule ATP depletion and cell injury result. Additionally, maleate conjugates the sulfhydryl group of glutathione (GSH), culminating in GSH depletion and potential oxidant tubular stress.

[0259] The following experiment tested whether FeS, SnPP or combined FeS + SnPP can mitigate this form of acute kidney injury (AKI). Twenty seven mice were subjected to 200 μ L IV tail injections of one of the following: 1) vehicle (phosphate buffered saline, PBS; n, 10); 2) 1 mg FeS (American Regent (Shirley, NY; n, 3); 3) 1 μ mole SnPP (Frontier Scientific, Logan, UT; n 7), or FeS +SnPP, n, 7). Eighteen hrs later, all mice received an IP injection of Na maleate (800 mg/Kg; in 500 μ L of PBS). Eighteen hrs later, the mice were deeply anesthetized with pentobarbital (50 mg/Kg IP), the abdominal cavities were opened, and blood samples were obtained from the abdominal vena cava. The severity of kidney injury was assessed by determining plasma blood urea nitrogen (BUN) and plasma creatinine (PCr) concentrations.

[0260] Renal ischemic–reperfusion injury (IRI) model of AKI. The following experiment assessed whether combination FeS+SnPP can mitigate the renal artery occlusion model of AKI. Mice received 200 μ L tail vein injections of either PBS (n, 9) or FeS +SnPP (n, 8), as noted above. Eighteen hrs later, the mice were deeply anesthetized with pentobarbital (40-50 mg/Kg IP), the abdominal cavities were opened, the renal pedicles were identified and both were occluded with microvascular clamps. Body temperature was maintained at 36-37° C throughout. Following 22 minutes of bilateral renal ischemia, the clamps were removed, uniform reperfusion was visually confirmed by the reappearance of a normal renal color (loss of tissue cyanosis), and then the abdominal cavities were closed in two layers with silk suture. Eighteen hrs later, the mice were re-anesthetized, the abdominal cavities were re-opened, and terminal blood samples were obtained from the vena cava. The severity of renal injury was determined by BUN and PCr concentrations.

[0261] FeS / B12 effects on the severity of AKI. Glycerol model of AKI. Mice received tail vein injections of either PBS vehicle (n 6), or combination FeS + 1 μ mole B12 (n, 6; B12 from Alfa Aesar, Ward Hill, MA). Eighteen hrs later, the mice were lightly anesthetized with isoflurane, and then the glycerol model of rhabdomyolysis AKI was induced (9 ml/Kg 50% glycerol, administered in two equally divided IM injections into the upper hind limbs). Eighteen hrs post glycerol injection, the mice were deeply anesthetized with pentobarbital and terminal vena cava blood samples were obtained. Renal injury severity was gauged by terminal BUN and PCr concentrations.

[0262] Maleate model of AKI. Mice received tail vein injections of either combination of FeS+B12 or vehicle (n, 6 per group). Eighteen hrs later they received IP maleate injections, as noted above. The severity of AKI was determined 18 hrs post maleate injection by terminal BUN and PCr assessments.

[0263] Effects of FeS, SnPP, and B12 on renal cortical induction of heme oxygenase 1 (HO-1). The following experiments assessed the effects of FeS, SnPP, and B12 on the possible induction of the cytoprotective protein HO-1. To this end, mice were injected with each of these agents, as noted above. Either 4 or 18 hrs later, they were anesthetized and the kidneys were removed through a midline abdominal incision. The renal cortices were dissected on ice and then extracted for protein and mRNA. The samples were then assayed for HO-1 protein by ELISA, and HO-1 mRNA by RT-PCR, factored by GAPDH levels. Five normal mice provided control values.

[0264] Results. Effects of FeS / SnPP on the severity of AKI. Maleate- induced AKI: As shown in FIG. 22, maleate injection caused severe AKI as denoted by marked BUN and PCr increases over maleate injected controls (C). Neither SnPP alone nor FeS alone significantly altered the severity of renal injury. However, combined FeS + SnPP conferred marked protection, as denoted by 75% reductions in BUN / PCr concentrations (the horizontal lines represent the means of BUN/ PCr levels in normal mice).

[0265] Renal ischemia-reperfusion (IRI) induced AKI: Within 18 hrs of inducing IRI, 4 fold elevations in BUN and PCr concentrations resulted (FIG 23). Pre-treatment with FeS + SNPP conferred significant protection, lowering the BUN and PCr levels by 50%. The horizontal lines represent mean BUN / PCr levels in normal mice.

[0266] Effects of FeS / B12 on AKI severity. Maleate induced AKI: Again, maleate injection induced severe AKI (FIG. 24). Pre-treatment with FeS + B12 markedly mitigated this injury, as denoted by BUN/ PCr reductions. The horizontal lines represent mean BUN / PCr levels in normal mice.

[0267] Glycerol model of AKI: Severe renal failure resulted within 18 hrs of glycerol injection (FIG. 25). Pre-with FeS + B12 conferred substantial functional protection, as denoted by marked

reductions in both 18 hr BUN and PCr concentrations. The horizontal lines represent mean BUN / PCr levels for normal mice.

[0268] Renal cortical HO-1 mRNA and protein levels. As shown in FIG. 26, each of the agents induced marked and significant increases in HO-1 mRNA, as assessed 4 hr post injection. By 18 hrs, HO-1mRNA levels returned to normal values. As shown in FIG. 27, a correlate of the 4 hr mRNA increases was a significant increase in HO-1 protein levels. These levels remained elevated at the 18 hr time point, particularly in the case of FeS administration.

[0269] Prophetic Examples. Prophetic Example 1. Whether a depot formulation confers equal or greater cytoprotection with less potential toxicity than intravenous (IV) myoglobin/SnPP treatment and/or Fe-S and/or B12 will be assessed. Different doses of myoglobin with SnPP and/or Fe-S and/or B12 will be added as a suspension to 100 mg/ml PEG (PEG 5000). There are two rationales for conducting this experiment. First, by injecting either intramuscularly (IM) or subcutaneously (SQ) the myoglobin and SnPP and/or Fe-S and/or B12 will be absorbed relatively slowly (vs. instantaneous systemic myoglobin /SnPP and/or Fe-S and/or B12 exposure following IV injection). By slowing the myoglobin and/or Fe-S and/or B12 absorption with a depot PEG injection, a slower, more sustained renal exposure to myoglobin and/or Fe-S and/or B12 will result. This will favor increased myoglobin and/or Fe-S and/or B12 uptake, and at the same time, decrease the potential for nephrotoxicity, as can occur due to rapid renal myoglobin and/or Fe-S and/or B12 loading (which results in obstructive cast formation within tubular lumina). Second, PEG is an osmotic agent and will undergo renal excretion. Because an acute increase in urinary osmolality can induce cytoprotective proteins on its own, and also confer protection by causing increased urinary flow rates, an additive or synergistic beneficial effect may be observed.

[0270] Prophetic Example 2. Hematin will inhibit HO, and like SnPP, it can also induce an increase in HO production (via enzyme feedback inhibition). Thus, hematin should recapitulate the beneficial effects of SnPP treatment. Importantly, hematin has been approved by the FDA for the treatment of the clinical disease, porphyria. Thus, if hematin is as effective as SnPP, hematin may be selected for further study and clinical development.

[0271] Prophetic Example 3. It is well documented that HO protects against experimental sepsis and endotoxemia. HO-1 will be up-regulated according to the compositions, kits, and methods disclosed herein and then 18 hrs later, the mice will be challenged with endotoxin. At 2 and 24 hrs later, the severity of sepsis is gauged by inflammatory cytokine (TNF, MCP-1) levels in plasma and in kidney. Also, because endotoxemia causes kidney injury, the severity of kidney dysfunction by BUN and creatinine levels will be tested. The results will be compared to naïve

mice subjected to Fendotoxin injection. When successful, this will greatly expand the utility of the disclosed protective strategies to patients at high risk of sepsis (e.g. ICU patients).

[0272] Prophetic Example 4. On-going studies will demonstrate the effectiveness of iron and/or vitamin B12 in protecting various organ systems from insult.

[0273] The compositions, kits, and methods disclosed herein are distinguished from “remote preconditioning” whereby one causes ischemia in the legs (e.g., by inflating blood pressure cuffs) to precondition other organs, which has met only very limited success. In particular embodiments, the compositions, kits and methods disclosed herein can be referred to as “remote *pharmacologic* preconditioning” (RPR).

[0274] As will be understood by one of ordinary skill in the art, each embodiment disclosed herein can comprise, consist essentially of, or consist of its particular stated element, step, ingredient or component. Thus, the terms “include” or “including” should be interpreted to recite: “comprise, consist of, or consist essentially of.” The transition term “comprise” or “comprises” means includes, but is not limited to, and allows for the inclusion of unspecified elements, steps, ingredients, or components, even in major amounts. The transitional phrase “consisting of” excludes any element, step, ingredient or component not specified. The transition phrase “consisting essentially of” limits the scope of the embodiment to the specified elements, steps, ingredients or components and to those that do not materially affect the embodiment. A material effect would cause a statistically-significant reduction in the ability of a disclosed composition, kit or method to protect an organ from a scheduled insult.

[0275] Unless otherwise indicated, all numbers expressing quantities of ingredients, properties such as molecular weight, reaction conditions, and so forth used in the specification and claims are to be understood as being modified in all instances by the term “about.” Accordingly, unless indicated to the contrary, the numerical parameters set forth in the specification and attached claims are approximations that can vary depending upon the desired properties sought to be obtained by the present invention. At the very least, and not as an attempt to limit the application of the doctrine of equivalents to the scope of the claims, each numerical parameter should at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques. When further clarity is required, the term “about” has the meaning reasonably ascribed to it by a person skilled in the art when used in conjunction with a stated numerical value or range, i.e. denoting somewhat more or somewhat less than the stated value or range, to within a range of $\pm 20\%$ of the stated value; $\pm 19\%$ of the stated value; $\pm 18\%$ of the stated value; $\pm 17\%$ of the stated value; $\pm 16\%$ of the stated value; $\pm 15\%$ of the stated value; $\pm 14\%$ of the stated value; $\pm 13\%$ of the stated value; $\pm 12\%$ of the stated value; $\pm 11\%$ of the stated

value; $\pm 10\%$ of the stated value; $\pm 9\%$ of the stated value; $\pm 8\%$ of the stated value; $\pm 7\%$ of the stated value; $\pm 6\%$ of the stated value; $\pm 5\%$ of the stated value; $\pm 4\%$ of the stated value; $\pm 3\%$ of the stated value; $\pm 2\%$ of the stated value; or $\pm 1\%$ of the stated value.

[0276] Notwithstanding that the numerical ranges and parameters setting forth the broad scope of the invention are approximations, the numerical values set forth in the specific examples are reported as precisely as possible. Any numerical value, however, inherently contains certain errors necessarily resulting from the standard deviation found in their respective testing measurements.

[0277] The terms “a,” “an,” “the”, and similar referents used in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. Recitation of ranges of values herein is merely intended to serve as a shorthand method of referring individually to each separate value falling within the range. Unless otherwise indicated herein, each individual value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., “such as”) provided herein is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention otherwise claimed. No language in the specification should be construed as indicating any non-claimed element essential to the practice of the invention.

[0278] Groupings of alternative elements or embodiments of the invention disclosed herein are not to be construed as limitations. Each group member can be referred to and claimed individually or in any combination with other members of the group or other elements found herein. It is anticipated that one or more members of a group can be included in, or deleted from, a group for reasons of convenience and/or patentability. When any such inclusion or deletion occurs, the specification is deemed to contain the group as modified thus fulfilling the written description of all Markush groups used in the appended claims.

[0279] Certain embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Of course, variations on these described embodiments will become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventor expects skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the

above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

[0280] Furthermore, numerous references have been made to patents, printed publications, journal articles and other written text throughout this specification (referenced materials herein). Each of the referenced materials are individually incorporated herein by reference in their entirety for their referenced teaching.

[0281] The particulars shown herein are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of various embodiments of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for the fundamental understanding of the invention, the description taken with the drawings and/or examples making apparent to those skilled in the art how the several forms of the invention can be embodied in practice.

[0282] Definitions and explanations used in the present disclosure are meant and intended to be controlling in any future construction unless clearly and unambiguously modified in the following examples or when application of the meaning renders any construction meaningless or essentially meaningless. In cases where the construction of the term would render it meaningless or essentially meaningless, the definition should be taken from Webster's Dictionary, 3rd Edition or a dictionary known to those of ordinary skill in the art, such as the Oxford Dictionary of Biochemistry and Molecular Biology (Ed. Anthony Smith, Oxford University Press, Oxford, 2004).

[0283] In closing, it is to be understood that the embodiments of the invention disclosed herein are illustrative of the principles of the present invention. Other modifications that can be employed are within the scope of the invention. Thus, by way of example, but not of limitation, alternative configurations of the present invention can be utilized in accordance with the teachings herein. Accordingly, the present invention is not limited to that precisely as shown and described.

CLAIMS

What is claimed is:

1. A kit for protecting an organ from injury, the kit comprising a therapeutically effective amount of a heme protein, vitamin B12, iron, or a combination thereof, wherein administration of the therapeutically effective amount of the heme protein, the vitamin B12, the iron, or the combination thereof to the organ protects the organ without causing injury to the organ.
2. A kit of claim 1, wherein the kit includes a therapeutically effective amount of the heme protein.
3. A kit of claim 1, wherein the kit includes a therapeutically effective amount of the vitamin B12.
4. A kit of claim 1, wherein the kit includes a therapeutically effective amount of the iron.
5. A kit of claim 1, wherein the kit includes a therapeutically effective amount of the combination of the vitamin B12 and the iron.
6. A kit of claim 1, further comprising administration instructions.
7. A kit of claim 1, wherein absence of organ injury caused by the administration is confirmed by comparison to a reference level.
8. A kit of claim 7, wherein the reference level is provided within the kit.
9. A kit of claim 1, wherein protection is evidenced by comparison to a reference level.
10. A kit of claim 9, wherein the reference level is provided within the kit.
11. A kit of claim 1, wherein the organ is protected from an injury based on an insult.
12. A kit of claim 11, wherein the insult is scheduled.
13. A kit of claim 12, wherein the administration occurs at least 8 hours before the scheduled insult.
14. A kit of claim 12, wherein the scheduled insult is surgery, chemotherapy, or radiocontrast toxicity.
15. A kit of claim 14, wherein the surgery is an organ transplant surgery.
16. A kit of claim 11, wherein the insult is sepsis.
17. A kit of claim 1, wherein the organ is a transplanted organ.
18. A kit of claim 1, wherein the organ is a heart, kidney, liver, or lung.
19. A kit of claim 1, wherein the organ is a heart and protection is evidenced by improvement of cardiac function, or reduction in cardiac enzyme release as compared to a reference level.
20. A kit of claim 19, wherein the cardiac enzyme is troponin.

21. A kit of claim 1, wherein the organ is a kidney and protection is evidenced by prevention or reduction in blood urea nitrogen (BUN) or serum creatinine increases as compared to a reference level.
22. A kit of claim 1, wherein the organ is a liver and protection is evidenced by prevention or reduction in liver enzyme increases as compared to a reference level.
23. A kit of claim 1, wherein the organ is a lung and protection is evidenced by reduction in blood gas deterioration, reduction in need for supplemental oxygen, or reduced ventilator requirements as compared to a reference level.
24. A kit of claim 2, wherein the heme protein is formulated within a composition.
25. A kit of claim 2, wherein the heme protein is a heme protein variant, a heme protein d-substituted analog, a heme protein modification, or combination thereof.
26. A kit of claim 2, wherein the heme protein is a modified heme protein.
27. A kit of claim 5, wherein the modified heme protein is a nitrated heme protein or a PEGylated heme protein.
28. A kit of claim 2, wherein the heme protein is myoglobin.
29. A kit of claim 2, wherein the heme protein is a myoglobin variant or a myoglobin modification.
30. A kit of claim 29, wherein the myoglobin modification is a nitrated myoglobin or a PEGylated myoglobin.
31. A kit of claim 2, further comprising a heme protein degradation inhibitor.
32. A kit of claim 31, wherein the heme protein degradation inhibitor is formulated within a composition.
33. A kit of claim 31, wherein the heme protein degradation inhibitor and the heme protein are formulated within the same composition.
34. A kit of claim 31, wherein the heme protein degradation inhibitor is a nitrated heme protein degradation inhibitor.
35. A kit of claim 31, wherein the heme protein degradation inhibitor is a heme oxygenase inhibitor.
36. A kit of claim 35, wherein the heme oxygenase inhibitor is a protoporphyrin, hemin, or hematin.
37. A kit of claim 35, wherein the heme oxygenase inhibitor is a metal protoporphyrin.
38. A kit of claim 37, wherein the metal protoporphyrin is Sn-protoporphyrin.
39. A kit of claim 2, wherein:
 - the heme protein is supplemented with the vitamin B12;
 - the heme protein is supplemented with the iron; or

wherein the heme protein is supplemented with the vitamin B12 and the iron.

40. A kit for generating acquired cytoresistance in an organ, the kit comprising a therapeutically effective amount of a heme protein, vitamin B12, iron, or a combination thereof, wherein administration of the therapeutically effective amount of the heme protein, the vitamin B12, the iron, or the combination thereof to the organ generates acquired cytoresistance in the organ in the absence of causing injury to the organ.
41. A kit of claim 40, wherein the kit includes a therapeutically effective amount of the heme protein.
42. A kit of claim 40, wherein the kit includes a therapeutically effective amount of the vitamin B12.
43. A kit of claim 40, wherein the kit includes a therapeutically effective amount of the iron.
44. A kit of claim 40, wherein the kit includes a therapeutically effective amount of the combination of the vitamin B12 and the iron.
45. A kit of claim 40, further comprising administration instructions.
46. A kit of claim 40, wherein absence of organ injury caused by the administration is confirmed by comparison to a reference level.
47. A kit of claim 46, wherein the reference level is provided within the kit.
48. A kit of claim 40, wherein the acquired cytoresistance protects the organ from an injury.
49. A kit of claim 48, wherein protection is evidenced by comparison to a reference level.
50. A kit of claim 49, wherein the reference level is provided within the kit.
51. A kit of claim 40, wherein the organ is protected from an injury based on an insult.
52. A kit of claim 51, wherein the insult is scheduled.
53. A kit of claim 52, wherein the administration occurs at least 8 hours before the scheduled insult.
54. A kit of claim 52, wherein the scheduled insult is surgery, chemotherapy, or radiocontrast toxicity.
55. A kit of claim 54, wherein the surgery is an organ transplant surgery.
56. A kit of claim 51, wherein the insult is sepsis.
57. A kit of claim 40, wherein the organ is a transplanted organ.
58. A kit of claim 40, wherein the organ is a heart, kidney, liver, or lung.
59. A kit of claim 58, wherein the organ is a heart and protection is evidenced by improvement of cardiac function, or reduction in cardiac enzyme release as compared to a reference level.
60. A kit of claim 59, wherein the cardiac enzyme is troponin.

61. A kit of claim 58, wherein the organ is a kidney and protection is evidenced by prevention or reduction in BUN or serum creatinine increases as compared to a reference level.
62. A kit of claim 58, wherein the organ is a liver and protection is evidenced by prevention or reduction in liver enzyme increases as compared to a reference level.
63. A kit of claim 58, wherein the organ is a lung and protection is evidenced by reduction in blood gas deterioration, reduction in need for supplemental oxygen, or reduced ventilator requirements as compared to a reference level.
64. A kit of claim 41, wherein the heme protein is formulated within a composition.
65. A kit of claim 41, wherein the heme protein is a heme protein variant, a heme protein d-substituted analog, a heme protein modification, or a combination thereof.
66. A kit of claim 41, wherein the heme protein is a modified heme protein.
67. A kit of claim 66, wherein the modified heme protein is a nitrated heme protein or a PEGylated heme protein.
68. A kit of claim 41, wherein the heme protein is myoglobin.
69. A kit of claim 41, wherein the heme protein is a myoglobin variant or a myoglobin modification.
70. A kit of claim 69, wherein the myoglobin modification is a nitrated myoglobin or a PEGylated myoglobin.
71. A kit of claim 41, further comprising a heme protein degradation inhibitor.
72. A kit of claim 71, wherein the heme protein degradation inhibitor is formulated within a composition.
73. A kit of claim 71, wherein the heme protein degradation inhibitor and the heme protein are formulated within the same composition
74. A kit of claim 71, wherein the heme protein degradation inhibitor is a nitrated heme protein degradation inhibitor
75. A kit of claim 71, wherein the heme protein degradation inhibitor is a heme oxygenase inhibitor.
76. A kit of claim 75, wherein the heme oxygenase inhibitor is a protoporphyrin, hemin, or hematin.
77. A kit of claim 75, wherein the heme oxygenase inhibitor is a metal protoporphyrin.
78. A kit of claim 77, wherein the metal protoporphyrin is Sn-protoporphyrin.
79. A kit of claim 41, wherein:
 - the heme protein is supplemented with the vitamin B12;
 - the heme protein is supplemented with the iron; or

wherein the heme protein is supplemented with the vitamin B12 and the iron.

80. A kit for up-regulating expression of protective stress proteins in an organ, the kit comprising a therapeutically effective amount of a heme protein, vitamin B12, iron, or a combination thereof, wherein administration of the therapeutically effective amount of the heme protein, the vitamin B12, the iron, or the combination thereof to the organ up-regulates expression of protective stress proteins in the organ without causing injury to the organ.
81. A kit of claim 80, wherein the kit includes the therapeutically effective amount of the heme protein.
82. A kit of claim 80, wherein the kit includes the therapeutically effective amount of the vitamin B12.
83. A kit of claim 80, wherein the kit includes the therapeutically effective amount of the iron.
84. A kit of claim 80, wherein the kit includes the therapeutically effective amount of the vitamin B12 and the iron.
85. A kit of claim 80, further comprising administration instructions.
86. A kit of claim 80, wherein absence of organ injury caused by the administration is confirmed by comparison to a reference level.
87. A kit of claim 86, wherein the reference level is provided within the kit.
88. A kit of claim 80, wherein the up-regulation of protective stress proteins protects the organ from an injury.
89. A kit of claim 88, wherein protection is evidenced by comparison to a reference level.
90. A kit of claim 89, wherein the reference level is provided within the kit.
91. A kit of claim 80, wherein the organ is protected from an injury based on an insult.
92. A kit of claim 91, wherein the insult is scheduled.
93. A kit of claim 92, wherein the administration occurs at least 8 hours before the scheduled insult.
94. A kit of claim 92, wherein the scheduled insult is surgery, chemotherapy, or radiocontrast toxicity.
95. A kit of claim 94, wherein the surgery is an organ transplant surgery.
96. A kit of claim 95, wherein the insult is sepsis.
97. A kit of claim 80, wherein the organ is a transplanted organ.
98. A kit of claim 80, wherein the organ is a heart, kidney, liver, or lung.
99. A kit of claim 98, wherein the organ is a heart and protection is evidenced by improvement of cardiac function, or reduction in cardiac enzyme release as compared to a reference level.
100. A kit of claim 99, wherein the cardiac enzyme is troponin.

101. A kit of claim 98, wherein the organ is a kidney and protection is evidenced by prevention or reduction in BUN or serum creatinine increases as compared to a reference level.
102. A kit of claim 98, wherein the organ is a liver and protection is evidenced by prevention or reduction in liver enzyme increases as compared to a reference level.
103. A kit of claim 98, wherein the organ is a lung and protection is evidenced by reduction in blood gas deterioration, reduction in need for supplemental oxygen, or reduced ventilator requirements as compared to a reference level.
104. A kit of claim 81, wherein the heme protein is formulated within a composition.
105. A kit of claim 81, wherein the heme protein is a heme protein variant, a heme protein d-substituted analog, a heme protein modification, or a combination thereof.
106. A kit of claim 81, wherein the heme protein is a modified heme protein.
107. A kit of claim 106, wherein the modified heme protein is a nitrated heme protein or a PEGylated heme protein.
108. A kit of claim 81, wherein the heme protein is myoglobin.
109. A kit of claim 81, wherein the heme protein is a myoglobin variant or a myoglobin modification.
110. A kit of claim 109, wherein the myoglobin modification is a nitrated myoglobin or a PEGylated myoglobin.
111. A kit of claim 81, wherein the protective stress proteins are selected from heme oxygenase, haptoglobin, hemopexin, hepcidin, alpha-1 antitrypsin, interleukin-10, heat-shock proteins, neutrophil gelatinase-associated lipocalin, and HMG CoA reductase.
112. A kit of claim 81, further comprising a heme protein degradation inhibitor.
113. A kit of claim 112, wherein the heme protein degradation inhibitor is formulated within a composition.
114. A kit of claim 112, wherein the heme protein degradation inhibitor and the heme protein are formulated within the same composition.
115. A kit of claim 112, wherein the heme protein degradation inhibitor is a nitrated heme protein degradation inhibitor.
116. A kit of claim 112, wherein the heme protein degradation inhibitor is a heme oxygenase inhibitor.
117. A kit of claim 116, wherein the heme oxygenase inhibitor is a protoporphyrin, hemin, or hematin.
118. A kit of claim 116, wherein the heme oxygenase inhibitor is a metal protoporphyrin.
119. A kit of claim 118, wherein the metal protoporphyrin is Sn-protoporphyrin.

120. A kit of claim 81, wherein:
 - the heme protein is supplemented with the vitamin B12;
 - the heme protein is supplemented with the iron; or
 - wherein the heme protein is supplemented with the vitamin B12 and the iron.
121. A composition comprising a therapeutically effective amount of myoglobin, a myoglobin variant, a myoglobin d-substituted analog, a myoglobin modification, vitamin B12, iron or a combination thereof.
122. A composition of claim 121, wherein the myoglobin is a myoglobin modification.
123. A composition of claim 122, wherein the myoglobin modification is a nitrated myoglobin or a PEGylated myoglobin.
124. A composition of claim 121, wherein the myoglobin is a myoglobin variant.
125. A composition of claim 121, comprising the myoglobin and further comprising a heme protein degradation inhibitor.
126. A composition of claim 125, wherein the heme protein degradation inhibitor is a nitrated heme protein degradation inhibitor.
127. A composition of claim 125, wherein the heme protein degradation inhibitor is a heme oxygenase inhibitor.
128. A composition of claim 127, wherein the heme oxygenase inhibitor is a protoporphyrin, hemin, or hematin.
129. A composition of claim 127, wherein the heme oxygenase inhibitor is a metal protoporphyrin.
130. A composition of claim 129, wherein the metal protoporphyrin is Sn-protoporphyrin.
131. A composition comprising a therapeutically effective amount of a heme protein and a heme protein degradation inhibitor.
132. A composition of claim 131, wherein the heme protein is a modified heme protein.
133. A composition of claim 132, wherein the modified heme protein is a nitrated heme protein or a PEGylated heme protein.
134. A composition of claim 131, wherein the heme protein is myoglobin.
135. A composition of claim 131, wherein the heme protein is a myoglobin variant or a myoglobin modification.
136. A composition of claim 135, wherein the myoglobin modification is a nitrated myoglobin or a PEGylated myoglobin.
137. A composition of claim 131, wherein the heme protein degradation inhibitor is a heme oxygenase inhibitor.

138. A composition of claim 137, wherein the heme oxygenase inhibitor is a protoporphyrin, hemin, or hematin.
139. A composition of claim 137, wherein the heme oxygenase inhibitor is a metal protoporphyrin.
140. A composition of claim 139, wherein the metal protoporphyrin is Sn-protoporphyrin.
141. A composition of claim 131, wherein the heme protein degradation inhibitor is a nitrited heme protein degradation inhibitor.
142. A method of protecting an organ from injury comprising administering to the organ a therapeutically effective amount of a composition comprising a heme protein, vitamin B12, iron, or a combination thereof, before the injury to the organ occurs, wherein the administering protects the organ from the injury without causing injury to the organ.
143. A method of claim 142, wherein the composition comprises the heme protein.
144. A method of claim 142, wherein the composition comprises the vitamin B12
145. A method of claim 142, wherein the composition comprises the iron.
146. A method of claim 142, wherein the composition comprises the combination of iron and vitamin B12.
147. A method of claim 142, wherein absence of organ injury caused by the administration is confirmed by comparison to a reference level.
148. A method of claim 142, wherein protection is evidenced by comparison to a reference level.
149. A method of claim 142, wherein the injury is an injury based on an insult.
150. A method of claim 149, wherein the insult is scheduled.
151. A method of claim 150, wherein the administration occurs at least 8 hours before the scheduled insult.
152. A method of claim 150, wherein the scheduled insult is surgery, chemotherapy, or radiocontrast toxicity.
153. A method of claim 152, wherein the surgery is an organ transplant surgery.
154. A method of claim 149, wherein the insult is sepsis.
155. A method of claim 142, wherein the organ is a transplanted organ.
156. A method of claim 142, wherein the organ is a heart, kidney, liver, or lung.
157. A method of claim 142, wherein the organ is a heart and protection is evidenced by improvement of cardiac function, or reduction in cardiac enzyme release as compared to a reference level.
158. A method of claim 157, wherein the cardiac enzyme is troponin.

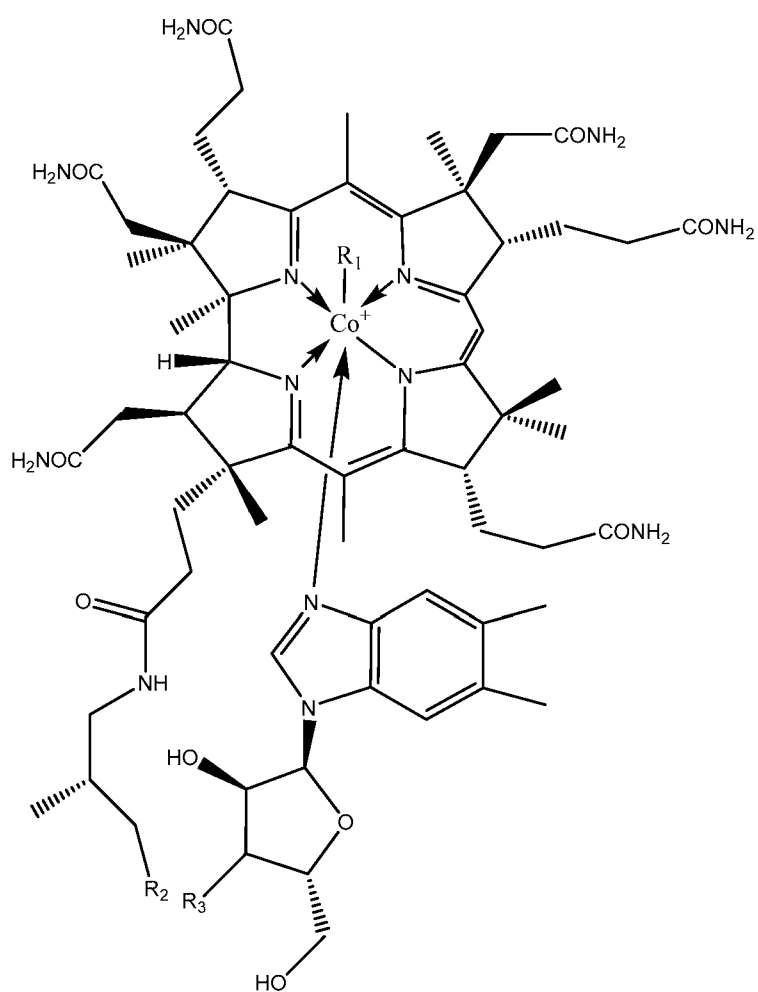
159. A method of claim 142, wherein the organ is a kidney and protection is evidenced by prevention or reduction in BUN or serum creatinine increases as compared to a reference level.
160. A method of claim 142, wherein the organ is a liver and protection is evidenced by prevention or reduction in liver enzyme increases as compared to a reference level.
161. A method of claim 142, wherein the organ is a lung and protection is evidenced by reduction in blood gas deterioration, reduction in need for supplemental oxygen, or reduced ventilator requirements as compared to a reference level.
162. A method of claim 143, wherein the composition comprises a modified heme protein.
163. A method of claim 162, wherein the modified heme protein is a nitrated heme protein or a PEGylated heme protein.
164. A method of claim 143, wherein the heme protein is myoglobin.
165. A method of claim 143, wherein the heme protein is a myoglobin variant or a myoglobin modification.
166. A method of claim 165, wherein the myoglobin modification is a nitrated myoglobin or a PEGylated myoglobin.
167. A method of claim 143, wherein the composition further comprises a heme protein degradation inhibitor.
168. A method of claim 167, wherein the heme protein degradation inhibitor is a nitrated heme protein degradation inhibitor.
169. A method of claim 143, further comprising administering to the organ a second composition comprising a heme protein degradation inhibitor.
170. A method of claim 167, wherein the heme protein degradation inhibitor is a heme oxygenase inhibitor.
171. A method of claim 170, wherein the heme oxygenase inhibitor is a protoporphyrin, hemin, or hematin.
172. A method of claim 170, wherein the heme oxygenase inhibitor is a metal protoporphyrin.
173. A method of claim 172, wherein the metal protoporphyrin is Sn-protoporphyrin.
174. A method of claim 143, wherein:
 - the heme protein is supplemented with the vitamin B12;
 - the heme protein is supplemented with the iron; or
 - wherein the heme protein is supplemented with the vitamin B12 and the iron.
175. A method of generating acquired cytoresistance in a organ comprising administering to the organ a therapeutically effective amount of a composition comprising a heme protein,

- vitamin B12, iron, or a combination thereof, wherein the administering generates acquired cytoresistance in the organ without causing injury to the organ.
176. A method of claim 175, wherein the composition comprises the heme protein.
177. A method of claim 175, wherein the composition comprises the vitamin B12.
178. A method of claim 175, wherein the composition comprises the iron.
179. A method of claim 175, wherein the composition comprises the vitamin B12 and the iron.
180. A method of claim 175, wherein absence of organ injury caused by the administration is confirmed by comparison to a reference level.
181. A method of claim 175, wherein the acquired cytoresistance protects the organ from injury.
182. A method of claim 181, wherein the protection is evidenced by comparison to a reference level.
183. A method of claim 175, wherein the injury is an injury based on an insult.
184. A method of claim 183, wherein the insult is scheduled.
185. A method of claim 184, wherein the administration occurs at least 8 hours before the scheduled insult.
186. A method of claim 184, wherein the scheduled insult is surgery, chemotherapy, or radiocontrast toxicity.
187. A method of claim 186, wherein the surgery is an organ transplant surgery.
188. A method of claim 183, wherein the insult is sepsis.
189. A method of claim 175, wherein the organ is a transplanted organ.
190. A method of claim 175, wherein the organ is a heart, kidney, liver, or lung.
191. A method of claim 190, wherein the organ is a heart and protection is evidenced by improvement of cardiac function, or reduction in cardiac enzyme release as compared to a reference level.
192. A method of claim 191, wherein the cardiac enzyme is troponin.
193. A method of claim 190, wherein the organ is a kidney and protection is evidenced by prevention or reduction in BUN or serum creatinine increases as compared to a reference level.
194. A method of claim 190, wherein the organ is a liver and protection is evidenced by prevention or reduction in liver enzyme increases as compared to a reference level.
195. A method of claim 190, wherein the organ is a lung and protection is evidenced by reduction in blood gas deterioration, reduction in need for supplemental oxygen, or reduced ventilator requirements as compared to a reference level.
196. A method of claim 176, wherein the composition comprises a modified heme protein.

197. A method of claim 196, wherein the modified heme protein is a nitrated heme protein or a PEGylated heme protein.
198. A method of claim 176, wherein the heme protein is myoglobin.
199. A method of claim 176, wherein the heme protein is a myoglobin variant or a myoglobin modification.
200. A method of claim 199, wherein the modified myoglobin is a nitrated myoglobin or a PEGylated myoglobin
201. A method of claim 176, wherein the composition further comprises a heme protein degradation inhibitor.
202. A method of claim 201, wherein the heme protein degradation inhibitor is a nitrated heme protein degradation inhibitor.
203. A method of claim 176, further comprising administering to the organ a second composition comprising a heme protein degradation inhibitor.
204. A method of claim 201, wherein the heme protein degradation inhibitor is a heme oxygenase inhibitor.
205. A method of claim 201, wherein the heme oxygenase inhibitor is a protoporphyrin, hemin, or hematin.
206. A method of claim 204, wherein the heme oxygenase inhibitor is a metal protoporphyrin.
207. A method of claim 206, wherein the metal protoporphyrin is Sn-protoporphyrin.
208. A method of claim 176, wherein:
 - the heme protein is supplemented with the vitamin B12;
 - the heme protein is supplemented with the iron; or
 - wherein the heme protein is supplemented with the vitamin B12 and the iron.
209. A method of up-regulating expression of protective stress proteins in an organ comprising administering to the organ a therapeutically effective amount of a composition comprising a heme protein, vitamin B12, iron, or a combination thereof, wherein the administering up-regulates expression of protective stress proteins in the organ without causing injury to the organ.
210. A method of claim 209, wherein the composition comprises the heme protein.
211. A method of claim 209, wherein the composition comprises the vitamin B12.
212. A method of claim 209, wherein the composition comprises the iron.
213. A method of claim 209, wherein the composition comprises the combination of the vitamin B12 and the iron.

214. A method of claim 209, wherein absence of organ injury caused by the administration is confirmed by comparison to a reference level.
215. A method of claim 209, wherein the up-regulated expression of protective stress proteins protects the organ from injury.
216. A method of claim 215, wherein protection is evidenced by comparison to a reference level.
217. A method of claim 209, wherein the injury is an injury based on an insult.
218. A method of claim 217, wherein the insult is scheduled.
219. A method of claim 218, wherein the administration occurs at least 8 hours before the scheduled insult.
220. A method of claim 218, wherein the scheduled insult is surgery, chemotherapy, or radiocontrast toxicity.
221. A method of claim 220, wherein the surgery is an organ transplant surgery.
222. A method of claim 217, wherein the insult is sepsis.
223. A method of claim 209, wherein the organ is a transplanted organ.
224. A method of claim 209, wherein the organ is a heart, kidney, liver, or lung.
225. A method of claim 224 wherein the organ is a heart and protection is evidenced by improvement of cardiac function, or reduction in cardiac enzyme release as compared to a reference level.
226. A method of claim 225, wherein the cardiac enzyme is troponin.
227. A method of claim 224, wherein the organ is a kidney and protection evidenced by prevention or reduction in BUN or serum creatinine increases as compared to a reference level.
228. A method of claim 224, wherein the organ is a liver and protection evidenced by prevention or reduction in liver enzyme increases as compared to a reference level.
229. A method of claim 224, wherein the organ is a lung and protection is evidenced by reduction in blood gas deterioration, reduction in need for supplemental oxygen, or reduced ventilator requirements as compared to a reference level.
230. A method of claim 210, wherein the protective stress proteins are selected from heme oxygenase, haptoglobin, hemopexin, hepcidin, alpha-1 antitrypsin, interleukin-10, heat-shock proteins, neutrophil gelatinase-associated lipocalin, or HMG CoA reductase.
231. A method of claim 210, wherein the composition comprises a modified heme protein.
232. A method of claim 231, wherein the modified heme protein is a nitrated heme protein or a PEGylated heme protein.
233. A method of claim 210, wherein the heme protein is myoglobin.

234. A method of claim 198, wherein the heme protein is a myoglobin variant or a myoglobin modification.
235. A method of claim 232, wherein the modified myoglobin is a nitrated myoglobin or a PEGylated myoglobin
236. A method of claim 210, wherein the composition further comprises a heme protein degradation inhibitor.
237. A method of claim 236, wherein the heme protein degradation inhibitor is a nitrated heme protein degradation inhibitor.
238. A method of claim 210, further comprising administering to the organ a second composition comprising a heme protein degradation inhibitor.
239. A method of claim 236, wherein the heme protein degradation inhibitor is a heme oxygenase inhibitor.
240. A method of claim 239, wherein the heme oxygenase inhibitor is a protoporphyrin, hemin, or hematin.
241. A method of claim 239, wherein the heme oxygenase inhibitor is a metal protoporphyrin.
242. A method of claim 241, wherein the metal protoporphyrin is Sn-protoporphyrin.
243. A method of claim 210, wherein:
the heme protein is supplemented with the vitamin B12;
the heme protein is supplemented with the iron; or
wherein the heme protein is supplemented with the vitamin B12 and the iron.
244. A composition comprising a therapeutically effective amount of:



where R₁ is 5'-deoxyadenosyl, CH₃, OH, or CN; R₂ is OH or H; and R₃ is OH or H.