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(72) Inventeurs/Inventors:
KUMAR, SANTHOSH V. R., US;
ANDERS, HANS-JOACHIM, US

(73) Propriétaire/Owner:
IMMUNOMEDICS, INC., US

(74) Agent: SMART & BIGGAR LP

(54) Titre : THERAPIE PAR ANTI-HISTONE POUR NECROSE VASCULAIRE DANS LA GLOMERULONEPHRITE SEVERE

(54) Title: ANTI-HISTONE THERAPY FOR VASCULAR NECROSIS IN SEVERE GLOMERULONEPHRITIS

(57) Abrégé/Abstract:
Severe glomerulonephritis involves cell necrosis as well as NETosis, programmed neutrophil death leading to expulsion of nuclear chromatin and neutrophil extracellular traps (NETs). Histones released by neutrophils undergoing NETosis killed glomerular endothelial cells, podocytes, and parietal epithelial cells. This was prevented by histone-neutralizing agents anti-histone IgG, activated protein C and heparin. Histone toxicity on glomeruli was TLR2/4-dependent. Anti-GBM glomerulonephritis involved NET formation and vascular necrosis. Pre-emptive anti-histone IgG administration significantly reduced all aspects of glomerulonephritis, including vascular necrosis, podocyte loss, albuminuria, cytokine induction, recruitment and activation of glomerular leukocytes and glomerular crescent formation. Subjects with established glomerulonephritis treated with anti-histone IgG, recombinant activated protein C, or heparin all abrogated severe glomerulonephritis suggesting that histone-mediated glomerular pathology is a subsequent, not initial event in necrotizing glomerulonephritis. Neutralizing extracellular histones is therapeutic in severe experimental glomerulonephritis.

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(71) Applicant: **IMMUNOMEDICS, INC.** [US/US]; 300 American Road, Morris Plains, New Jersey 07950 (US).

(72) Inventors: **KUMAR, Santhosh V. R.**; 300 American Road, Morris Plains, New Jersey 07950 (US). **ANDERS, Hans-Joachim**; 300 American Road, Morris Plains, New Jersey 07950 (US).

(74) Agent: **NAKASHIMA, Richard, A.**; 300 American Road, Morris Plains, New Jersey 07950 (US).

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ANTI-HISTONE THERAPY FOR VASCULAR NECROSIS IN SEVERE GLOMERULONEPHRITIS

Inventors: **Santhosh V. R. Kumar, Hans-Joachim Anders**

RELATED APPLICATIONS

[01] This application claims the benefit under 35 U.S.C. 119(e) of provisional U.S. Patent Application Serial No. 62/016,277, filed June 24, 2014.

[02]

FIELD OF THE INVENTION

[03] The invention relates to compositions and methods of use of histone-neutralizing agents, such as anti-histone IgG, activated protein C, or heparin, for treatment of vascular necrosis in severe glomerulonephritis. In certain preferred embodiments, the histone-neutralizing agent is an anti-histone antibody or antigen-binding fragment thereof, such as the BWA-3 anti-H4 antibody. In other embodiments, the anti-histone antibodies bind to human histones H2B, H3 or H4. More particular embodiments may concern chimeric or more preferably humanized forms of anti-histone antibodies. However, any other known histone-neutralizing agent may be utilized for treating vascular necrosis in severe glomerulonephritis.

BACKGROUND

[04] Rapidly progressive glomerulonephritis (RPGN) is a kidney syndrome characterized by rapid loss of renal function. If untreated RPGN can result in acute renal failure and death within months. In about 50% of cases, RPGN is associated with an underlying disease, such as Goodpasture syndrome, systemic lupus erythematosus, or granulomatosis with polyangitis; the remaining cases are idiopathic. RPGN encompasses a heterogeneous group of disorders resulting in severe glomerular inflammation and injury. Clinically, RPGN is characterized by a rapid loss of glomerular filtration rate, haematuria, and proteinuria caused by characteristic glomerular lesions such as capillary necrosis and hyperplasia of the parietal epithelial cells (PEC) along Bowman`s capsule forming crescents.

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[05] The pathogenesis of RPGN involves autoantibodies, immune complex-mediated activation of complement, the local production of cytokines and chemokines and glomerular leukocyte recruitment (Couser, 2012, *J Am Soc Nephrol* 23:381). RPGN is more common in anti-neutrophil cytoplasmic antibody (ANCA)-associated GN or anti-glomerular basement membrane (GBM) disease than in other forms of GN (Berden *et al.*, 2010, *J Am Soc Nephrol* 21:1628; Jennette et al., 2006, *J Am Soc Nephrol* 17:1235). The hallmark of severe GN is glomerular capillary necrosis leading to hematuria and plasma leakage (Bonsib, 1985, *Am J Pathol* 119:357). PEC exposure to plasma is sufficient to trigger crescent formation (Ryu *et al.*, 2012, *J Pathol* 228:382) but inflammation and PEC injury serve as additional stimuli (Sicking *et al.*, 2012, *J Am Soc Nephrol* 23:629). The question of what causes vascular necrosis inside the glomerulus has not previously been answered.

[06] Severe glomerulonephritis involves cell necrosis as well as NETosis, a programmed neutrophil death leading to expulsion of nuclear chromatin leading to neutrophil extracellular traps (NETs). ETosis is a programmed form of cell death of mostly neutrophils (referred to as NETosis) and other granulocytes (Brinkmann *et al.*, 2004, *Science* 303:1532). NETosis causes an explosion-like directed expulsion of chromatin generating a meshwork called neutrophil extracellular traps (NETs), which immobilize and kill bacteria during infections (Brinkmann *et al.*, 2004, *Science* 303:1532). Cytokine-induced NETosis also drives sterile injury including necrotizing GN (Kessenbrock *et al.*, 2009, *Nat Med* 15:623; Kambas *et al.*, 2013, *Ann Rheum Dis* 73:1854; Nakazawa et al., 2012, *Front Immunol* 3:333; Tsuboi *et al.*, 2002, *J Immunol* 169:2026). Many cytosolic or chromatin-related components could account for the toxic and pro-inflammatory effect of NETs, such as proteolytic enzymes or intracellular molecules with immunostimulatory effects, referred to as danger-associated molecular patterns (DAMPs) (Rock et al., 2010, *Annual Review of Immunology* 28:321).

[07] Histones are nuclear proteins that wind up the double-stranded DNA to form chromatin. Dynamic modifications of histone residues regulate gene transcription by determining the accessibility of transcription factors to their DNA binding sites (Helin & Dhanak, 2013, *Nature* 502:480). When cell necrosis releases histones into the extracellular space they display significant cytotoxic effects (Hirsch, 1958, *J Exp Med* 108:925; Xu *et al.*, 2009, *Nat Med* 15:1318; Chaput & Zychlinsky, 2009, *Nat Med* 15:1245; Allam et al., 2014, *J Mol Med* 92:465). Histones contribute to fatal outcomes in murine endotoxinemia caused by microvascular injury and activation of coagulation (Xu *et al.*, 2009, *Nat Med* 15:1318; Abrams *et al.*, 2013, *Am J Respir Crit Care Med* 187:160; Saffarzadeh *et al.*, 2012, *PLoS One* 7:e32366; Semeraro *et al.*, 2011, *Blood* 118:1952). We previously showed that dying renal cells release extracellular histones that promote septic and post-ischemic acute kidney injury (Allam *et al.*, 2012, *J Am Soc Nephrol* 23:1375). We further demonstrated that histones act as DAMPs by activating Toll-like receptor (TLR)-2 and -4 as well as NLRP3 (Allam *et al.*, 2012, *J Am Soc Nephrol* 23:1375; Allam et al., 2013, *Eur J Immunol* 43:3336), which was confirmed by other groups (Semeraro *et al.*, 2011, *Blood* 118:1952; Huang *et al.*, 2013, *J Immunol* 191:2665; Xu et al., 2011, *J Immunol* 187:2626). TLR2/-4-mediated pathology is an essential mechanism of crescentic GN (Brown et al., 2006, *J Immunol* 177:1925; Brown *et al.*, 2007, *J Am Soc Nephrol* 18:1732).

[08] A need exists for improved methods and compositions for treatment of vascular necrosis in severe glomerulonephritis, preferably using histone-neutralizing agents such as anti-histone antibodies or fragments thereof.

SUMMARY

[09] The present invention concerns compositions and methods of anti-histone therapy for vascular necrosis in severe glomerulonephritis. Preferably the anti-histone therapy may involve use of agents such as activated protein C, heparin, or anti-histone antibodies, such as antibodies against histone H2B, H3 or H4. In more preferred embodiments, the anti-histone antibody may be a BWA-3 anti-H4 antibody (see, e.g., U.S. Patent Application Serial No. 14/620,315).

[010] Preferably, the anti-histone antibodies or fragments thereof may be chimeric, humanized or human. The antibody can be of various isotypes, preferably human IgG1, IgG2, IgG3 or IgG4, more preferably comprising human IgG1 hinge and constant region sequences. Most preferably, the antibody or fragment thereof may be designed or selected to comprise human constant region sequences that belong to specific allotypes, which may result in reduced immunogenicity when the immunoconjugate is administered to a human subject. Preferred allotypes for administration include a non-G1m1 allotype (nG1m1), such as G1m3, G1m3,1, G1m3,2 or G1m3,1,2. More preferably, the allotype is selected from the group consisting of the nG1m1, G1m3, nG1m1,2 and Km3 allotypes. Exemplary humanized anti-histone antibodies are disclosed in U.S. Patent Application Serial No. 14/620,315.

[011] In certain preferred embodiments, a combination of anti-histone antibodies may be used. Antibodies against human histones H1, H2A, H2B, H3 or H4 may be used in any combination. Other non-antibody therapeutic agents targeted against either histones or downstream effectors of a histone-mediated pathway may also be utilized in combination

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with anti-histone antibodies or fragments thereof, administered either before, simultaneously with, or following administration of one or more anti-histone antibodies or fragments thereof. Various therapeutic agents of use in treating histone-associated diseases are known in the art, such as activated protein C (APC), thrombomodulin, a peptide fragment of histone H1, H2A, H2B, H3 or H4, granzyme A, granzyme B, plasmin, Factor 7-activating protease, heparin, and any such known agent may be utilized in combination with anti-histone antibodies or antibody fragments. A human histone H4 peptide may comprise residues 50-67 or 40-78 of human H4 (see, e.g., U.S. Publ. No. 20090117099). Depending on the underlying etiology, the anti-histone agents may also be utilized in combination with one or more standard treatments for glomerulonephritis and/or kidney failure, such as corticosteroids, immune-suppressing drugs or plasmapheresis.

[0011a] The present invention as claimed relates to:

- use of an anti-histone agent for treating rapidly-progressive glomerulonephritis (RPGN) in a subject, wherein the agent is selected from the group consisting of an anti-histone antibody or antigen-binding fragment thereof, activated protein C (APC), and heparin;
-use of an anti-histone agent for treating anti-neutrophil cytoplasmic antibody (ANCA) associated glomerulonephritis in a subject, wherein the agent is selected from the group consisting of an anti-histone antibody or antigen-binding fragment thereof, activated protein C (APC), and heparin; and
- use of an anti-histone agent for treating vascular necrosis in severe glomerulonephritis in a subject, wherein the agent is selected from the group consisting of an anti-histone antibody or antigen-binding fragment thereof, activated protein C (APC), and heparin.

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BRIEF DESCRIPTION OF THE DRAWINGS

[012] The following drawings are provided to illustrate preferred embodiments of the invention. However, the claimed subject matter is in no way limited by the illustrative embodiments disclosed in the drawings.

[013] FIG. 1A. TLR2 and TLR4 expression in human crescentic glomerulonephritis. Toll-like receptor (TLR)-2 and -4 immunostaining was performed on healthy kidney tissue. Original magnification x400.

[014] FIG. 1B. TLR2 and TLR4 expression in human crescentic glomerulonephritis. Toll-like receptor (TLR)-2 and -4 immunostaining was performed on kidney biopsies of a patient with newly diagnosed ANCA vasculitis and clinical signs of glomerulonephritis. **FIG. 1B** shows representative glomeruli unaffected by loop necrosis or crescent formation. Original magnification x400.

[015] FIG. 1C. TLR2 and TLR4 expression in human crescentic glomerulonephritis. Toll-like receptor (TLR)-2 and -4 immunostaining was performed on kidney biopsies of a patient with newly diagnosed ANCA vasculitis and clinical signs of glomerulonephritis. **FIG. 1C** shows representative glomeruli affected by loop necrosis or crescent formation. Original magnification x400.

[016] FIG. 1D. TLR2 and TLR4 expression in human crescentic glomerulonephritis. Toll-like receptor (TLR)-2 and -4 immunostaining was performed on kidney biopsies of a patient with newly diagnosed ANCA vasculitis and clinical signs of glomerulonephritis. **FIG. 1D** shows representative glomeruli affected by loop necrosis or crescent formation. Original magnification x400.

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[017] **FIG. 2A. NETosis-related extracellular histones kill glomerular cells.** Murine glomerular endothelial cells (GEnC), podocytes, and parietal epithelial cells (PECs) were incubated with increasing doses of histones together with either control IgG or anti-histone IgG. Cell viability was determined after 24 hours by MTT assay. Data represent mean OD ± SEM of three experiments measured at a wavelength of 570 nm. * $p<0.05$, ** $p<0.01$, ***$p<0.001$ versus control IgG.

[018] **FIG. 2B. NETosis-related extracellular histones kill glomerular cells.** Immunostaining of naïve (left) and TNF-α-activated neutrophils (right) in culture. Staining for elastase (red) and histones (green) illustrates how TNF-α triggers NETosis leading to neutrophil extracellular trap (NET) formation, i.e. expelling cytoplasmic and nuclear contents in the extracellular space.

[019] **FIG. 2C. NETosis-related extracellular histones kill glomerular cells.** Scanning electron microscopy was performed on monolayers of glomerular endothelial cells, which appear flat and evenly laid out on scanning electron microscopy (left). However, neutrophil ETosis leads to severe injury and death of endothelial cells appearing as bulging white balls with corrugated surfaces adjacent to activated NETs (middle). This effect was almost entirely prevented by anti-histone IgG demonstrated by significant reversal of the structural integrity of the endothelial cell monolayer (right).

[020] **FIG. 2D. NETosis-related extracellular histones kill glomerular cells.** Immunostaining for elastase, histone, and DAPI was performed on monolayers of glomerular endothelial cells. Conditions were as stated at the bottom of the Figure.

[021] **FIG. 2E. NETosis-related extracellular histones kill glomerular cells.** MTT assay analysis of endothelial cell viability allowed to quantify this effect, which was identical for TNF-α and PMA, two known inducers of NETosis. Data represent mean OD ± SEM of three experiments measured at a wavelength of 570 nm. * $p<0.05$, ** $p<0.01$, ***$p<0.001$ versus control IgG.

[022] **FIG. 3A. Extracellular histones injure glomeruli in a TLR2/4-dependent manner.** Glomeruli were isolated from wild type and Tlr2/4-deficient mice and incubated with histones (30 μg/ml). After 12 hours LDH release into the supernatant was measured as a marker of glomerular cell injury. Data represent mean OD ± SEM of three experiments measured at a wavelength of 492 nm. ** $p<0.01$, ***$p<0.001$ versus control.

[023] **FIG. 3B. Extracellular histones injure glomeruli in a TLR2/4-dependent manner.** For intra-arterial histone injection the abdominal aorta was prepared and a micro-cannula was

placed into the left renal artery to inject histones directly into the kidney. Images show hematoxylin-eosin staining of representative glomeruli of the different groups as indicated.

[024] **FIG. 3C. Extracellular histones injure glomeruli in a TLR2/4-dependent manner.** Fibrinogen immunostaining displayed three different staining patterns. **FIG. 3C** shows diffuse positivity of glomerular endothelial cells.

[025] **FIG. 3D. Extracellular histones injure glomeruli in a TLR2/4-dependent manner.** Fibrinogen immunostaining displayed three different staining patterns. **FIG. 3D** shows entire luminal positivity indicating microthrombus formation.

[026] **FIG. 3E. Extracellular histones injure glomeruli in a TLR2/4-dependent manner.** Fibrinogen immunostaining displayed three different staining patterns. **FIG. 3E** shows global positivity of glomerular loop indicating loop necrosis.

[027] **FIG. 3F. Extracellular histones injure glomeruli in a TLR2/4-dependent manner.** A quantitative analysis of these lesions revealed that histone injection massively increased luminal and global fibrinogen positivity, which was partially prevented in Tlr2/4-deficient mice. ** $p<0.01$, ***$p<0.001$ versus saline, # $p<0.05$, ## $p<0.01$ versus histone group.

[028] **FIG. 4A. Neutralizing histones protects from severe glomerulonephritis.** Blood urea nitrogen (BUN) levels were determined 1 and 7 days after intravenous injection of GBM antiserum. Mice were either treated with control IgG or anti-histone IgG starting from the day before antiserum injection.

[029] **FIG. 4B. Neutralizing histones protects from severe glomerulonephritis.** Representative HE stainings of glomeruli are shown at an original magnification of 400x.

[030] **FIG. 4C. Neutralizing histones protects from severe glomerulonephritis.** Morphometrical analysis of segmental and global glomerular lesions (left) and of glomeruli with crescents (right) as described in methods.

[031] **FIG. 4D. Neutralizing histones protects from severe glomerulonephritis.** CD31 and MPO immumostaining representing NETs formation in the glomeruli close association with the endothelial cells, control IgG group shows focal loss of endothelial cell positivity compare to anti-histone IgG group. Data means ± SEM from five to six mice in each group. * $p<0.05$, ** $p<0.01$, *** $p<0.001$ versus control IgG.

[032] **FIG. 5A. Neutralizing histones protects the glomerular filtration barrier in glomerulonephritis.** Transmission electron microscopy of antiserum-induced GN revealed extensive glomerular injury with fibrinoid necrosis (upper left), endothelial cell swelling, luminal thrombosis, and intraluminal granulocytes (upper middle and right). Podocytes show foot process effacement (all upper images). Pre-emptive treatment with anti-histone IgG

decreased most of these abnormalities; particularly endothelial cell and podocyte ultrasturcture (lower images).

[033] **FIG. 5B. Neutralizing histones protects the glomerular filtration barrier in glomerulonephritis.** Immunostaining for WT-1 (red) and nephrin (green) was used to quantify podocytes.

[034] **FIG. 5C. Neutralizing histones protects the glomerular filtration barrier in glomerulonephritis.** Anti-histone IgG doubled the number of nephrin/WT-1+ podocytes at day 7 of antiserum-induced GN.

[035] **FIG. 5D. Neutralizing histones protects the glomerular filtration barrier in glomerulonephritis.** Urinary albumin/creatinine ratio was determined at day 1 and day 7 after antiserum injection. Data represent mean ± SEM from five to six mice of each group. * $p<0.05$, *** $p<0.001$ versus control IgG.

[036] **FIG. 6A. Leukocyte recruitment and activation in glomerulonephritis.** Glomerular neutrophil and macrophage infiltrates were quantified by immunostaining. Representative images are shown at an original magnification of 400x.

[037] **FIG. 6B. Leukocyte recruitment and activation in glomerulonephritis.** Leukocyte activation was quantified by flow cytometry of renal cell suspensions harvested 7 days after antiserum injection. Data represent mean ± SEM from five to six mice of each group.

[038] **FIG. 6C. Leukocyte recruitment and activation in glomerulonephritis.** Cultured dendritic cells were exposed to increasing doses of histones as indicated. After 24h flow cytometry was used to determine the percentage of cells that express the activation markers MHC II, CD40, CD80, and CD86. Data are means ± SEM from three independent experiments. * $p<0.05$, ** $p<0.01$, *** $p<0.001$ versus control IgG.

[039] **FIG. 7A. Histones activate TNF-α production.** Cultured J774 macrophages and bone marrow dendritic cells (BMDCs) respond to histone exposure by inducing the secretion of TNF-α, which is blocked by anti-histone IgG. Data are means ± SEM from three independent experiments. *** $p<0.001$ versus control IgG.

[040] **FIG. 7B. Histones activate TNF-α production.** TNF-α immunostaining on renal sections from both treatment groups taken at day 7 after antiserum injection. Representative images are shown at an original magnification of 400x.

[041] **FIG. 7C. Histones activate TNF-α production.** Real time RT-PCR for TNF-α mRNA on renal tissue at day 7 after antiserum injection. Data are means ± SEM from at least five to six mice in each group. * $p<0.05$ versus control IgG.

[042] **FIG. 7D. Histones activate TNF-α production.** Fibrinogen immunostaining on renal sections from both treatment groups taken at day 7 after antiserum injection. Representative images are shown at an original magnification of 400x.

[043] **FIG. 7E. Histones activate TNF-α production.** Real time RT-PCR for fibrinogen mRNA on renal tissue at day 7 after antiserum injection. Data are means ± SEM from at least five to six mice in each group. * $p<0.05$ versus control IgG.

[044] **FIG. 7F. Histones activate TNF-α production.** Immunostaining of renal sections of all groups for claudin-1 (red, marker for parietal epithelial cells/PECs and some tubular cells), WT-1 (green, marker for podocytes and activated PECs), and DAPI (blue, DNA marker) illustrates that in severe GN crescents consist of WT-1+ PECs, which is reversed with anti-histone IgG. Original magnification: x200.

[045] **FIG. 7G. Histones activate TNF-α production.** Mouse PEC viability (MTT assay) when cultured in the presence of different serum concentrations together with a low concentration (20μg/ml) of histones that without serum reduces PEC viability. Together with serum histones rather promote PEC growth.

[046] **FIG. 7H. Histones activate TNF-α production.** Mouse PEC viability (MTT assay) experiment showing that blocking anti-TLR2 and anti-TLR4 antibodies neutralize the histone effect on PEC growth. Data are mean OD ± SEM of three experiments measured at a wavelength of 570 nm. ** $p<0.01$, ***$p<0.001$ versus control IgG.

[047] **FIG. 7I. Histones activate TNF-α production.** RT-PCR analysis of PECs stimulated with histones and various neutralizing compounds (anti-histone IgG, heparin 50 μg/ml, activated protein C 500 nM, anti-TLR2 or -4 1ng/ml). Note that all these interventions block histone-induced CD44 and WT-1 mRNA expression, which serve as markers of PEC activation. Data are means ± SEM of three experiments. * $p<0.05$, ** $p<0.01$, ***$p<0.001$ versus histone group.

[048] **FIG. 8A. Delayed histone blockade still improves glomerulonephritis.** Glomeruli were isolated from wild type mice and incubated with histones in the presence or absence of anti-histone IgG, heparin or aPC as before. LDH release was measured in supernatants as a marker of glomerular cell injury. Data are mean OD ± SEM of three experiments. * $p<0.05$, ** $p<0.01$, ***$p<0.001$ versus control IgG or vehicle group histone group, respectively.

[049] **FIG. 8B. Delayed histone blockade still improves glomerulonephritis.** Further experiments used the model of antiserum-induced GN using anti-histone IgG, heparin or recombinant aPC initiated only after disease onset, i.e. 24h after antiserum injection, when the urinary albumin/creatinine ratio was around 80 μg/mg.

[050] **FIG. 8C. Delayed histone blockade still improves glomerulonephritis.** Data show plasma creatinine levels at day 7 and albuminuria also at day 2.

[051] **FIG. 8D. Delayed histone blockade still improves glomerulonephritis.** Podocytes were quantified as nephrin/WT-1+ cells on renal sections at day 7.

[052] **FIG. 8E. Delayed histone blockade still improves glomerulonephritis.** Glomerular lesions were quantified by morphometry from PAS sections taken at day 7. Glomerular podocyte numbers were assessed by WT-1/nephrin co-staining on glomerular cross sections. Data represent mean ± SEM from five to six mice of each group. * $p<0.05$, ** $p<0.01$, *** $p<0.001$ versus control IgG or vehicle, respectively.

[053] **FIG. 8F. Delayed histone blockade still improves glomerulonephritis.** Glomerular crescents were quantified by morphometry from PAS sections taken at day 7. Glomerular podocyte numbers were assessed by WT-1/nephrin co-staining on glomerular cross sections. Data represent mean ± SEM from five to six mice of each group. * $p<0.05$, ** $p<0.01$, *** $p<0.001$ versus control IgG or vehicle, respectively.

[054] **FIG. 8G. Delayed histone blockade still improves glomerulonephritis.** Tubular injury was quantified by morphometry from PAS sections taken at day 7. Glomerular podocyte numbers were assessed by WT-1/nephrin co-staining on glomerular cross sections. Data represent mean ± SEM from five to six mice of each group. * $p<0.05$, ** $p<0.01$, *** $p<0.001$ versus control IgG or vehicle, respectively.

[055] **FIG. 9A. Histones and endothelial cell microtubes in vitro**. Murine glomerular endothelial cells were seeded into a matrigel matrix for angiogenesis experiments as described in methods. Histones +/- anti-histone IgG were added during microtube formation to test histone toxicity on microtube forming. Quantitative assessment included the number of living cells and network formation. Data represent the mean of these endpoints ± SEM of three independent experiments at the indicated time points. * $p<0.05$, ** $p<0.01$, ***$p<0.001$ versus control IgG.

[056] **FIG. 9B. Histones and endothelial cell microtubes in vitro**. Murine glomerular endothelial cells were seeded into a matrigel matrix for angiogenesis experiments as described in methods. Histones +/- anti-histone IgG were added 8h after microtube formation to test histone toxicity on microtube destruction. Quantitative assessment included the number of living cells and network formation. Data represent the mean of these endpoints ± SEM of three independent experiments at the indicated time points. * $p<0.05$, ** $p<0.01$, ***$p<0.001$ versus control IgG.

[057] **FIG. 10. Anti-histone IgG and podocyte detachment in vitro.** Murine podocytes were exposed to histones or GBM antiserum with or without anti-histone IgG. Data show the mean percentage ± SEM of podocytes that detached from the culture dish within 24 hours. * p<0.05, ***p<0.001 versus control.

[058] **FIG. 11A. Cytokine induction in glomeruli ex vivo exposed to histones.** Glomeruli were isolated from wild type mice and *Tlr2-/4* double knockout mice and exposed to histones. 12 hours later the mRNA levels of TNF-α were determined by real-time RT-PCR. Data show the mRNA expression level corrected for the housekeeper 18srRNA ± SEM each done in triplicate. * p<0.05, **p<0.01, n.s. = not significant.

[059] **FIG. 11B. Cytokine induction in glomeruli ex vivo exposed to histones.** Glomeruli were isolated from wild type mice and *Tlr2-/4* double knockout mice and exposed to histones. 12 hours later the mRNA levels of IL-6 were determined by real-time RT-PCR. Data show the mRNA expression level corrected for the housekeeper 18srRNA ± SEM each done in triplicate. * p<0.05, **p<0.01, n.s. = not significant.

[060] **FIG. 11C. Cytokine induction in glomeruli ex vivo exposed to histones.** Glomeruli were isolated from wild type mice and *Tlr2-/4* double knockout mice and exposed to histones. IL-6 protein release was determined in cell culture supernatants. * p<0.05, **p<0.01, n.s. = not significant.

[061] **FIG. 12A. MIP2/CXCXL2 mRNA expression in glomerular endothelial cells (GEnC).** Seven days after sheep GBM antiserum injection *in vivo* only sheep IgG (left) deposits were found in glomeruli but no mouse IgG.

[062] **FIG. 12B. MIP2/CXCXL2 mRNA expression in glomerular endothelial cells (GEnC).** Exposure to glomerular basement membrane (GBM) antiserum induces the mRNA expression levels of MIP2/CXCL2. Data are means ± SEM from three independent experiments.

[063] **FIG. 13A. Heparin and activated protein C (aPC) block histone toxicity on glomerular endothelial cells.** Glomerular endothelial cells were exposed to increasing doses of histones with or without heparin as indicated. Data represent mean OD ± SEM of three MTT assay experiments measured at a wave length of 492 nm.

[064] **FIG. 13B. Heparin and activated protein C (aPC) block histone toxicity on glomerular endothelial cells.** Glomerular endothelial cells were exposed to increasing doses of histones with or without aPC as indicated. Data represent mean OD ± SEM of three MTT assay experiments measured at a wave length of 492 nm.

[065] **FIG. 14A. Therapeutic histone blockade and renal leukocytes.** Renal sections were obtained at day 7 of the experiment and stained for GR-1 (neutrophils). Data represent mean glomerular cell counts ± SEM of 5-6 mice in each group.

[066] **FIG. 14B. Therapeutic histone blockade and renal leukocytes.** Renal sections were obtained at day 7 of the experiment and stained for Mac2 (macrophages). Data represent mean glomerular cell counts ± SEM of 5-6 mice in each group.

[067] **FIG. 14C. Therapeutic histone blockade and renal leukocytes.** Renal sections were obtained at day 7 of the experiment. Flow cytometry data for various leukocyte subsets as indicated. * $p<0.05$, ** $p<0.01$, ***$p<0.001$ versus control IgG or vehicle, respectively.

[068] **FIG. 14D. Therapeutic histone blockade and renal leukocytes.** Renal sections were obtained at day 7 of the experiment. Flow cytometry data for various leukocyte subsets as indicated. * $p<0.05$, ** $p<0.01$, ***$p<0.001$ versus control IgG or vehicle, respectively.

DETAILED DESCRIPTION OF THE INVENTION

Definitions

[069] In the description that follows, a number of terms are used and the following definitions are provided to facilitate understanding of the claimed subject matter. Terms that are not expressly defined herein are used in accordance with their plain and ordinary meanings.

[070] Unless otherwise specified, "a" or "an" means "one or more".

[071] As used herein, the terms “and” and “or” may be used to mean either the conjunctive or disjunctive. That is, both terms should be understood as equivalent to “and/or” unless otherwise stated.

[072] A "therapeutic agent" is an atom, molecule, or compound that is useful in the treatment of a disease. Examples of therapeutic agents include antibodies, antibody fragments, peptides, drugs, toxins, enzymes, nucleases, hormones, immunomodulators, antisense oligonucleotides, small interfering RNA (siRNA), chelators, boron compounds, photoactive agents, dyes, and radioisotopes.

[073] A "diagnostic agent" is an atom, molecule, or compound that is useful in diagnosing a disease. Useful diagnostic agents include, but are not limited to, radioisotopes, dyes (such as with the biotin-streptavidin complex), contrast agents, fluorescent compounds or molecules, and enhancing agents (e.g., paramagnetic ions) for magnetic resonance imaging (MRI).

[074] An "antibody" as used herein refers to a full-length (i.e., naturally occurring or formed by normal immunoglobulin gene fragment recombinatorial processes) immunoglobulin

molecule *(e.g.,* an IgG antibody). An "antibody" includes monoclonal, polyclonal, bispecific, multispecific, murine, chimeric, humanized and human antibodies.

[075] A "naked antibody" is an antibody or antigen binding fragment thereof that is not attached to a therapeutic or diagnostic agent. The Fc portion of an intact naked antibody can provide effector functions, such as complement fixation and ADCC (see, *e.g.*, Markrides, *Pharmacol Rev* 50:59-87, 1998). Other mechanisms by which naked antibodies induce cell death may include apoptosis. (Vaswani and Hamilton, *Ann Allergy Asthma Immunol* 81: 105-119, 1998.)

[076] An "antibody fragment" is a portion of an intact antibody such as $F(ab')_2$, $F(ab)_2$, Fab', Fab, Fv, sFv, scFv, dAb and the like. Regardless of structure, an antibody fragment binds with the same antigen that is recognized by the full-length antibody. For example, antibody fragments include isolated fragments consisting of the variable regions, such as the "Fv" fragments consisting of the variable regions of the heavy and light chains or recombinant single chain polypeptide molecules in which light and heavy variable regions are connected by a peptide linker ("scFv proteins"). "Single-chain antibodies", often abbreviated as "scFv" consist of a polypeptide chain that comprises both a V_H and a V_L domain which interact to form an antigen- binding site. The V_H and V_L domains are usually linked by a peptide of 1 to 25 amino acid residues. Antibody fragments also include diabodies, triabodies and single domain antibodies (dAb). Fragments of antibodies that do not bind to the same antigen as the intact antibody, such as the Fc fragment, are not included within the scope of an "antibody fragment" as used herein.

[077] A "chimeric antibody" is a recombinant protein that contains the variable domains of both the heavy and light antibody chains, including the complementarity determining regions (CDRs) of an antibody derived from one species, preferably a rodent antibody, more preferably a murine antibody, while the constant domains of the antibody molecule are derived from those of a human antibody. For veterinary applications, the constant domains of the chimeric antibody may be derived from that of other species, such as a primate, cat or dog.

[078] A "humanized antibody" is a recombinant protein in which the CDRs from an antibody from one species; e.g., a murine antibody, are transferred from the heavy and light variable chains of the murine antibody into human heavy and light variable domains (framework regions). The constant domains of the antibody molecule are derived from those of a human antibody. In some cases, specific residues of the framework region of the humanized antibody, particularly those that are touching or close to the CDR sequences, may be modified, for example replaced with the corresponding residues from the original murine, rodent, subhuman primate, or other antibody.

[079] A "human antibody" is an antibody obtained, for example, from transgenic mice that have been "engineered" to produce human antibodies in response to antigenic challenge. In this technique, elements of the human heavy and light chain loci are introduced into strains of mice derived from embryonic stem cell lines that contain targeted disruptions of the endogenous heavy chain and light chain loci. The transgenic mice can synthesize human antibodies specific for various antigens, and the mice can be used to produce human antibody-secreting hybridomas. Methods for obtaining human antibodies from transgenic mice are described by Green *et al., Nature Genet. 7*:13 (1994), Lonberg *et al., Nature 368*:856 (1994), and Taylor *et al., Int. Immun. 6*:579 (1994). A fully human antibody also can be constructed by genetic or chromosomal transfection methods, as well as phage display technology, all of which are known in the art. See for example, McCafferty *et al., Nature* 348:552-553 (1990) for the production of human antibodies and fragments thereof *in vitro*, from immunoglobulin variable domain gene repertoires from unimmunized donors. In this technique, human antibody variable domain genes are cloned in-frame into either a major or minor coat protein gene of a filamentous bacteriophage, and displayed as functional antibody fragments on the surface of the phage particle. Because the filamentous particle contains a single-stranded DNA copy of the phage genome, selections based on the functional properties of the antibody also result in selection of the gene encoding the antibody exhibiting those properties. In this way, the phage mimics some of the properties of the B cell. Phage display can be performed in a variety of formats, for their review, see e.g. Johnson and Chiswell, *Current Opinion in Structural Biology* 3:5564-571 (1993). Human antibodies may also be generated by *in vitro* activated B cells. See U.S. Patent Nos. 5,567,610 and 5,229,275.

[080] An "immunoconjugate" is an antibody, antigen-binding antibody fragment, antibody complex or antibody fusion protein that is conjugated to a therapeutic agent. Conjugation may be covalent or non-covalent. Preferably, conjugation is covalent.

[081] As used herein, the term "antibody fusion protein" is a recombinantly-produced antigen-binding molecule in which one or more natural antibodies, single-chain antibodies or antibody fragments are linked to another moiety, such as a protein or peptide, a toxin, a cytokine, a hormone, etc. In certain preferred embodiments, the fusion protein may comprise two or more of the same or different antibodies, antibody fragments or single-chain

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antibodies fused together, which may bind to the same epitope, different epitopes on the same antigen, or different antigens.

[082] An "immunomodulator" is a therapeutic agent that when present, alters, suppresses or stimulates the body's immune system. Typically, an immunomodulator of use stimulates immune cells to proliferate or become activated in an immune response cascade, such as macrophages, dendritic cells, B-cells, and/or T-cells. However, in some cases an immunomodulator may suppress proliferation or activation of immune cells. An example of an immunomodulator as described herein is a cytokine, which is a soluble small protein of approximately 5-20 kDa that is released by one cell population (e.g., primed T-lymphocytes) on contact with specific antigens, and which acts as an intercellular mediator between cells. As the skilled artisan will understand, examples of cytokines include lymphokines, monokines, interleukins, and several related signaling molecules, such as tumor necrosis factor (TNF) and interferons. Chemokines are a subset of cytokines. Certain interleukins and interferons are examples of cytokines that stimulate T cell or other immune cell proliferation. Exemplary interferons include interferon-α, interferon-β, interferon-γ and interferon-λ.

[083] An anti-histone antibody or antibody fragment, or a composition described herein, is said to be administered in a "therapeutically effective amount" if the amount administered is physiologically significant. An agent is physiologically significant if its presence results in a detectable change in the physiology of a recipient subject. In particular embodiments, an antibody preparation is physiologically significant if its presence invokes an antitumor response or mitigates the signs and symptoms of an autoimmune disease state. A physiologically significant effect could also be the evocation of a humoral and/or cellular immune response in the recipient subject leading to growth inhibition or death of target cells.

Anti-Histone Antibodies

[084] Various anti-histone antibodies and/or antigen-binding fragments thereof may be of use. The murine BWA-3 (anti-H4), LG2-1 (anti-H3) and LG2-2 (anti-H2B) hybridomas were reported by Monestier et al. (1993, *Mol. Immunol* 30:1069-75). However, murine antibodies are generally not appropriate for human therapeutic use, due to the formation of human anti-mouse antibodies (HAMA) that can neutralize these anatibodies and thus make them less active.

[085] In preferred embodiments, a humanized or chimeric anti-histone H4 antibody is one that comprises the heavy chain complementarity-determining region (CDR) sequences CDR1 (DDYLH, SEQ ID NO:90), CDR2 (WIGWIDPENGDTEYASKFQG, SEQ ID NO:91) and

CDR3 (PLVHLRTFAY, SEQ ID NO:92) and the light chain CDR sequences CDR1 (RASESVDSYDNSLH, SEQ ID NO:93), CDR2 (LASNLES, SEQ ID NO:94) and CDR3 (QQNNEDPWT, SEQ ID NO:95). (See, e.g., U.S. Patent No. 8,987,421.)

[086] In other preferred embodiments, a humanized or chimeric anti-histoe H3 antibody is one that comprises the heavy chain CDR sequences CDR1 (SYWMH, SEQ ID NO:96), CDR2 (NIDPSDSETHYNQKFKD, SEQ ID NO:97) and CDR3 (EKITDDYNYFDY, SEQ ID NO:98) and the light chain CDR sequences CDR1 (RASESVDSYGNSFMH, SEQ ID NO:99), CDR2 (HASNLES, SEQ ID NO:100) and CDR3 (QQNNEDPLT, SEQ ID NO:101) (see, e.g., U.S. Patent No. 8,987,421).

[087] In still other preferred embodiments, a humanized or chimeric anti-histone H2B antibody is one that comprises the heavy chain CDR sequences CDR1 (SYVMY, SEQ ID NO:102), CDR2 (YINPYNDGTKYNEKFKG, SEQ ID NO:103) and CDR3 (PGDGYPFDY, SEQ ID NO:104) and the light chain CDR sequences CDR1 (RSSQSIVHSNGNTYLE, SEQ ID NO:105), CDR2 (KVSNRFS, SEQ ID NO:106) and CDR3 (FQGSHVPYT, SEQ ID NO:107) (see, e.g., U.S. Patent No. 8,987,421).

General Techniques for Antibodies and Antibody Fragments

[088] Techniques for preparing monoclonal antibodies against virtually any target antigen are well known in the art. *See*, for example, Kohler and Milstein, *Nature 256*: 495 (1975), and Coligan *et al.* (eds.), CURRENT PROTOCOLS IN IMMUNOLOGY, VOL. 1, pages 2.5.1-2.6.7 (John Wiley & Sons 1991). The person of ordinary skill may readily produce antibodies against any known and characterized target antigen, using only routine experimentation. Known antigens that may be targeted include, but are not limited to, human histone H4 (e.g., NCBI Ref. No. NP_778224.1), human histone H3 (e.g., GenBank Ref. No. CAB02546.1) or human histone H2B (e.g., GenBank Ref. No. CAB02542.1)

[089] Briefly, monoclonal antibodies can be obtained by injecting mice with a composition comprising an antigen, removing the spleen to obtain B-lymphocytes, fusing the B-lymphocytes with myeloma cells to produce hybridomas, cloning the hybridomas, selecting positive clones which produce antibodies to the antigen, culturing the clones that produce antibodies to the antigen, and isolating the antibodies from the hybridoma cultures.

[090] MAbs can be isolated and purified from hybridoma cultures by a variety of well-established techniques. Such isolation techniques include affinity chromatography with Protein-A Sepharose, size-exclusion chromatography, and ion-exchange chromatography.

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See, for example, Coligan at pages 2.7.1-2.7.12 and pages 2.9.1-2.9.3. Also, see Baines *et al.*, "Purification of Immunoglobulin G (IgG)," in METHODS IN MOLECULAR BIOLOGY, VOL. 10, pages 79-104 (The Humana Press, Inc. 1992).

[091] After the initial raising of antibodies to the immunogen, the antibodies can be sequenced and subsequently prepared by recombinant techniques. Humanization and chimerization of murine antibodies and antibody fragments are well known to those skilled in the art. The use of antibody components derived from humanized, chimeric or human antibodies obviates potential problems associated with the immunogenicity of murine constant regions.

Chimeric Antibodies

[092] A chimeric antibody is a recombinant protein in which the variable regions of a human antibody have been replaced by the variable regions of, for example, a mouse antibody, including the complementarity-determining regions (CDRs) of the mouse antibody. Chimeric antibodies exhibit decreased immunogenicity and increased stability when administered to a subject. General techniques for cloning murine immunoglobulin variable domains are disclosed, for example, in Orlandi *et al., Proc. Nat'l Acad. Sci. USA 86*: 3833 (1989). Techniques for constructing chimeric antibodies are well known to those of skill in the art. As an example, Leung *et al., Hybridoma 13:*469 (1994), produced an LL2 chimera by combining DNA sequences encoding the V_κ and V_H domains of murine LL2, an anti-CD22 monoclonal antibody, with respective human κ and IgG_1 constant region domains.

Humanized Antibodies

[093] Techniques for producing humanized MAbs are well known in the art (see, e.g., Jones *et al., Nature 321*: 522 (1986), Riechmann *et al., Nature 332*: 323 (1988), Verhoeyen *et al., Science 239*: 1534 (1988), Carter *et al., Proc. Nat'l Acad. Sci. USA 89*: 4285 (1992), Sandhu, *Crit. Rev. Biotech. 12*: 437 (1992), and Singer *et al., J. Immun. 150*: 2844 (1993)). A chimeric or murine monoclonal antibody may be humanized by transferring the mouse CDRs from the heavy and light variable chains of the mouse immunoglobulin into the corresponding variable domains of a human antibody. The mouse framework regions (FR) in the chimeric monoclonal antibody are also replaced with human FR sequences. As simply transferring mouse CDRs into human FRs often results in a reduction or even loss of antibody affinity, additional modification might be required in order to restore the original affinity of the murine antibody. This can be accomplished by the replacement of one or more human residues in the FR regions with their murine counterparts to obtain an antibody that possesses good binding affinity to its epitope. See, for example, Tempest *et al.*, *Biotechnology* 9:266 (1991) and Verhoeyen *et al.*, *Science* 239: 1534 (1988). Generally, those human FR amino acid residues that differ from their murine counterparts and are located close to or touching one or more CDR amino acid residues would be candidates for substitution.

Human Antibodies

[094] Methods for producing fully human antibodies using either combinatorial approaches or transgenic animals transformed with human immunoglobulin loci are known in the art (*e.g.*, Mancini et al., 2004, *New Microbiol.* 27:315-28; Conrad and Scheller, 2005, *Comb. Chem. High Throughput Screen.* 8:117-26; Brekke and Loset, 2003, *Curr. Opin. Phamacol.* 3:544-50). A fully human antibody also can be constructed by genetic or chromosomal transfection methods, as well as phage display technology, all of which are known in the art. See for example, McCafferty *et al.*, *Nature* 348:552-553 (1990). Such fully human antibodies are expected to exhibit even fewer side effects than chimeric or humanized antibodies and to function *in vivo* as essentially endogenous human antibodies. In certain embodiments, the claimed methods and procedures may utilize human antibodies produced by such techniques.

[095] In one alternative, the phage display technique may be used to generate human antibodies (*e.g.*, Dantas-Barbosa et al., 2005, *Genet. Mol. Res.* 4:126-40). Human antibodies may be generated from normal humans or from humans that exhibit a particular disease state, such as cancer (Dantas-Barbosa et al., 2005). The advantage to constructing human antibodies from a diseased individual is that the circulating antibody repertoire may be biased towards antibodies against disease-associated antigens.

[096] In one non-limiting example of this methodology, Dantas-Barbosa et al. (2005) constructed a phage display library of human Fab antibody fragments from osteosarcoma patients. Generally, total RNA was obtained from circulating blood lymphocytes (*Id.*). Recombinant Fab were cloned from the μ, γ and κ chain antibody repertoires and inserted into a phage display library (*Id.*). RNAs were converted to cDNAs and used to make Fab cDNA libraries using specific primers against the heavy and light chain immunoglobulin sequences (Marks et al., 1991, *J. Mol. Biol.* 222:581-97). Library construction was performed according to Andris-Widhopf et al. (2000, In: *Phage Display Laboratory Manual*, Barbas et al. (eds), 1st edition, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, NY pp. 9.1 to 9.22). The final Fab fragments were digested with restriction endonucleases and inserted into the bacteriophage genome to make the phage display library. Such libraries may be screened by standard phage display methods, as known in the art (see, e.g., Pasqualini and Ruoslahti, 1996, Nature 380:364-366; Pasqualini, 1999, The Quart. J. Nucl. Med. 43:159-162).

[097] Phage display can be performed in a variety of formats, for their review, see e.g. Johnson and Chiswell, *Current Opinion in Structural Biology* 3:5564-571 (1993). Human antibodies may also be generated by *in vitro* activated B cells. See U.S. Patent Nos. 5,567,610 and 5,229,275. The skilled artisan will realize that these techniques are exemplary and any known method for making and screening human antibodies or antibody fragments may be utilized.

[098] In another alternative, transgenic animals that have been genetically engineered to produce human antibodies may be used to generate antibodies against essentially any immunogenic target, using standard immunization protocols. Methods for obtaining human antibodies from transgenic mice are disclosed by Green *et al., Nature Genet. 7*:13 (1994), Lonberg *et al., Nature 368*:856 (1994), and Taylor *et al., Int. Immun. 6*:579 (1994). A non-limiting example of such a system is the XenoMouse® (*e.g.*, Green et al., 1999, *J. Immunol. Methods* 231:11-23) from Abgenix (Fremont, CA). In the XenoMouse® and similar animals, the mouse antibody genes have been inactivated and replaced by functional human antibody genes, while the remainder of the mouse immune system remains intact.

[099] The XenoMouse® was transformed with germline-configured YACs (yeast artificial chromosomes) that contained portions of the human IgH and Igkappa loci, including the majority of the variable region sequences, along accessory genes and regulatory sequences. The human variable region repertoire may be used to generate antibody producing B cells, which may be processed into hybridomas by known techniques. A XenoMouse® immunized with a target antigen will produce human antibodies by the normal immune response, which may be harvested and/or produced by standard techniques discussed above. A variety of strains of XenoMouse® are available, each of which is capable of producing a different class of antibody. Transgenically produced human antibodies have been shown to have therapeutic potential, while retaining the pharmacokinetic properties of normal human antibodies (Green et al., 1999). The skilled artisan will realize that the claimed compositions and methods are not limited to use of the XenoMouse® system but may utilize any transgenic animal that has been genetically engineered to produce human antibodies.

Antibody Fragments

[0100] Antibody fragments which recognize specific epitopes can be generated by known techniques. Antibody fragments are antigen binding portions of an antibody, such as $F(ab')_2$,

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Fab', $F(ab)_2$, Fab, Fv, sFv and the like. $F(ab')_2$ fragments can be produced by pepsin digestion of the antibody molecule and Fab′ fragments can be generated by reducing disulfide bridges of the $F(ab')_2$ fragments. Alternatively, Fab′ expression libraries can be constructed (Huse *et al.*, 1989, *Science*, 246:1274-1281) to allow rapid and easy identification of monoclonal Fab′ fragments with the desired specificity. $F(ab)_2$ fragments may be generated by papain digestion of an antibody.

[0101] A single chain Fv molecule (scFv) comprises a VL domain and a VH domain. The VL and VH domains associate to form a target binding site. These two domains are further covalently linked by a peptide linker (L). Methods for making scFv molecules and designing suitable peptide linkers are described in US Patent No. 4,704,692, US Patent No. 4,946,778, R. Raag and M. Whitlow, "*Single Chain Fvs.*" FASEB Vol 9:73-80 (1995) and R.E. Bird and B.W. Walker, "*Single Chain Antibody Variable Regions*," TIBTECH, Vol 9: 132-137 (1991).

[0102] Techniques for producing single domain antibodies are also known in the art, as disclosed for example in Cossins et al. (2006, Prot Express Purif 51:253-259). Single domain antibodies (VHH) may be obtained, for example, from camels, alpacas or llamas by standard immunization techniques. (See, e.g., Muyldermans et al., TIBS 26:230-235, 2001; Yau et al., J Immunol Methods 281:161-75, 2003; Maass et al., J Immunol Methods 324:13-25, 2007). The VHH may have potent antigen-binding capacity and can interact with novel epitopes that are inaccessible to conventional VH-VL pairs. (Muyldermans et al., 2001). Alpaca serum IgG contains about 50% camelid heavy chain only IgG antibodies (HCAbs) (Maass et al., 2007). Alpacas may be immunized with known antigens, such as TNF-α, and VHHs can be isolated that bind to and neutralize the target antigen (Maass et al., 2007). PCR primers that amplify virtually all alpaca VHH coding sequences have been identified and may be used to construct alpaca VHH phage display libraries, which can be used for antibody fragment isolation by standard biopanning techniques well known in the art (Maass et al., 2007). In certain embodiments, anti-pancreatic cancer VHH antibody fragments may be utilized in the claimed compositions and methods.

[0103] An antibody fragment can be prepared by proteolytic hydrolysis of the full length antibody or by expression in *E. coli* or another host of the DNA coding for the fragment. An antibody fragment can be obtained by pepsin or papain digestion of full length antibodies by conventional methods. These methods are described, for example, by Goldenberg, U.S. Patent Nos. 4,036,945 and 4,331,647 and references contained therein. Also, see Nisonoff *et al., Arch Biochem. Biophys. 89*: 230 (1960); Porter, *Biochem. J. 73*: 119 (1959), Edelman *et*

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al., in METHODS IN ENZYMOLOGY VOL. 1, page 422 (Academic Press 1967), and Coligan at pages 2.8.1-2.8.10 and 2.10.-2.10.4.

Known Antibodies

[0104] In various embodiments, the claimed methods and compositions may utilize any of a variety of antibodies known in the art. Antibodies of use may be commercially obtained from a number of known sources. For example, a variety of antibody secreting hybridoma lines are available from the American Type Culture Collection (ATCC, Manassas, VA). A large number of antibodies against various disease targets, including but not limited to tumor-associated antigens, have been deposited at the ATCC and/or have published variable region sequences and are available for use in the claimed methods and compositions. See, e.g., U.S. Patent Nos. 7,312,318; 7,282,567; 7,151,164; 7,074,403; 7,060,802; 7,056,509; 7,049,060; 7,045,132; 7,041,803; 7,041,802; 7,041,293; 7,038,018; 7,037,498; 7,012,133; 7,001,598; 6,998,468; 6,994,976; 6,994,852; 6,989,241; 6,974,863; 6,965,018; 6,964,854; 6,962,981; 6,962,813; 6,956,107; 6,951,924; 6,949,244; 6,946,129; 6,943,020; 6,939,547; 6,921,645; 6,921,645; 6,921,533; 6,919,433; 6,919,078; 6,916,475; 6,905,681; 6,899,879; 6,893,625; 6,887,468; 6,887,466; 6,884,594; 6,881,405; 6,878,812; 6,875,580; 6,872,568; 6,867,006; 6,864,062; 6,861,511; 6,861,227; 6,861,226; 6,838,282; 6,835,549; 6,835,370; 6,824,780; 6,824,778; 6,812,206; 6,793,924; 6,783,758; 6,770,450; 6,767,711; 6,764,688; 6,764,681; 6,764,679; 6,743,898; 6,733,981; 6,730,307; 6,720,155; 6,716,966; 6,709,653; 6,693,176; 6,692,908; 6,689,607; 6,689,362; 6,689,355; 6,682,737; 6,682,736; 6,682,734; 6,673,344; 6,653,104; 6,652,852; 6,635,482; 6,630,144; 6,610,833; 6,610,294; 6,605,441; 6,605,279; 6,596,852; 6,592,868; 6,576,745; 6,572;856; 6,566,076; 6,562,618; 6,545,130; 6,544,749; 6,534,058; 6,528,625; 6,528,269; 6,521,227; 6,518,404; 6,511,665; 6,491,915; 6,488,930; 6,482,598; 6,482,408; 6,479,247; 6,468,531; 6,468,529; 6,465,173; 6,461,823; 6,458,356; 6,455,044; 6,455,040, 6,451,310; 6,444,206’ 6,441,143; 6,432,404; 6,432,402; 6,419,928; 6,413,726; 6,406,694; 6,403,770; 6,403,091; 6,395,276; 6,395,274; 6,387,350; 6,383,759; 6,383,484; 6,376,654; 6,372,215; 6,359,126; 6,355,481; 6,355,444; 6,355,245; 6,355,244; 6,346,246; 6,344,198; 6,340,571; 6,340,459; 6,331,175; 6,306,393; 6,254,868; 6,187,287; 6,183,744; 6,129,914; 6,120,767; 6,096,289; 6,077,499; 5,922,302; 5,874,540; 5,814,440; 5,798,229; 5,789,554; 5,776,456; 5,736,119; 5,716,595; 5,677,136; 5,587,459; 5,443,953, 5,525,338. These are exemplary only and a wide variety of other antibodies and their hybridomas are known in the art. The skilled artisan will realize that antibody sequences or antibody-secreting hybridomas against almost any disease-associated antigen may be obtained by a simple

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search of the ATCC, NCBI and/or USPTO databases for antibodies against a selected disease-associated target of interest. The antigen binding domains of the cloned antibodies may be amplified, excised, ligated into an expression vector, transfected into an adapted host cell and used for protein production, using standard techniques well known in the art (see, e.g., U.S. Patent Nos. 7,531,327; 7,537,930; 7,608,425 and 7,785,880).

[0105] Particular antibodies that may be of use include, but are not limited to, LL1 (anti-CD74), LL2 and RFB4 (anti-CD22), MN-14 (anti-carcinoembryonic antigen (CEA, also known as CD66e), hL243 (anti-HLA-DR), alemtuzumab (anti-CD52), gemtuzumab (anti-CD33), ibritumomab tiuxetan (anti-CD20); rituximab (anti-CD20); tositumomab (anti-CD20); and GA101 (anti-CD20). Such antibodies are known in the art (e.g., U.S. Patent Nos. 5,686,072; 5,874,540; 6,107,090; 6,183,744; 6,306,393; 6,653,104; 6,730.300; 6,899,864; 6,926,893; 6,962,702; 7,074,403; 7,230,084; 7,238,785; 7,238,786; 7,256,004; 7,282,567; 7,300,655; 7,312,318; 7,585,491; 7,612,180; 7,642,239; and U.S. Patent Application Publ. No. 20040202666 (now abandoned); 20050271671; and 20060193865.)
Specific known antibodies of use include hA20 (U.S. Patent No. 7,251,164), hA19 (U.S. Patent No. 7,109,304), hLL1 (U.S. Patent No. 7,312,318,), hLL2 (U.S. Patent No. 7,074,403), hL243 (U.S. Patent No. 7,612,180), hMN-14 (U.S. Patent No. 6,676,924), hMN-15 (U.S. Patent No. 7,541,440), and hMN-3 (U.S. Patent No. 7,541,440).

[0106] Anti-TNF-α antibodies are known in the art and may be of use to treat immune diseases, such as autoimmune disease, immune dysfunction (e.g., graft-versus-host disease, organ transplant rejection) or diabetes. Known antibodies against TNF-α include the human antibody CDP571 (Ofei et al., 2011, Diabetes 45:881-85); murine antibodies MTNFAI, M2TNFAI, M3TNFAI, M3TNFABI, M302B and M303 (Thermo Scientific, Rockford, IL); infliximab (Centocor, Malvern, PA); certolizumab pegol (UCB, Brussels, Belgium); and adalimumab (Abbott, Abbott Park, IL). These and many other known anti-TNF-α antibodies may be used in the claimed methods and compositions. Other antibodies of use for therapy of immune dysregulatory or autoimmune disease include, but are not limited to, anti-B-cell antibodies such as veltuzumab, epratuzumab, milatuzumab or hL243; tocilizumab (anti-IL-6 receptor); basiliximab (anti-CD25); daclizumab (anti-CD25); efalizumab (anti-CD11a); muromonab-CD3 (anti-CD3 receptor); anti-CD40L (UCB, Brussels, Belgium); natalizumab (anti-α4 integrin) and omalizumab (anti-IgE).

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[0107] Macrophage migration inhibitory factor (MIF) is an important regulator of innate and adaptive immunity and apoptosis. It has been reported that CD74 is the endogenous receptor for MIF (Leng et al., 2003, J Exp Med 197:1467-76). The therapeutic effect of antagonistic anti-CD74 antibodies on MIF-mediated intracellular pathways may be of use for treatment of a broad range of disease states, such as autoimmune diseases like rheumatoid arthritis and systemic lupus erythematosus (Morand & Leech, 2005, Front Biosci 10:12-22; Shachar & Haran, 2011, Leuk Lymphoma 52:1446-54); kidney diseases such as renal allograft rejection (Lan, 2008, Nephron Exp Nephrol. 109:e79-83); and numerous inflammatory diseases (Meyer-Siegler et al., 2009, Mediators Inflamm epub March 22, 2009; Takahashi et al., 2009, Respir Res 10:33; Milatuzumab (hLL1) is an exemplary anti-CD74 antibody of therapeutic use for treatment of MIF-mediated diseases.

Bispecific and Multispecific Antibodies

[0108] Bispecific or multispecific antibodies can be prepared by a variety of procedures, ranging from glutaraldehyde linkage to more specific linkages between functional groups. The antibodies and/or antibody fragments are preferably covalently bound to one another, directly or through a linker moiety, through one or more functional groups on the antibody or fragment, e. g., amine, carboxyl, phenyl, thiol, or hydroxyl groups. Various conventional linkers in addition to glutaraldehyde can be used, e. g., disiocyanates, diiosothiocyanates, bis (hydroxysuccinimide) esters, carbodiimides, maleimidehydroxy-succinimde esters, and the like. The optimal length of the linker may vary according to the type of target cell.

[0109] A simple method to produce multivalent antibodies is to mix the antibodies or fragments in the presence of glutaraldehyde. The initial Schiff base linkages can be stabilized, e. g., by borohydride reduction to secondary amines. A diiosothiocyanate or carbodiimide can be used in place of glutaraldehyde as a non-site-specific linker.

[0110] The simplest form of a multivalent, multispecific antibody is a bispecific antibody. Bispecific antibodies can be made by a variety of conventional methods, e. g., disulfide cleavage and reformation of mixtures of whole IgG or, preferably F $(ab')_2$ fragments, fusions of more than one hybridoma to form polyomas that produce antibodies having more than one specificity, and by genetic engineering. Bispecific antibodies have been prepared by oxidative cleavage of Fab' fragments resulting from reductive cleavage of different antibodies. This is advantageously carried out by mixing two different F $(ab')_2$ fragments produced by pepsin digestion of two different antibodies, reductive cleavage to form a mixture of Fab' fragments, followed by oxidative reformation of the disulfide linkages to produce a mixture of F $(ab')_2$ fragments including bispecific antibodies containing a Fab' portion specific to each of the original epitopes.

[0111] General techniques for the preparation of multivalent antibodies may be found, for example, in Nisonhoff et al., Arch Biochem. Biophys. 93: 470 (1961), Hammerling et al., J. Exp. Med. 128: 1461 (1968), and U. S. Patent No. 4,331,647.

[0112] More selective linkage can be achieved by using a heterobifunctional linker such as maleimide-hydroxysuccinimide ester. Reaction of the ester with an antibody or fragment will derivatize amine groups on the antibody or fragment, and the derivative can then be reacted with, e. g., an antibody Fab fragment having free sulfhydryl groups (or, a larger fragment or intact antibody with sulfhydryl groups appended thereto by, e. g., Traut's Reagent. Such a linker is less likely to crosslink groups in the same antibody and improves the selectivity of the linkage.

[0113] It is advantageous to link the antibodies or fragments at sites remote from the antigen binding sites. This can be accomplished by, e. g., linkage to cleaved interchain sulfydryl groups, as noted above. Another method involves reacting an antibody having an oxidized carbohydrate portion with another antibody which has at least one free amine function. This results in an initial Schiff base (imine) linkage, which is preferably stabilized by reduction to a secondary amine, e. g., by borohydride reduction, to form the final product. Such site-specific linkages are disclosed, for small molecules, in U. S. Patent No. 4,671,958, and for larger addends in U. S. Patent No. 4,699,784.

[0114] Alternatively, such bispecific antibodies can be produced by fusing two hybridoma cell lines that produce appropriate Mabs. Techniques for producing tetradomas are described, for example, by Milstein et al., *Nature* 305: 537 (1983) and Pohl et al., *Int. J. Cancer* 54: 418 (1993).

[0115] Alternatively, chimeric genes can be designed that encode both binding domains. General techniques for producing bispecific antibodies by genetic engineering are described, for example, by Songsivilai et al., *Biochem Biophys Res. Commun* 164: 271 (1989); Traunecker et al., *EMBO J.* 10: 3655 (1991); and Weiner et al., *J. Immunol.* 147: 4035 (1991).

[0116] A higher order multivalent, multispecific molecule can be obtained by adding various antibody components to a bispecific antibody, produced as above. For example, a bispecific antibody can be reacted with 2-iminothiolane to introduce one or more sulfhydryl groups for use in coupling the bispecific antibody to a further antibody derivative that binds an the same or a different epitope of the target antigen, using the bis-maleimide activation procedure described above. These techniques for producing multivalent antibodies are well known to those of skill in the art. See, for example, U. S. Patent No. 4,925,648, and Goldenberg, international publication No. WO 92/19273.

DOCK-AND-LOCK™ (DNL™)

[0117] In preferred embodiments, a bispecific or multispecific antibody is formed as a DOCK-AND-LOCK™ (DNL™) complex (see, e.g., U.S. Patent Nos. 7,521,056; 7,527,787; 7,534,866; 7,550,143 and 7,666,400.) Generally, the technique takes advantage of the specific and high-affinity binding interactions that occur between a dimerization and docking domain (DDD) sequence of the regulatory (R) subunits of cAMP-dependent protein kinase (PKA) and an anchor domain (AD) sequence derived from any of a variety of AKAP proteins (Baillie *et al.*, *FEBS Letters*. 2005; 579: 3264. Wong and Scott, *Nat. Rev. Mol. Cell Biol.* 2004; 5: 959). The DDD and AD peptides may be attached to any protein, peptide or other molecule. Because the DDD sequences spontaneously dimerize and bind to the AD sequence, the technique allows the formation of complexes between any selected molecules that may be attached to DDD or AD sequences.

[0118] Although the standard DNL™ complex comprises a trimer with two DDD-linked molecules attached to one AD-linked molecule, variations in complex structure allow the formation of dimers, trimers, tetramers, pentamers, hexamers and other multimers. In some embodiments, the DNL™ complex may comprise two or more antibodies, antibody fragments or fusion proteins which bind to the same antigenic determinant or to two or more different antigens. The DNL™ complex may also comprise one or more other effectors, such as proteins, peptides, immunomodulators, cytokines, interleukins, interferons, binding proteins, peptide ligands, carrier proteins, toxins, ribonucleases such as onconase, inhibitory oligonucleotides such as siRNA, antigens or xenoantigens, polymers such as PEG, enzymes, therapeutic agents, hormones, cytotoxic agents, anti-angiogenic agents, pro-apoptotic agents or any other molecule or aggregate.

[0119] PKA, which plays a central role in one of the best studied signal transduction pathways triggered by the binding of the second messenger cAMP to the R subunits, was first isolated from rabbit skeletal muscle in 1968 (Walsh *et al.*, J. Biol. Chem. 1968;243:3763). The structure of the holoenzyme consists of two catalytic subunits held in an inactive form by the R subunits (Taylor, *J. Biol. Chem.* 1989;264:8443). Isozymes of PKA are found with two types of R subunits (RI and RII), and each type has α and β isoforms (Scott, *Pharmacol.*

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Ther. 1991;50:123). Thus, the four isoforms of PKA regulatory subunits are RIα, RIβ, RIIα and RIIβ. The R subunits have been isolated only as stable dimers and the dimerization domain has been shown to consist of the first 44 amino-terminal residues of RIIα (Newlon *et al., Nat. Struct. Biol.* 1999; 6:222). As discussed below, similar portions of the amino acid sequences of other regulatory subunits are involved in dimerization and docking, each located near the N-terminal end of the regulatory subunit. Binding of cAMP to the R subunits leads to the release of active catalytic subunits for a broad spectrum of serine/threonine kinase activities, which are oriented toward selected substrates through the compartmentalization of PKA via its docking with AKAPs (Scott *et al., J. Biol. Chem.* 1990;265;21561)

[0120] Since the first AKAP, microtubule-associated protein-2, was characterized in 1984 (Lohmann *et al., Proc. Natl. Acad. Sci USA*. 1984; 81:6723), more than 50 AKAPs that localize to various sub-cellular sites, including plasma membrane, actin cytoskeleton, nucleus, mitochondria, and endoplasmic reticulum, have been identified with diverse structures in species ranging from yeast to humans (Wong and Scott, *Nat. Rev. Mol. Cell Biol.* 2004;5:959). The AD of AKAPs for PKA is an amphipathic helix of 14-18 residues (Carr *et al., J. Biol. Chem.* 1991;266:14188). The amino acid sequences of the AD are quite varied among individual AKAPs, with the binding affinities reported for RII dimers ranging from 2 to 90 nM (Alto *et al., Proc. Natl. Acad. Sci. USA*. 2003;100:4445). AKAPs will only bind to dimeric R subunits. For human RIIα, the AD binds to a hydrophobic surface formed by the 23 amino-terminal residues (Colledge and Scott, Trends Cell Biol. 1999; 6:216). Thus, the dimerization domain and AKAP binding domain of human RIIα are both located within the same N-terminal 44 amino acid sequence (Newlon *et al., Nat. Struct. Biol.* 1999;6:222; Newlon *et al., EMBO J.* 2001;20:1651), which is termed the DDD herein.

[0121] We have developed a platform technology to utilize the DDD of human PKA regulatory subunits and the AD of AKAP as an excellent pair of linker modules for docking any two entities, referred to hereafter as **A** and **B**, into a noncovalent complex, which could be further locked into a DNL™ complex through the introduction of cysteine residues into both the DDD and AD at strategic positions to facilitate the formation of disulfide bonds. The general methodology of the approach is as follows. Entity **A** is constructed by linking a DDD sequence to a precursor of **A**, resulting in a first component hereafter referred to as **a**. Because the DDD sequence would effect the spontaneous formation of a dimer, **A** would thus be composed of $\mathbf{a_2}$. Entity **B** is constructed by linking an AD sequence to a precursor of **B**, resulting in a second component hereafter referred to as **b**. The dimeric motif of DDD contained in a_2 will create a docking site for binding to the AD sequence contained in **b,** thus facilitating a ready association of a_2 and **b** to form a binary, trimeric complex composed of a_2b. This binding event is made irreversible with a subsequent reaction to covalently secure the two entities via disulfide bridges, which occurs very efficiently based on the principle of effective local concentration because the initial binding interactions should bring the reactive thiol groups placed onto both the DDD and AD into proximity (Chmura *et al., Proc. Natl. Acad. Sci. USA.* 2001;98:8480) to ligate site-specifically. Using various combinations of linkers, adaptor modules and precursors, a wide variety of DNL™ constructs of different stoichiometry may be produced and used (see, e.g., U.S. Nos. 7,550,143; 7,521,056; 7,534,866; 7,527,787 and 7,666,400.)

[0122] By attaching the DDD and AD away from the functional groups of the two precursors, such site-specific ligations are also expected to preserve the original activities of the two precursors. This approach is modular in nature and potentially can be applied to link, site-specifically and covalently, a wide range of substances, including peptides, proteins, antibodies, antibody fragments, and other effector moieties with a wide range of activities. Utilizing the fusion protein method of constructing AD and DDD conjugated effectors described in the Examples below, virtually any protein or peptide may be incorporated into a DNL™ construct. However, the technique is not limiting and other methods of conjugation may be utilized.

[0123] A variety of methods are known for making fusion proteins, including nucleic acid synthesis, hybridization and/or amplification to produce a synthetic double-stranded nucleic acid encoding a fusion protein of interest. Such double-stranded nucleic acids may be inserted into expression vectors for fusion protein production by standard molecular biology techniques (see, e.g. Sambrook et al., Molecular Cloning, A laboratory manual, 2nd Ed, 1989). In such preferred embodiments, the AD and/or DDD moiety may be attached to either the N-terminal or C-terminal end of an effector protein or peptide. However, the skilled artisan will realize that the site of attachment of an AD or DDD moiety to an effector moiety may vary, depending on the chemical nature of the effector moiety and the part(s) of the effector moiety involved in its physiological activity. Site-specific attachment of a variety of effector moieties may be performed using techniques known in the art, such as the use of bivalent cross-linking reagents and/or other chemical conjugation techniques.

Structure-Function Relationships in AD and DDD Moieties

[0124] For different types of DNL™ constructs, different AD or DDD sequences may be utilized. Exemplary DDD and AD sequences are provided below.

DDD1

SHIQIPPGLTELLQGYTVEVLRQQPPDLVEFAVEYFTRLREARA (SEQ ID NO:1)

DDD2

CGHIQIPPGLTELLQGYTVEVLRQQPPDLVEFAVEYFTRLREARA (SEQ ID NO:2)

AD1

QIEYLAKQIVDNAIQQA (SEQ ID NO:3)

AD2

CGQIEYLAKQIVDNAIQQAGC (SEQ ID NO:4)

[0125] The skilled artisan will realize that DDD1 and DDD2 are based on the DDD sequence of the human RIIα isoform of protein kinase A. However, in alternative embodiments, the DDD and AD moieties may be based on the DDD sequence of the human RIα form of protein kinase A and a corresponding AKAP sequence, as exemplified in DDD3, DDD3C and AD3 below.

DDD3

SLRECELYVQKHNIQALLKDSIVQLCTARPERPMAFLREYFERLEKEEAK (SEQ ID NO:5)

DDD3C

MSCGGSLRECELYVQKHNIQALLKDSIVQLCTARPERPMAFLREYFERLEKEEAK (SEQ ID NO:6)

AD3

CGFEELAWKIAKMIWSDVFQQGC (SEQ ID NO:7)

[0126] In other alternative embodiments, other sequence variants of AD and/or DDD moieties may be utilized in construction of the DNL™ complexes. For example, there are only four variants of human PKA DDD sequences, corresponding to the DDD moieties of PKA RIα, RIIα, RIβ and RIIβ. The RIIα DDD sequence is the basis of DDD1 and DDD2 disclosed above. The four human PKA DDD sequences are shown below. The DDD sequence represents residues 1-44 of RIIα, 1-44 of RIIβ, 12-61 of RIα and 13-66 of RIβ. (Note that the sequence of DDD1 is modified slightly from the human PKA RIIα DDD moiety.)

PKA RIα

SLRECELYVQKHNIQALLKDVSIVQLCTARPERPMAFLREYFEKLEKEEAK (SEQ ID

NO:8)

PKA RIβ

SLKGCELYVQLHGIQQVLKDCIVHLCISKPERPMKFLREHFEKLEKEENRQILA (SEQ ID NO:9)

PKA RIIα

SHIQIPPGLTELLQGYTVEVGQQPPDLVDFAVEYFTRLREARRQ (SEQ ID NO:10)

PKA RIIβ

SIEIPAGLTELLQGFTVEVLRHQPADLLEFALQHFTRLQQENER (SEQ ID NO:11)

[0127] The structure-function relationships of the AD and DDD domains have been the subject of investigation. (See, e.g., Burns-Hamuro et al., 2005, *Protein Sci* 14:2982-92; Carr et al., 2001, *J Biol Chem* 276:17332-38; Alto et al., 2003, Proc Natl Acad Sci USA 100:4445-50; Hundsrucker et al., 2006, *Biochem J* 396:297-306; Stokka et al., 2006, *Biochem J* 400:493-99; Gold et al., 2006, *Mol Cell* 24:383-95; Kinderman et al., 2006, *Mol Cell* 24:397-408.)

[0128] For example, Kinderman et al. (2006, Mol Cell 24:397-408) examined the crystal structure of the AD-DDD binding interaction and concluded that the human DDD sequence contained a number of conserved amino acid residues that were important in either dimer formation or AKAP binding, underlined in SEQ ID NO:1 below. (See Figure 1 of Kinderman et al., 2006.) The skilled artisan will realize that in designing sequence variants of the DDD sequence, one would desirably avoid changing any of the underlined residues, while conservative amino acid substitutions might be made for residues that are less critical for dimerization and AKAP binding.

SHIQIPPGLTELLQGYTVEVLRQQPPDLVEFAVEYFTRLREARA (SEQ ID NO:1)

[0129] As discussed in more detail below, conservative amino acid substitutions have been characterized for each of the twenty common L-amino acids. Thus, based on the data of Kinderman (2006) and conservative amino acid substitutions, potential alternative DDD sequences based on SEQ ID NO:1 are shown in **Table 1**. In devising **Table 1**, only highly conservative amino acid substitutions were considered. For example, charged residues were only substituted for residues of the same charge, residues with small side chains were substituted with residues of similar size, hydroxyl side chains were only substituted with other hydroxyls, etc. Because of the unique effect of proline on amino acid secondary structure, no other residues were substituted for proline. A limited number of such potential alternative DDD moiety sequences are shown in SEQ ID NO:12 to SEQ ID NO:31 below. The skilled artisan will realize that an almost unlimited number of alternative species within the genus of DDD moieties can be constructed by standard techniques, for example using a commercial peptide synthesizer or well known site-directed mutagenesis techniques. The effect of the amino acid substitutions on AD moiety binding may also be readily determined by standard binding assays, for example as disclosed in Alto et al. (2003, *Proc Natl Acad Sci USA* 100:4445-50).

Table 1. Conservative Amino Acid Substitutions in DDD1 (SEQ ID NO:1). Consensus sequence disclosed as SEQ ID NO:87.

S	**H**	**I**	**Q**	**I**	**P**	**P**	**G**	**L**	**T**	**E**	**L**	**L**	**Q**	**G**	**Y**	**T**	**V**	**E**	**V**	**L**	**R**
T	K R		N				A		S	D			N	A		S		D			K

Q	**Q**	**P**	**P**	**D**	**L**	**V**	**E**	**F**	**A**	**V**	**E**	**Y**	**F**	**T**	**R**	**L**	**R**	**E**	**A**	**R**	**A**
N	N			E			D		L I V		D			S	K		K	D	L I V	K	L I V

THIQIPPGLTELLQGYTVEVLRQQPPDLVEFAVEYFTRLREARA (SEQ ID NO:12)
SKIQIPPGLTELLQGYTVEVLRQQPPDLVEFAVEYFTRLREARA (SEQ ID NO:13)
SRIQIPPGLTELLQGYTVEVLRQQPPDLVEFAVEYFTRLREARA (SEQ ID NO:14)
SHINIPPGLTELLQGYTVEVLRQQPPDLVEFAVEYFTRLREARA (SEQ ID NO:15)
SHIQIPPALTELLQGYTVEVLRQQPPDLVEFAVEYFTRLREARA (SEQ ID NO:16)
SHIQIPPGLSELLQGYTVEVLRQQPPDLVEFAVEYFTRLREARA (SEQ ID NO:17)
SHIQIPPGLTDLLQGYTVEVLRQQPPDLVEFAVEYFTRLREARA (SEQ ID NO:18)
SHIQIPPGLTELLNGYTVEVLRQQPPDLVEFAVEYFTRLREARA (SEQ ID NO:19)
SHIQIPPGLTELLQAYTVEVLRQQPPDLVEFAVEYFTRLREARA (SEQ ID NO:20)
SHIQIPPGLTELLQGYSVEVLRQQPPDLVEFAVEYFTRLREARA (SEQ ID NO:21)
SHIQIPPGLTELLQGYTVDVLRQQPPDLVEFAVEYFTRLREARA (SEQ ID NO:22)
SHIQIPPGLTELLQGYTVEVLKQQPPDLVEFAVEYFTRLREARA (SEQ ID NO:23)
SHIQIPPGLTELLQGYTVEVLRNQPPDLVEFAVEYFTRLREARA (SEQ ID NO:24)
SHIQIPPGLTELLQGYTVEVLRQNPPDLVEFAVEYFTRLREARA (SEQ ID NO:25)
SHIQIPPGLTELLQGYTVEVLRQQPPELVEFAVEYFTRLREARA (SEQ ID NO:26)
SHIQIPPGLTELLQGYTVEVLRQQPPDLVDFAVEYFTRLREARA (SEQ ID NO:27)
SHIQIPPGLTELLQGYTVEVLRQQPPDLVEFLVEYFTRLREARA (SEQ ID NO:28)
SHIQIPPGLTELLQGYTVEVLRQQPPDLVEFIVEYFTRLREARA (SEQ ID NO:29)

SHIQIPPGLTELLQGYTVEVLRQQPPDLVEFVVEYFTRLREARA (SEQ ID NO:30)
SHIQIPPGLTELLQGYTVEVLRQQPPDLVEFAVDYFTRLREARA (SEQ ID NO:31)

[0130] Alto et al. (2003, Proc Natl Acad Sci USA 100:4445-50) performed a bioinformatic analysis of the AD sequence of various AKAP proteins to design an RII selective AD sequence called AKAP-IS (SEQ ID NO:3), with a binding constant for DDD of 0.4 nM. The AKAP-IS sequence was designed as a peptide antagonist of AKAP binding to PKA. Residues in the AKAP-IS sequence where substitutions tended to decrease binding to DDD are underlined in SEQ ID NO:3 below. The skilled artisan will realize that in designing sequence variants of the AD sequence, one would desirably avoid changing any of the underlined residues, while conservative amino acid substitutions might be made for residues that are less critical for DDD binding. **Table 2** shows potential conservative amino acid substitutions in the sequence of AKAP-IS (AD1, SEQ ID NO:3), similar to that shown for DDD1 (SEQ ID NO:1) in **Table 1** above.

[0131] A limited number of such potential alternative AD moiety sequences are shown in SEQ ID NO:32 to SEQ ID NO:49 below. Again, a very large number of species within the genus of possible AD moiety sequences could be made, tested and used by the skilled artisan, based on the data of Alto et al. (2003). It is noted that Figure 2 of Alto (2003) shows an even large number of potential amino acid substitutions that may be made, while retaining binding activity to DDD moieties, based on actual binding experiments.

AKAP-IS

QIEYLAKQIVDNAIQQA (SEQ ID NO:3)

Table 2. Conservative Amino Acid Substitutions in AD1 (SEQ ID NO:3). Consensus sequence disclosed as SEQ ID NO:88.

Q	I	E	Y	L	A	K	Q	I	V	D	N	A	I	Q	Q	A
N	L V	D	F T S	I V		R	N			E	Q			N	N	L I V

NIEYLAKQIVDNAIQQA (SEQ ID NO:32)
QLEYLAKQIVDNAIQQA (SEQ ID NO:33)
QVEYLAKQIVDNAIQQA (SEQ ID NO:34)
QIDYLAKQIVDNAIQQA (SEQ ID NO:35)
QIEFLAKQIVDNAIQQA (SEQ ID NO:36)

QIETLAKQIVDNAIQQA (SEQ ID NO:37)
QIESLAKQIVDNAIQQA (SEQ ID NO:38)
QIEYIAKQIVDNAIQQA (SEQ ID NO:39)
QIEYVAKQIVDNAIQQA (SEQ ID NO:40)
QIEYLARQIVDNAIQQA (SEQ ID NO:41)
QIEYLAKNIVDNAIQQA (SEQ ID NO:42)
QIEYLAKQIVENAIQQA (SEQ ID NO:43)
QIEYLAKQIVDQAIQQA (SEQ ID NO:44)
QIEYLAKQIVDNAINQA (SEQ ID NO:45)
QIEYLAKQIVDNAIQNA (SEQ ID NO:46)
QIEYLAKQIVDNAIQQL (SEQ ID NO:47)
QIEYLAKQIVDNAIQQI (SEQ ID NO:48)
QIEYLAKQIVDNAIQQV (SEQ ID NO:49)

[0132] Gold et al. (2006, Mol Cell 24:383-95) utilized crystallography and peptide screening to develop a SuperAKAP-IS sequence (SEQ ID NO:50), exhibiting a five order of magnitude higher selectivity for the RII isoform of PKA compared with the RI isoform. Underlined residues indicate the positions of amino acid substitutions, relative to the AKAP-IS sequence, which increased binding to the DDD moiety of RIIα. In this sequence, the N-terminal Q residue is numbered as residue number 4 and the C-terminal A residue is residue number 20. Residues where substitutions could be made to affect the affinity for RIIα were residues 8, 11, 15, 16, 18, 19 and 20 (Gold et al., 2006). It is contemplated that in certain alternative embodiments, the SuperAKAP-IS sequence may be substituted for the AKAP-IS AD moiety sequence to prepare DNL™ constructs. Other alternative sequences that might be substituted for the AKAP-IS AD sequence are shown in SEQ ID NO:51-53. Substitutions relative to the AKAP-IS sequence are underlined. It is anticipated that, as with the AD2 sequence shown in SEQ ID NO:4, the AD moiety may also include the additional N-terminal residues cysteine and glycine and C-terminal residues glycine and cysteine.

SuperAKAP-IS
QIEYVAKQIVDYAIHQA (SEQ ID NO:50)
Alternative AKAP sequences
QIEYKAKQIVDHAIHQA (SEQ ID NO:51)
QIEYHAKQIVDHAIHQA (SEQ ID NO:52)

QIEYVAKQIVDHAIHQA (SEQ ID NO:53)

[0133] Figure 2 of Gold et al. disclosed additional DDD-binding sequences from a variety of AKAP proteins, shown below.

RII-Specific AKAPs

AKAP-KL

PLEYQAGLLVQNAIQQAI (SEQ ID NO:54)

AKAP79

LLIETASSLVKNAIQLSI (SEQ ID NO:55)

AKAP-Lbc

LIEEAASRIVDAVIEQVK (SEQ ID NO:56)

RI-Specific AKAPs

AKAPce

ALYQFADRFSELVISEAL (SEQ ID NO:57)

RIAD

LEQVANQLADQIIKEAT (SEQ ID NO:58)

PV38

FEELAWKIAKMIWSDVF (SEQ ID NO:59)

Dual-Specificity AKAPs

AKAP7

ELVRLSKRLVENAVLKAV (SEQ ID NO:60)

MAP2D

TAEEVSARIVQVVTAEAV (SEQ ID NO:61)

DAKAP1

QIKQAAFQLISQVILEAT (SEQ ID NO:62)

DAKAP2

LAWKIAKMIVSDVMQQ (SEQ ID NO:63)

[0134] Stokka et al. (2006, Biochem J 400:493-99) also developed peptide competitors of AKAP binding to PKA, shown in SEQ ID NO:64-66. The peptide antagonists were designated as Ht31 (SEQ ID NO:64), RIAD (SEQ ID NO:65) and PV-38 (SEQ ID NO:66). The Ht-31 peptide exhibited a greater affinity for the RII isoform of PKA, while the RIAD and PV-38 showed higher affinity for RI.

Ht31

DLIEEAASRIVDAVIEQVKAAGAY (SEQ ID NO:64)

RIAD

LEQYANQLADQIIKEATE (SEQ ID NO:65)

PV-38

FEELAWKIAKMIWSDVFQQC (SEQ ID NO:66)

[0135] Hundsrucker et al. (2006, *Biochem J* 396:297-306) developed still other peptide competitors for AKAP binding to PKA, with a binding constant as low as 0.4 nM to the DDD of the RII form of PKA. The sequences of various AKAP antagonistic peptides are provided in Table 1 of Hundsrucker et al., reproduced in **Table 3** below. AKAPIS represents a synthetic RII subunit-binding peptide. All other peptides are derived from the RII-binding domains of the indicated AKAPs.

Table 3. AKAP Peptide sequences

	Peptide Sequence
AKAPIS	QIEYLAKQIVDNAIQQA (SEQ ID NO:3)
AKAPIS-P	QIEYLAKQIPDNAIQQA (SEQ ID NO:67)
Ht31	KGADLIEEAASRIVDAVIEQVKAAG (SEQ ID NO:68)
Ht31-P	KGADLIEEAASRIPDAPIEQVKAAG (SEQ ID NO:69)
AKAP7δ-wt-pep	PEDAELVRLSKRLVENAVLKAVQQY (SEQ ID NO:70)
AKAP7δ-L304T-pep	PEDAELVRTSKRLVENAVLKAVQQY (SEQ ID NO:71)
AKAP7δ-L308D-pep	PEDAELVRLSKRDVENAVLKAVQQY (SEQ ID NO:72)
AKAP7δ-P-pep	PEDAELVRLSKRLPENAVLKAVQQY (SEQ ID NO:73)
AKAP7δ-PP-pep	PEDAELVRLSKRLPENAPLKAVQQY (SEQ ID NO:74)
AKAP7δ-L314E-pep	PEDAELVRLSKRLVENAVEKAVQQY (SEQ ID NO:75)
AKAP1-pep	EEGLDRNEEIKRAAFQIISQVISEA (SEQ ID NO:76)
AKAP2-pep	LVDDPLEYQAGLLVQNAIQQAIAEQ (SEQ ID NO:77)
AKAP5-pep	QYETLLIETASSLVKNAIQLSIEQL (SEQ ID NO:78)
AKAP9-pep	LEKQYQEQLEEEVAKVIVSMSIAFA (SEQ ID NO:79)
AKAP10-pep	NTDEAQEELAWKIAKMIVSDIMQQA (SEQ ID NO:80)
AKAP11-pep	VNLDKKAVLAEKIVAEAIEKAEREL (SEQ ID NO:81)
AKAP12-pep	NGILELETKSSKLVQNIIQTAVDQF (SEQ ID NO:82)
AKAP14-pep	TQDKNYEDELTQVALALVEDVINYA (SEQ ID NO:83)
Rab32-pep	ETSAKDNINIEEAARFLVEKILVNH (SEQ ID NO:84)

[0136] Residues that were highly conserved among the AD domains of different AKAP proteins are indicated below by underlining with reference to the AKAP IS sequence (SEQ ID NO:3). The residues are the same as observed by Alto et al. (2003), with the addition of the C-terminal alanine residue. (See FIG. 4 of Hundsrucker et al. (2006)). The sequences of peptide antagonists with particularly high affinities for the RII DDD sequence were those of AKAP-IS, AKAP7δ-wt-pep, AKAP7δ-L304T-pep and AKAP7δ-L308D-pep.

AKAP-IS

QIEYLAKQIVDNAIQQA (SEQ ID NO:3)

[0137] Carr et al. (2001, J Biol Chem 276:17332-38) examined the degree of sequence homology between different AKAP-binding DDD sequences from human and non-human proteins and identified residues in the DDD sequences that appeared to be the most highly conserved among different DDD moieties. These are indicated below by underlining with reference to the human PKA RIIα DDD sequence of SEQ ID NO:1. Residues that were particularly conserved are further indicated by italics. The residues overlap with, but are not identical to those suggested by Kinderman et al. (2006) to be important for binding to AKAP proteins. The skilled artisan will realize that in designing sequence variants of DDD, it would be most preferred to avoid changing the most conserved residues (italicized), and it would be preferred to also avoid changing the conserved residues (underlined), while conservative amino acid substitutions may be considered for residues that are neither underlined nor italicized..

SHIQ*IP*P*GL*TE*LL*QGY*T*VE*VLR*Q*QP*P*DL*VEF*A*VE*YF*TR*L*REA*R*A (SEQ ID NO:1)

[0138] A modified set of conservative amino acid substitutions for the DDD1 (SEQ ID NO:1) sequence, based on the data of Carr et al. (2001) is shown in **Table 4.** Even with this reduced set of substituted sequences, there are over 65,000 possible alternative DDD moiety sequences that may be produced, tested and used by the skilled artisan without undue experimentation. The skilled artisan could readily derive such alternative DDD amino acid sequences as disclosed above for **Table 1** and **Table 2.**

Table 4. Conservative Amino Acid Substitutions in DDD1 (SEQ ID NO:1). Consensus sequence disclosed as SEQ ID NO:89.

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S	**H**	**I**	**Q**	***I***	***P***	**P**	***G***	***L***	**T**	**E**	***L***	***L***	**Q**	***G***	***Y***	***T***	**V**	***E***	***V***	***L***	***R***
T			N						S								I L A				

Q	***Q***	***P***	**P**	***D***	***L***	**V**	**E**	***F***	***A***	**V**	**E**	***Y***	***F***	**T**	**R**	***L***	**R**	**E**	**A**	***R***	**A**
N										I L A	D			S	K		K		L I V		L I V

[0139] The skilled artisan will realize that these and other amino acid substitutions in the DDD or AD amino acid sequences may be utilized to produce alternative species within the genus of AD or DDD moieties, using techniques that are standard in the field and only routine experimentation.

Alternative DNL™ Structures

[0140] In certain alternative embodiments, DNL™ constructs may be formed using alternatively constructed antibodies or antibody fragments, in which an AD moiety may be attached at the C-terminal end of the kappa light chain (C_k), instead of the C-terminal end of the Fc on the heavy chain. The alternatively formed DNL™ constructs may be prepared as disclosed in Provisional U.S. Patent Application Serial Nos. 61/654,310, filed June 1, 2012, 61/662,086, filed June 20, 2012, 61/673,553, filed July 19, 2012, and 61/682,531, filed August 13, 2012. The light chain conjugated DNL™ constructs exhibit enhanced Fc-effector function activity *in vitro* and improved pharmacokinetics, stability and anti-lymphoma activity *in vivo* (Rossi et al., 2013, Bioconjug Chem 24:63-71).

[0141] C_k-conjugated DNL™ constructs may be prepared as disclosed in Provisional U.S. Patent Application Serial Nos. 61/654,310, 61/662,086, 61/673,553, and 61/682,531. Briefly, C_k-AD2-IgG, was generated by recombinant engineering, whereby the AD2 peptide was fused to the C-terminal end of the kappa light chain. Because the natural C-terminus of C_K is a cysteine residue, which forms a disulfide bridge to C_H1, a 16-amino acid residue "hinge" linker was used to space the AD2 from the C_K-V_H1 disulfide bridge. The mammalian expression vectors for C_k-AD2-IgG-veltuzumab and C_k-AD2-IgG-epratuzumab were constructed using the pdHL2 vector, which was used previously for expression of the homologous C_H3-AD2-IgG modules. A 2208-bp nucleotide sequence was synthesized comprising the pdHL2 vector sequence ranging from the *Bam HI* restriction site within the

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V_K/C_K intron to the *Xho I* restriction site 3' of the C_k intron, with the insertion of the coding sequence for the hinge linker (EFPKPSTPPGSSGGAP, SEQ ID NO:108) and AD2, in frame at the 3'end of the coding sequence for C_K. This synthetic sequence was inserted into the IgG-pdHL2 expression vectors for veltuzumab and epratuzumab via *Bam HI* and *Xho I* restriction sites. Generation of production clones with SpESFX-10 were performed as described for the C_H3-AD2-IgG modules. C_k-AD2-IgG-veltuzumab and C_k-AD2-IgG-epratuzumab were produced by stably-transfected production clones in batch roller bottle culture, and purified from the supernatant fluid in a single step using MabSelect (GE Healthcare) Protein A affinity chromatography.

[0142] Following the same DNL process described previously for 22-(20)-(20) (Rossi et al., 2009, *Blood* 113:6161-71), C_k-AD2-IgG-epratuzumab was conjugated with C_H1-DDD2-Fab-veltuzumab, a Fab-based module derived from veltuzumab, to generate the bsHexAb 22*-(20)-(20), where the 22* indicates the C_k-AD2 module of epratuzumab and each (20) symbolizes a stabilized dimer of veltuzumab Fab. The properties of 22*-(20)-(20) were compared with those of 22-(20)-(20), the homologous Fc-bsHexAb comprising C_H3-AD2-IgG-epratuzumab, which has similar composition and molecular size, but a different architecture.

[0143] Following the same DNL process described previously for 20-2b (Rossi et al., 2009, *Blood* 114:3864-71), C_k-AD2-IgG-veltuzumab, was conjugated with IFNα2b-DDD2, a module of IFNα2b with a DDD2 peptide fused at its C-terminal end, to generate 20*-2b, which comprises veltuzumab with a dimeric IFNα2b fused to each light chain. The properties of 20*-2b were compared with those of 20-2b, which is the homologous Fc-IgG-IFNα.

[0144] Each of the bsHexAbs and IgG-IFNα were isolated from the DNL reaction mixture by MabSelect affinity chromatography. The two C_k-derived prototypes, an anti-CD22/CD20 bispecific hexavalent antibody, comprising epratuzumab (anti-CD22) and four Fabs of veltuzumab (anti-CD20), and a CD20-targeting immunocytokine, comprising veltuzumab and four molecules of interferon-α2b, displayed enhanced Fc-effector functions *in vitro*, as well as improved pharmacokinetics, stability and anti-lymphoma activity *in vivo*, compared to their Fc-derived counterparts.

Amino Acid Substitutions

[0145] In alternative embodiments, the disclosed methods and compositions may involve production and use of proteins or peptides with one or more substituted amino acid residues.

For example, the DDD and/or AD sequences used to make DNL™ constructs may be modified as discussed above.

[0146] The skilled artisan will be aware that, in general, amino acid substitutions typically involve the replacement of an amino acid with another amino acid of relatively similar properties (i.e., conservative amino acid substitutions). The properties of the various amino acids and effect of amino acid substitution on protein structure and function have been the subject of extensive study and knowledge in the art.

[0147] For example, the hydropathic index of amino acids may be considered (Kyte & Doolittle, 1982, *J. Mol. Biol.*, 157:105-132). The relative hydropathic character of the amino acid contributes to the secondary structure of the resultant protein, which in turn defines the interaction of the protein with other molecules. Each amino acid has been assigned a hydropathic index on the basis of its hydrophobicity and charge characteristics (Kyte & Doolittle, 1982), these are: isoleucine (+4.5); valine (+4.2); leucine (+3.8); phenylalanine (+2.8); cysteine/cystine (+2.5); methionine (+1.9); alanine (+1.8); glycine (-0.4); threonine (-0.7); serine (-0.8); tryptophan (-0.9); tyrosine (-1.3); proline (-1.6); histidine (-3.2); glutamate (-3.5); glutamine (-3.5); aspartate (-3.5); asparagine (-3.5); lysine (-3.9); and arginine (-4.5). In making conservative substitutions, the use of amino acids whose hydropathic indices are within ± 2 is preferred, within ± 1 are more preferred, and within ± 0.5 are even more preferred.

[0148] Amino acid substitution may also take into account the hydrophilicity of the amino acid residue (e.g., U.S. Pat. No. 4,554,101). Hydrophilicity values have been assigned to amino acid residues: arginine (+3.0); lysine (+3.0); aspartate (+3.0); glutamate (+3.0); serine (+0.3); asparagine (+0.2); glutamine (+0.2); glycine (0); threonine (-0.4); proline (-0.5 .+-.1); alanine (-0.5); histidine (-0.5); cysteine (-1.0); methionine (-1.3); valine (-1.5); leucine (-1.8); isoleucine (-1.8); tyrosine (-2.3); phenylalanine (-2.5); tryptophan (-3.4). Replacement of amino acids with others of similar hydrophilicity is preferred.

[0149] Other considerations include the size of the amino acid side chain. For example, it would generally not be preferred to replace an amino acid with a compact side chain, such as glycine or serine, with an amino acid with a bulky side chain, e.g., tryptophan or tyrosine. The effect of various amino acid residues on protein secondary structure is also a consideration. Through empirical study, the effect of different amino acid residues on the tendency of protein domains to adopt an alpha-helical, beta-sheet or reverse turn secondary structure has been determined and is known in the art (see, e.g., Chou & Fasman, 1974, *Biochemistry*, 13:222-245; 1978, *Ann. Rev. Biochem.*, 47: 251-276; 1979, *Biophys. J.*, 26:367-384).

[0150] Based on such considerations and extensive empirical study, tables of conservative amino acid substitutions have been constructed and are known in the art. For example: arginine and lysine; glutamate and aspartate; serine and threonine; glutamine and asparagine; and valine, leucine and isoleucine. Alternatively: Ala (A) leu, ile, val; Arg (R) gln, asn, lys; Asn (N) his, asp, lys, arg, gln; Asp (D) asn, glu; Cys (C) ala, ser; Gln (Q) glu, asn; Glu (E) gln, asp; Gly (G) ala; His (H) asn, gln, lys, arg; Ile (I) val, met, ala, phe, leu; Leu (L) val, met, ala, phe, ile; Lys (K) gln, asn, arg; Met (M) phe, ile, leu; Phe (F) leu, val, ile, ala, tyr; Pro (P) ala; Ser (S), thr; Thr (T) ser; Trp (W) phe, tyr; Tyr (Y) trp, phe, thr, ser; Val (V) ile, leu, met, phe, ala.

[0151] Other considerations for amino acid substitutions include whether or not the residue is located in the interior of a protein or is solvent exposed. For interior residues, conservative substitutions would include: Asp and Asn; Ser and Thr; Ser and Ala; Thr and Ala; Ala and Gly; Ile and Val; Val and Leu; Leu and Ile; Leu and Met; Phe and Tyr; Tyr and Trp. (See, e.g., PROWL website at rockefeller.edu) For solvent exposed residues, conservative substitutions would include: Asp and Asn; Asp and Glu; Glu and Gln; Glu and Ala; Gly and Asn; Ala and Pro; Ala and Gly; Ala and Ser; Ala and Lys; Ser and Thr; Lys and Arg; Val and Leu; Leu and Ile; Ile and Val; Phe and Tyr. (Id.) Various matrices have been constructed to assist in selection of amino acid substitutions, such as the PAM250 scoring matrix, Dayhoff matrix, Grantham matrix, McLachlan matrix, Doolittle matrix, Henikoff matrix, Miyata matrix, Fitch matrix, Jones matrix, Rao matrix, Levin matrix and Risler matrix (*Idem.*)

[0152] In determining amino acid substitutions, one may also consider the existence of intermolecular or intramolecular bonds, such as formation of ionic bonds (salt bridges) between positively charged residues (e.g., His, Arg, Lys) and negatively charged residues (e.g., Asp, Glu) or disulfide bonds between nearby cysteine residues.

[0153] Methods of substituting any amino acid for any other amino acid in an encoded protein sequence are well known and a matter of routine experimentation for the skilled artisan, for example by the technique of site-directed mutagenesis or by synthesis and assembly of oligonucleotides encoding an amino acid substitution and splicing into an expression vector construct.

Antibody Allotypes

[0154] Immunogenicity of therapeutic antibodies is associated with increased risk of infusion reactions and decreased duration of therapeutic response (Baert et al., 2003, *N Engl J Med* 348:602-08). The extent to which therapeutic antibodies induce an immune response in the host may be determined in part by the allotype of the antibody (Stickler et al., 2011, *Genes and Immunity* 12:213-21). Antibody allotype is related to amino acid sequence variations at specific locations in the constant region sequences of the antibody. The allotypes of IgG antibodies containing a heavy chain γ-type constant region are designated as Gm allotypes (1976, *J Immunol* 117:1056-59).

[0155] For the common IgG1 human antibodies, the most prevalent allotype is G1m1 (Stickler et al., 2011, *Genes and Immunity* 12:213-21). However, the G1m3 allotype also occurs frequently in Caucasians (*Id.*). It has been reported that G1m1 antibodies contain allotypic sequences that tend to induce an immune response when administered to non-G1m1 (nG1m1) recipients, such as G1m3 patients (*Id.*). Non-G1m1 allotype antibodies are not as immunogenic when administered to G1m1 patients (*Id.*).

[0156] The human G1m1 allotype comprises the amino acids aspartic acid at Kabat position 356 and leucine at Kabat position 358 in the CH3 sequence of the heavy chain IgG1. The nG1m1 allotype comprises the amino acids glutamic acid at Kabat position 356 and methionine at Kabat position 358. Both G1m1 and nG1m1 allotypes comprise a glutamic acid residue at Kabat position 357 and the allotypes are sometimes referred to as DEL and EEM allotypes. A non-limiting example of the heavy chain constant region sequences for G1m1 and nG1m1 allotype antibodies is shown for the exemplary antibodies rituximab (SEQ ID NO:85) and veltuzumab (SEQ ID NO:86).

Rituximab heavy chain variable region sequence (SEQ ID NO:85)

ASTKGPSVFPLAPSSKSTSGGTAALGCLVKDYFPEPVTVSWNSGALTSGVHTFPAVL
QSSGLYSLSSVVTVPSSSLGTQTYICNVNHKPSNTKVDK**KA**EPKSCDKTHTCPPCPAP
ELLGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSHEDPEVKFNWYVDGVEVHNAK
TKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISKAKGQPRE
PQVYTLPPSR**D**E**L**TKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTTPPVLDSDG
SFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGK

Veltuzumab heavy chain variable region (SEQ ID NO:86)

ASTKGPSVFPLAPSSKSTSGGTAALGCLVKDYFPEPVTVSWNSGALTSGVHTFPAVL
QSSGLYSLSSVVTVPSSSLGTQTYICNVNHKPSNTKVDK**RV**EPKSCDKTHTCPPCPAP
ELLGGPSVFLFPPKPKDTLMISRTPEVTCVVVDVSHEDPEVKFNWYVDGVEVHNAK

TKPREEQYNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKALPAPIEKTISKAKGQPRE PQVYTLPPSR**EEM**TKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTTPPVLDSDG SFFLYSKLTVDKSRWQQGNVFSCSVMHEALHNHYTQKSLSLSPGK

[0157] Jefferis and Lefranc (2009, *mAbs* 1:1-7) reviewed sequence variations characteristic of IgG allotypes and their effect on immunogenicity. They reported that the G1m3 allotype is characterized by an arginine residue at Kabat position 214, compared to a lysine residue at Kabat 214 in the G1m17 allotype. The nG1m1,2 allotype was characterized by glutamic acid at Kabat position 356, methionine at Kabat position 358 and alanine at Kabat position 431. The G1m1,2 allotype was characterized by aspartic acid at Kabat position 356, leucine at Kabat position 358 and glycine at Kabat position 431. In addition to heavy chain constant region sequence variants, Jefferis and Lefranc (2009) reported allotypic variants in the kappa light chain constant region, with the Km1 allotype characterized by valine at Kabat position 153 and leucine at Kabat position 191, the Km1,2 allotype by alanine at Kabat position 153 and leucine at Kabat position 191, and the Km3 allotypoe characterized by alanine at Kabat position 153 and valine at Kabat position 191.

[0158] With regard to therapeutic antibodies, veltuzumab and rituximab are, respectively, humanized and chimeric IgG1 antibodies against CD20, of use for therapy of a wide variety of hematological malignancies and/or autoimmune diseases. **Table 1** compares the allotype sequences of rituximab vs. veltuzumab. As shown in **Table 1**, rituximab (G1m17,1) is a DEL allotype IgG1, with an additional sequence variation at Kabat position 214 (heavy chain CH1) of lysine in rituximab vs. arginine in veltuzumab. It has been reported that veltuzumab is less immunogenic in subjects than rituximab (*see, e.g.,* Morchhauser et al., 2009, *J Clin Oncol* 27:3346-53; Goldenberg et al., 2009, *Blood* 113:1062-70; Robak & Robak, 2011, *BioDrugs* 25:13-25), an effect that has been attributed to the difference between humanized and chimeric antibodies. However, the difference in allotypes between the EEM and DEL allotypes likely also accounts for the lower immunogenicity of veltuzumab.

Table 1. Allotypes of Rituximab vs. Veltuzumab

		Heavy chain position and associated allotypes					
	Complete allotype	*214*	*(allotype)*	*356/358*	*(allotype)*	*431*	*(allotype)*
Rituximab	*G1m17,1*	*K*	*17*	*D/L*	*1*	*A*	*-*
Veltuzumab	*G1m3*	*R*	*3*	*E/M*	*-*	*A*	*-*

[0159] In order to reduce the immunogenicity of therapeutic antibodies in individuals of nG1m1 genotype, it is desirable to select the allotype of the antibody to correspond to the G1m3 allotype, characterized by arginine at Kabat 214, and the nG1m1,2 null-allotype, characterized by glutamic acid at Kabat position 356, methionine at Kabat position 358 and alanine at Kabat position 431. Surprisingly, it was found that repeated subcutaneous administration of G1m3 antibodies over a long period of time did not result in a significant immune response. In alternative embodiments, the human IgG4 heavy chain in common with the G1m3 allotype has arginine at Kabat 214, glutamic acid at Kabat 356, methionine at Kabat 359 and alanine at Kabat 431. Since immunogenicity appears to relate at least in part to the residues at those locations, use of the human IgG4 heavy chain constant region sequence for therapeutic antibodies is also a preferred embodiment. Combinations of G1m3 IgG1 antibodies with IgG4 antibodies may also be of use for therapeutic administration.

[0160] Exemplary antibody constant region sequences of use in the chimeric and humanized anti-histone antibodies are disclosed in SEQ ID NO:109 and SEQ ID NO:110 below.

Exemplary human heavy chain constant region

ASTKGPSVFPLAPCSRSTSESTAALGCLVKDYFPEPVTVSWNSGALTSGVHTFPAVLQ
SSGLYSLSSVVTVPSSSLGTKTYTCNVDHKPSNTKVDKRVESKYGPPCPPCPAPEFLG
GPSVFLFPPKPKDTLMISRTPEVTCVVVDVSQEDPEVQFNWYVDGVEVHNAKTKPR
EEQFNSTYRVVSVLTVLHQDWLNGKEYKCKVSNKGLPSSIEKTISKAKGQPREPQVY
TLPPSQEEMTKNQVSLTCLVKGFYPSDIAVEWESNGQPENNYKTTPPVLDSDGSFFL
YSRLTVDKSRWQEGNVFSCSVMHEALHNHYTQKSLSLSLGK (SEQ ID NO:109)

Exemplary human light chain constant region

TVAAPSVFIFPPSDEQLKSGTASVVCLLNNFYPREAKVQWKVDNALQSGNSQESVTE
QDSKDSTYSLSSTLTLSKADYEKHKVYACEVTHQGLSSPVTKSFNRGEC (SEQ ID
NO:110)

Immunoconjugates

[0161] In certain embodiments, the antibodies or fragments thereof may be conjugated to one or more therapeutic or diagnostic agents. The therapeutic agents do not need to be the same but can be different, e.g. a drug and a radioisotope. For example, ^{131}I can be incorporated into a tyrosine of an antibody or fusion protein and a drug attached to an epsilon amino group of a lysine residue. Therapeutic and diagnostic agents also can be attached, for example to reduced SH groups and/or to carbohydrate side chains. Many methods for making covalent or non-covalent conjugates of therapeutic or diagnostic agents with antibodies or fusion proteins are known in the art and any such known method may be utilized.

[0162] A therapeutic or diagnostic agent can be attached at the hinge region of a reduced antibody component via disulfide bond formation. Alternatively, such agents can be attached using a heterobifunctional cross-linker, such as *N*-succinyl 3-(2-pyridyldithio)propionate (SPDP). Yu *et al., Int. J. Cancer 56*: 244 (1994). General techniques for such conjugation are well-known in the art. See, for example, Wong, CHEMISTRY OF PROTEIN CONJUGATION AND CROSS-LINKING (CRC Press 1991); Upeslacis *et al.*, "Modification of Antibodies by Chemical Methods," in MONOCLONAL ANTIBODIES: PRINCIPLES AND APPLICATIONS, Birch *et al.* (eds.), pages 187-230 (Wiley-Liss, Inc. 1995); Price, "Production and Characterization of Synthetic Peptide-Derived Antibodies," in MONOCLONAL ANTIBODIES: PRODUCTION, ENGINEERING AND CLINICAL APPLICATION, Ritter *et al.* (eds.), pages 60-84 (Cambridge University Press 1995). Alternatively, the therapeutic or diagnostic agent can be conjugated via a carbohydrate moiety in the Fc region of the antibody. The carbohydrate group can be used to increase the loading of the same agent that is bound to a thiol group, or the carbohydrate moiety can be used to bind a different therapeutic or diagnostic agent.

[0163] Methods for conjugating peptides to antibody components via an antibody carbohydrate moiety are well-known to those of skill in the art. See, for example, Shih *et al., Int. J. Cancer 41*: 832 (1988); Shih *et al., Int. J. Cancer 46*: 1101 (1990); and Shih *et al.*, U.S. Patent No. 5,057,313. The general method involves reacting an antibody component having an oxidized carbohydrate portion with a carrier polymer that has at least one free amine function. This reaction results in an initial Schiff base (imine) linkage, which can be stabilized by reduction to a secondary amine to form the final conjugate.

[0164] The Fc region may be absent if the antibody used as the antibody component of the immunoconjugate is an antibody fragment. However, it is possible to introduce a carbohydrate moiety into the light chain variable region of a full length antibody or antibody fragment. See, for example, Leung *et al., J. Immunol. 154*: 5919 (1995); Hansen *et al.*, U.S. Patent No. 5,443,953 (1995), Leung *et al.,* U.S. patent No. 6,254,868. The engineered carbohydrate moiety is used to attach the therapeutic or diagnostic agent.

[0165] In some embodiments, a chelating agent may be attached to an antibody, antibody fragment or fusion protein and used to chelate a therapeutic or diagnostic agent, such as a radionuclide. Exemplary chelators include but are not limited to DTPA (such as Mx-DTPA), DOTA, TETA, NETA or NOTA. Methods of conjugation and use of chelating agents to attach metals or other ligands to proteins are well known in the art (see, e.g., U.S. Patent No. 7,563,433).

[0166] In certain embodiments, radioactive metals or paramagnetic ions may be attached to proteins or peptides by reaction with a reagent having a long tail, to which may be attached a

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multiplicity of chelating groups for binding ions. Such a tail can be a polymer such as a polylysine, polysaccharide, or other derivatized or derivatizable chains having pendant groups to which can be bound chelating groups such as, *e.g.*, ethylenediaminetetraacetic acid (EDTA), diethylenetriaminepentaacetic acid (DTPA), porphyrins, polyamines, crown ethers, bis-thiosemicarbazones, polyoximes, and like groups known to be useful for this purpose.

[0167] Chelates may be directly linked to antibodies or peptides, for example as disclosed in U.S. Patent 4,824,659. Particularly useful metal-chelate combinations include 2-benzyl-DTPA and its monomethyl and cyclohexyl analogs, used with diagnostic isotopes in the general energy range of 60 to 4,000 keV, such as ^{125}I, ^{131}I, ^{123}I, ^{124}I, ^{62}Cu, ^{64}Cu, ^{18}F, ^{111}In, ^{67}Ga, ^{68}Ga, ^{99m}Tc, ^{94m}Tc, ^{11}C, ^{13}N, ^{15}O, ^{76}Br, for radioimaging. The same chelates, when complexed with non-radioactive metals, such as manganese, iron and gadolinium are useful for MRI. Macrocyclic chelates such as NOTA, DOTA, and TETA are of use with a variety of metals and radiometals, most particularly with radionuclides of gallium, yttrium and copper, respectively. Such metal-chelate complexes can be made very stable by tailoring the ring size to the metal of interest. Other ring-type chelates such as macrocyclic polyethers, which are of interest for stably binding nuclides, such as ^{223}Ra for RAIT are encompassed.

[0168] More recently, methods of ^{18}F-labeling of use in PET scanning techniques have been disclosed, for example by reaction of F-18 with a metal or other atom, such as aluminum. The ^{18}F-Al conjugate may be complexed with chelating groups, such as DOTA, NOTA or NETA that are attached directly to antibodies or used to label targetable constructs in pre-targeting methods. Such F-18 labeling techniques are disclosed in U.S. Patent No. 7,563,433.

Therapeutic Agents

[0169] In alternative embodiments, therapeutic agents such as cytotoxic agents, anti-angiogenic agents, pro-apoptotic agents, antibiotics, hormones, hormone antagonists, chemokines, drugs, prodrugs, toxins, enzymes or other agents may be used, either conjugated to the subject anti-histone antibodies or other histone-neutralizing agents, or else separately administered before, simultaneously with, or after the histone-neutralizing agent. Drugs of use may possess a pharmaceutical property selected from the group consisting of antimitotic, antikinase (e.g., anti-tyrosine kinase), alkylating, antimetabolite, antibiotic, alkaloid, anti-angiogenic, pro-apoptotic agents, immune modulators, and combinations thereof.

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[0170] Exemplary drugs of use may include 5-fluorouracil, aplidin, azaribine, anastrozole, anthracyclines, bendamustine, bleomycin, bortezomib, bryostatin-1, busulfan, calicheamycin, camptothecin, carboplatin, 10-hydroxycamptothecin, carmustine, celebrex, chlorambucil, cisplatin (CDDP), Cox-2 inhibitors, irinotecan (CPT-11), SN-38, carboplatin, cladribine, camptothecans, cyclophosphamide, cytarabine, dacarbazine, docetaxel, dactinomycin, daunorubicin, doxorubicin, 2-pyrrolinodoxorubicine (2P-DOX), cyano-morpholino doxorubicin, doxorubicin glucuronide, epirubicin glucuronide, estramustine, epipodophyllotoxin, estrogen receptor binding agents, etoposide (VP16), etoposide glucuronide, etoposide phosphate, floxuridine (FUdR), 3',5'-O-dioleoyl-FudR (FUdR-dO), fludarabine, flutamide, farnesyl-protein transferase inhibitors, gemcitabine, hydroxyurea, idarubicin, ifosfamide, L-asparaginase, lenolidamide, leucovorin, lomustine, mechlorethamine, melphalan, mercaptopurine, 6-mercaptopurine, methotrexate, mitoxantrone, mithramycin, mitomycin, mitotane, navelbine, nitrosourea, plicomycin, procarbazine, paclitaxel, pentostatin, PSI-341, raloxifene, semustine, streptozocin, tamoxifen, taxol, temazolomide (an aqueous form of DTIC), transplatinum, thalidomide, thioguanine, thiotepa, teniposide, topotecan, uracil mustard, vinorelbine, vinblastine, vincristine and vinca alkaloids.

[0171] Toxins of use may include ricin, abrin, alpha toxin, saporin, ribonuclease (RNase), e.g., onconase, DNase I, *Staphylococcal* enterotoxin-A, pokeweed antiviral protein, gelonin, diphtheria toxin, *Pseudomonas* exotoxin, and *Pseudomonas* endotoxin.

[0172] Chemokines of use may include RANTES, MCAF, MIP1-alpha, MIP1-Beta and IP-10.

[0173] Immunomodulators of use may be selected from a cytokine, a stem cell growth factor, a lymphotoxin, a hematopoietic factor, a colony stimulating factor (CSF), an interferon (IFN), erythropoietin, thrombopoietin and a combination thereof. Specifically useful are lymphotoxins such as tumor necrosis factor (TNF), hematopoietic factors, such as interleukin (IL), colony stimulating factor, such as granulocyte-colony stimulating factor (G-CSF) or granulocyte macrophage-colony stimulating factor (GM-CSF), interferon, such as interferons-α, -β or -γ, and stem cell growth factor, such as that designated "S1 factor". Included among the cytokines are growth hormones such as human growth hormone, N-methionyl human growth hormone, and bovine growth hormone; parathyroid hormone; thyroxine; insulin; proinsulin; relaxin; prorelaxin; glycoprotein hormones such as follicle stimulating hormone (FSH), thyroid stimulating hormone (TSH), and luteinizing hormone (LH); hepatic growth factor; prostaglandin, fibroblast growth factor; prolactin; placental lactogen, OB protein; tumor necrosis factor-α and - ß; mullerian-inhibiting substance; mouse gonadotropin-associated peptide; inhibin; activin; vascular endothelial growth factor; integrin; thrombopoietin (TPO); nerve growth factors such as NGF-ß; platelet-growth factor; transforming growth factors (TGFs) such as TGF- α and TGF- ß; insulin-like growth factor-I and -II; erythropoietin (EPO); osteoinductive factors; interferons such as interferon-α, -β, and -γ; colony stimulating factors (CSFs) such as macrophage-CSF (M-CSF); interleukins (ILs) such as IL-1, IL-1α, IL-2, IL-3, IL-4, IL-5, IL-6, IL-7, IL-8, IL-9, IL-10, IL-11, IL-12; IL-13, IL-14, IL-15, IL-16, IL-17, IL-18, IL-21, IL-25, LIF, kit-ligand or FLT-3, angiostatin, thrombospondin, endostatin, tumor necrosis factor and LT. Lenolidamide is yet another immunomodulator that has shown activity in controlling certain cancers, such as multiple myeloma and hematopoietic tumors.

[0174] Other useful therapeutic agents may comprise oligonucleotides, especially antisense oligonucleotides that preferably are directed against oncogenes and oncogene products, such as bcl-2. A preferred form of therapeutic oligonucleotide is siRNA.

Immune Dysregulatory Disease

[0175] In various embodiments, the histone-neutralizing agents are of use to treat immune-dysregulatory diseases, such as glomerulonephritis. In certain preferred embodiments, the therapy may utilize either a combination of two or more histone-neutralizing agents.

[0176] Additional therapeutic agents that may be added in combination include a cytokine, a chemokine, a coagulation inhibitor, an anti-T cell or anti B-cell antibody or antibody fragment, an immunomodulator, a stem cell growth factor, a lymphotoxin, a hematopoietic factor, a colony stimulating factor, an interferon, erythropoietin or thrombopoietin. An optional therapeutic agent may include activated protein C, heparin or thrombomodulin, as mentioned above. Combinations of anti-histone antibodies or fragments thereof with other histone neutralizing agents, including but not limited to antibodies or antibody fragments against additional immune system target antigens, as discussed below, may be utilized in certain embodiments.

[0177] The immune system comprises both the innate immune system and the adaptive or acquired immune system. Many host cells participate in the processes of innate and adaptive immunity, such as neutrophils, T- and B-lymphocytes, macrophages and monocytes, dendritic cells, and plasma cells. They usually act in concert, affecting one another, particularly in the regulation of certain factors and cytokines that contribute to the recognition and processing of innate and external noxients, and these systems have evolved over the millions of years of the development of vertebrate, mammalian, and human organisms.

[0178] A major goal of immunotherapy is to exploit or enhance a patient's immune system against an innate or foreign noxient, such as a malignant cell or an invading microorganism. The immune system has been studied more in relation to recognizing and responding to exogenous noxients, such as microbial organisms, than it has in relation to indigenous malfunctions, such as cancer and certain autoimmune and immune-dysregulatory diseases, particularly since the latter may have both genetic as well as environmental components. The defenses against microbial organisms, such as bacteria, fungi, parasites, and viruses, are innate to the particular organism, with the immune system being programmed to recognize biochemical patterns of these microorganisms and to respond to attack them without requiring prior exposure to the microorganism. This innate immune system includes, for example, neutrophils, natural killer cells and monocytes/macrophages that can eradicate the invading microorganisms by direct engulfment and destruction.

[0179] The innate immune response is often referred to as a nonspecific one that controls an invading external noxient until the more specific adaptive immune system can marshal specific antibodies and T cells (cf. Modlin et al., *N Engl J Med* 1999, 340:1834-1835; Das, *Crit. Care* 2000; 4:290-296). The nonspecific immune responses involve the lymphatic system and phagocytes. The lymphatic system includes the lymphocytes and macrophages. Macrophages can engulf, kill and dispose of foreign particles. Phagocytes include neutrophils and macrophages, which again ingest, degrade and dispose of debris, and have receptors for complement and antibody. In summary, the innate immune system provides a line of defense again certain antigens because of inherited characteristics.

[0180] In contrast, the adaptive, or acquired, immune system, is highly evolved and very specific in its responses. It is called an adaptive system because it occurs during the lifetime of an individual as an adaptation to infection with a pathogen. Adaptive immunity can be artificially acquired in response to a vaccine (antigens) or by administering antibodies, or can be naturally acquired by infection. The acquired immunity can be active, if an antibody was produced, or it can be passive, if exogenous antibody made from another source is injected.

[0181] The adaptive immune system produces antibodies specific to a given antigen. The simplest and most direct way in which antibodies provide protection is by binding to them and thereby blocking their access to cells that they may infect or destroy. This is known as neutralization. Binding by antibodies, however, is not sufficient to arrest the replication of bacteria that multiply outside cells. In this case, one role of antibody is to enable a phagocytic cell to ingest and destroy the bacterium. This is known as opsonization. The third function of antibodies is to activate a system of plasma proteins, known as complement. In many cases, the adaptive immune system confers lifelong protective immunity to re-infection with the same pathogen, because the adaptive immune system has a `memory` of the antigens presented to it.

[0182] Antibody-mediated immunity is called humoral immunity and is regulated by B cells and the antibodies they produce. Cell-mediated immunity is controlled by T cells. Both humoral and cell-mediated immunity participate in protecting the host from invading organisms. This interplay can result in an effective killing or control of foreign organisms. Occasionally, however, the interplay can become erratic. In these cases, there is a dysregulation that can cause disease. Sometimes the disease is life-threatening, such as with septic shock and certain autoimmune disorders.

[0183] The B and T lymphocytes are critical components of a specific immune response. B cells are activated by antigen to engender clones of antigen-specific cells that mediate adaptive immunity. Most clones differentiate to plasma cells that secrete antibody, while a few clones form memory cells that revert to plasma cells. Upon subsequent re-infection, memory cells produce a higher level of antibody in a shorter period than in the primary response. Antibodies secreted by the plasma cells can play multiple roles in immunity, such as binding and neutralizing a foreign agent, acting as opsonins (IgG) to promote phagocytosis, directly affecting metabolism and growth of some organisms, engaging in antigen-antibody reactions that activate complement, causing phagocytosis and membrane attack complex, and/or engaging in antigen-antibody reactions that activate T cells and other killer cells.

[0184] T lymphocytes function as both helper cells and suppressor cells. Helper T cells induce antigen-specific B cells and effector T cells to proliferate and differentiate. Suppressor T cells interact with helper T cells to prevent an immune response or to suppress an ongoing one, or to regulate effector T cells. Cytotoxic T cells destroy antigen by binding to target cells. In a delayed-type hypersensitivity reaction, the T cells do not destroy antigen, but attract macrophages, neutrophils and other cells to destroy and dispose of the antigen.

[0185] T cells can detect the presence of intracellular pathogens because infected cells display on their surface peptide fragments derived from the pathogens' proteins. These foreign peptides are delivered to the cell surface by specialized host-cell glycoproteins, termed Major Histocompatibility Complex (MHC) molecules. The recognition of antigen as a small peptide fragment bound to a MHC molecule and displayed at the cell surface is one of the most distinctive features of T cells. There are two different classes of MHC molecules, known as MHC class I and MHC class II, that deliver peptides from different cellular compartments to the surface of the infected cell. Peptides from the cytosol are bound to MHC class I molecules which are expressed on the majority of nucleated cells and are recognized by CD8+ T cells. MHC class II molecules, in contrast, traffic to lysosomes for sampling endocytosed protein antigens which are presented to the CD4+ T cells (Bryant and Ploegh, *Curr Opin Immunol* 2004; 16:96-102).

[0186] CD8+ T cells differentiate into cytotoxic T cells, and kill the cell. CD4+ T cells differentiate into two types of effector T cells. Pathogens that accumulate in large numbers inside macrophage vesicles tend to stimulate the differentiation of T_{H1} cells which activate macrophages and induce B cells to make IgG antibodies that are effective in opsonizing extracellular pathogens for uptake by phagocytes. Extracellular antigens tend to stimulate the production of T_{H2} cells which initiate the humoral immune response by activating naive antigen-specific B cells to produce IgM antibodies, inter alia.

[0187] The innate and adaptive immune systems interact, in that the cells of the innate immune system can express various molecules that can interact with or trigger the adaptive immune system by activating certain cells capable of producing immune factors, such as by activating T and B cells of the lymphatic series of leukocytes. The early induced but non-adaptive responses are important for two main reasons. First, they can repel a pathogen or, more often, control it until an adaptive immune response can be mounted. Second, these early responses influence the adaptive response in several ways. For example, the innate immune response produces cytokines and other inflammatory mediators that have profound effects on subsequent events, including the recruitment of new phagocytic cells to local sites of infection. Another effect of these mediators is to induce the expression of adhesion molecules on the endothelial cells of the local blood vessels, which bind to the surface of circulating monocytes and neutrophils and greatly increase their rate of migration of these cells out of the blood and into the tissues. These events all are included under the term inflammation, which is a feature of the innate immune system that forms part of the protective response at a localized site to isolate, destroy and remove a foreign material. This is followed by repair. Inflammation is divided into acute and chronic forms.

[0188] The immune system communicates via nonspecific tissue resistance factors. These include the interferons, which are proteins produced in response to viruses, endotoxins and certain bacteria. Interferons inhibit viral replication and activate certain host-defense responses. Infected cells produce interferon that binds the infected cells to other, neighboring cells, causing them to produce antiviral proteins and enzymes that interfere with viral gene transcription and proteins synthesis. Interferons can also affect normal cell growth and suppress cell-mediated immunity.

[0189] Complement is another nonspecific tissue resistance factor, and comprises plasma proteins and membrane proteins that mediate specific and non-specific defenses. Complement has two pathways, the classical pathway associated with specific defense, and the alternative pathway that is activated in the absence of specific antibody, and is thus non-specific. In the classical pathway, antigen-antibody complexes are recognized when C1 interacts with the Fc of the antibody, such as IgM and to some extent, IgG, ultimately causing mast cells to release chemotactic factors, vascular mediators and a respiratory burst in phagocytes, as one of many mechanisms. The key complement factors include C3a and C5a, which cause mast cells to release chemotactic factors such as histamine and serotonin that attract phagocytes, antibodies and complement, etc. Other key complement factors are C3b and C5b, which enhance phagocytosis of foreign cells, and C8 and C9, which induce lysis of foreign cells (membrane attack complex).

[0190] Gelderman et al. (*Mol Immunol* 2003; 40:13-23) reported that membrane-bound complement regulatory proteins (mCRP) inhibit complement activation by an immunotherapeutic mAb in a syngeneic rat colorectal cancer model. While the use of mAb against tumor antigens and mCRP overcame an observed effect of mCRP on tumor cells, there has been no direct evidence to support this approach. Still other attempts to use bispecific antibodies against CD55 and against a tumor antigen (G250 or EpCAM) have been suggested by Gelderman et al. (*Lab Invest* 2002; 82:483-493; *Eur J Immunol* 2002; 32:128-135) based on in vitro studies that showed a 2-13-fold increase in C3 deposition compared to use of the parental antitumor antibody. However, no results involving enhanced cell killing were reported. Jurianz et al. (*Immunopharmacology* 1999; 42:209-218) also suggested that combining treatment of a tumor with anti-HER2 antibodies in vitro could be enhanced by prior treatment with antibody-neutralization of membrane-complement-regulatory protein, but again no in vivo results were provided. Sier et al. (*Int J Cancer* 2004; 109:900-908) recently reported that a bispecific antibody made against an antigen expressed on renal cell carcinoma (Mab G250) and CD55 enhanced killing of renal cancer cells in spheroids when beta-glucan was added, suggesting that the presence of CR3-priming beta-glucan was obligatory.

[0191] Neutrophils, another cell involved in innate immune response, also ingest, degrade and dispose of debris. Neutrophils have receptors for complement and antibody. By means of complement-receptor bridges and antibody, the foreign noxients can be captured and presented to phagocytes for engulfment and killing.

[0192] Macrophages are white blood cells that are part of the innate system that continually search for foreign antigenic substances. As part of the innate immune response, macrophages engulf, kill and dispose of foreign particles. However, they also process antigens for presentation to B and T cells, invoking humoral or cell-mediated immune responses.

[0193] The dendritic cell is one of the major means by which innate and adaptive immune systems communicate (Reis e Sousa, *Curr Opin Immunol* 2004; 16:21-25). It is believed that these cells shape the adaptive immune response by the reactions to microbial molecules or signals. Dendritic cells capture, process and present antigens, thus activating CD4+ and CD8+ naive T lymphocytes, leading to the induction of primary immune responses, and derive their stimulatory potency from expression of MHC class I, MHC class II, and accessory molecules, such as CD40, CD54, CD80, CD86, and T-cell activating cytokines (Steinman, *J Exp Hematol* 1996; 24:859-862; Banchereau and Steinman, *Nature* 1998; 392:245-252). These properties have made dendritic cells candidates for immunotherapy of cancers and infectious diseases (Nestle, *Oncogene* 2000; 19:673-679; Fong and Engleman, *Annu Rev Immunol* 2000; 18:245-273; Lindquist and Pisa, *Med Oncol* 2002; 19:197-211), and have been shown to induce antigen-specific cytotoxic T cells that result in strong immunity to viruses and tumors (Kono et al., Clin *Cancer Res* 2002; 8:394-40).

[0194] Also important for interaction of the innate and adaptive immune systems is the NK cell, which appears as a lymphocyte but behaves like a part of the innate immune system. NK cells have been implicated in the killing of tumor cells as well as essential in the response to viral infections (Lanier, *Curr Opin Immunol* 2003; 15:308-314; Carayannopoulos and Yokoyama, *Curr Opin Immunol* 2004; 16:26-33). Yet another important mechanism of the innate immune system is the activation of cytokine mediators that alert other cells of the mammalian host to the presence of infection, of which a key component is the transcription factor NF-κB (Li and Verna, *Nat Rev Immunol* 2002; 2:725-734).

[0195] As mentioned earlier, the immune system can overreact, resulting in allergies or autoimmune diseases. It can also be suppressed, absent, or destroyed, resulting in disease and death. When the immune system cannot distinguish between "self" and "nonself," it can attach and destroy cells and tissues of the body, producing autoimmune diseases, e.g., juvenile diabetes, multiple sclerosis, myasthenia gravis, systemic lupus erythematosus, rheumatoid arthritis, and immune thrombocytopenic purpura. Immunodeficiency disease results from the lack or failure of one or more parts of the immune system, and makes the individuals susceptible to diseases that usually do not affect individuals with a normal immune system. Examples of immunodeficiency disease are severe combined immunodeficiency disease (SCID) and acquired immunodeficiency disease (AIDS). The latter results from human immunodeficiency virus (HIV) and the former from enzyme or other inherited defects, such as adenosine deaminase deficiency.

[0196] Numerous and diverse methods of immunosuppression or of neutralizing proinflammatory cytokines have proven to be unsuccessful clinically in patients with sepsis and septic shock anti-inflammatory strategies. (Riedmann, et al., cited above; Van Amersfoort et al. (*Clin Microbiol Rev* 2003; 16:379-414), such as general immunosuppression, use of nonsteroidal anti-inflammatory drugs, TNF-α antibody (infliximab) or a TNF-R:Fc fusion protein (etanercept), IL-1 (interleukin-1) receptor antagonist, or high doses of corticosteroids. However, a success in the treatment of sepsis in adults was the PROWESS study (Human Activated Protein C Worldwide Evaluation in Severe Sepsis (Bernard et al., *N Engl J Med* 2001; 344:699-709)), showing a lower mortality (24.7%) than in the placebo group (30.8%). This activated protein C (APC) agent probably inhibits both thrombosis and inflammation, whereas fibrinolysis is fostered. Friggeri et al. (2012, *Mol Med* 18:825-33) reported that APC degrades histones H3 and H4, which block uptake and clearance of apoptotic cells by macrophages and thereby contribute to organ system dysfunction and mortality in acute inflammatory states. Van Amersfoort et al. state, in their review (ibid.) that: "Although the blocking or modulation of a number of other targets including complement and coagulation factors, neutrophil adherence, and NO release, are promising in animals, it remains to be determined whether these therapeutic approaches will be effective in humans." This is further emphasized in a review by Abraham, "Why immunomodulatory therapies have not worked in sepsis" (*Intensive Care Med* 1999; 25:556-566). In general, although many rodent models of inflammation and sepsis have shown encouraging results with diverse agents over the past decade or more, most agents translated to the clinic failed to reproduce in humans what was observed in these animal models, so that there remains a need to provide new agents that can control the complex presentations and multiple-organ involvement of various diseases involving sepsis, coagulopathy, and certain neurodegenerative conditions having inflammatory or immune dysregulatory components.

[0197] More recent work on immunoglobulins in sepsis or septic shock has been reported. For example, Toussaint and Gerlach (2012, *Curr Infect Dis Rep* 14:522-29) summarized the use of ivIG as an adjunct therapy in sepsis. The metanalysis failed to show any strong correlation between general immunoglobulin therapy and outcome. LaRosa and Opal (2012, *Curr Infect Dis Rep* 14:474-83) reported on new therapeutic agents of potential use in sepsis. Among other agents, anti-TNF antibodies are in current clinical trials for sepsis, while complement antagonists have shown promising results in preclinical models of sepsis. Nalesso et al. (2012, *Curr Infect Dis Rep* 14:462-73) suggested that combination therapies with multiple agents may prove more effective for sepsis treatment. The immunopathogenesis of sepsis has been summarized by Cohen (2002, *Nature* 420:885-91).

[0198] The immune system in sepsis is believed to have an early intense proinflammatory response after infection or trauma, leading to organ damage, but it is also believed that the innate immune system often fails to effectively kill invading microorganisms (Riedmann and Ward, *Expert Opin Biol Ther* 2003; 3:339-350). There have been some studies of macrophage migration inhibitory factor (MIF) in connection with sepsis that have shown some promise. For example, blockage of MIF or targeted disruption of the MIF gene significantly improved survival in a model of septic shock in mice (Calandra et al., *Nature Med* 2000; 6:164-170), and several lines of evidence have pointed to MIF as a potential target for therapeutic intervention in septic patients (Riedmann et al., cited above). Bucala et al. (U.S. Pat. No. 6,645,493 B1) have claimed that an anti-MIF antibody can be effective therapeutically for treating a condition or disease caused by cytokine-mediated toxicity, including different forms of sepsis, inflammatory diseases, acute respiratory disease syndrome, granulomatous diseases, chronic infections, transplant rejection, cachexia, asthma, viral infections, parasitic infections, malaria, and bacterial infections, which is incorporated herein in its entirety, including references. The use of anti-LPS (lipopolysaccharide) antibodies alone similarly has had mixed results in the treatment of patients with septic shock (Astiz and Rackow, *Lancet* 1998; 351:1501-1505; Van Amersfoort et al., *Clin Microbiol Rev* 2003; 16:379-414.

[0199] Complement C5a, like C3a, is an anaphylatoxin. It mediates inflammation and is a chemotactic attractant for induction of neutrophilic release of antimicrobial proteases and oxygen radicals. Therefore, C5a and its predecessor C5 are particularly preferred targets. By targeting C5, not only is C5a affected, but also C5b, which initiates assembly of the membrane-attack complex. Thus, C5 is another preferred target. C3b, and its predecessor C3, also are preferred targets, as both the classical and alternate complement pathways depend upon C3b. Three proteins affect the levels of this factor, C1 inhibitor, protein H and Factor I, and these are also preferred targets according to the invention. Complement regulatory proteins, such as CD46, CD55, and CD59, may be targets to which the multispecific antibodies bind.

[0200] Coagulation factors also are preferred targets according to the invention, particularly tissue factor (TF), thrombomodulin, and thrombin. TF is also known also as tissue thromboplastin, CD142, coagulation factor III, or factor III. TF is an integral membrane receptor glycoprotein and a member of the cytokine receptor superfamily. The ligand binding extracellular domain of TF consists of two structural modules with features that are consistent with the classification of TF as a member of type-2 cytokine receptors. TF is involved in the blood coagulation protease cascade and initiates both the extrinsic and intrinsic blood coagulation cascades by forming high affinity complexes between the extracellular domain of TF and the circulating blood coagulation factors, serine proteases factor VII or factor VIIa. These enzymatically active complexes then activate factor IX and factor X, leading to thrombin generation and clot formation.

[0201] TF is expressed by various cell types, including monocytes, macrophages and vascular endothelial cells, and is induced by IL-1, TNF-α or bacterial lipopolysaccharides. Protein kinase C is involved in cytokine activation of endothelial cell TF expression. Induction of TF by endotoxin and cytokines is an important mechanism for initiation of disseminated intravascular coagulation seen in patients with Gram-negative sepsis. TF also appears to be involved in a variety of non-hemostatic functions including inflammation, cancer, brain function, immune response, and tumor-associated angiogenesis. Thus, multispecific antibodies that target TF are useful not only in the treatment of coagulopathies, but also in the treatment of sepsis, cancer, pathologic angiogenesis, and other immune and inflammatory dysregulatory diseases according to the invention. A complex interaction between the coagulation pathway and the cytokine network is suggested by the ability of several cytokines to influence TF expression in a variety of cells and by the effects of ligand binding to the receptor. Ligand binding (factor VIIa) has been reported to give an intracellular calcium signal, thus indicating that TF is a true receptor.

[0202] Thrombin is the activated form of coagulation factor II (prothrombin); it converts fibrinogen to fibrin. Thrombin is a potent chemotaxin for macrophages, and can alter their production of cytokines and arachidonic acid metabolites. It is of particular importance in the coagulopathies that accompany sepsis. Numerous studies have documented the activation of the coagulation system either in septic patients or following LPS administration in animal models. Despite more than thirty years of research, the mechanisms of LPS-induced liver toxicity remain poorly understood. It is now clear that they involve a complex and sequential series of interactions between cellular and humoral mediators. In the same period of time, gram-negative systemic sepsis and its sequallae have become a major health concern, attempts to use monoclonal antibodies directed against LPS or various inflammatory mediators have yielded only therapeutic failures, as noted elsewhere herein. Multispecific antibodies according to the invention that target both thrombin and at least one other target address the clinical failures in sepsis treatment.

[0203] A recombinant form of thrombomodulin has been approved for treatment of disseminated intravascular coagulation (DIC) and is in phase II clinical trials for DIC associated with sepsis (Okamoto et al., 2012, *Crit Care Res Pract*, Epub 2012 Feb 28). Thrombomodulin has a pivotal role in the protein C system that is important in the pathogensis of sepsis (Levi and Van der Poll, *Minerva Anestesiol* Epub Dec 17, 2012). Downregulation of thrombomodulin in sepsis causes impaired activation of protein C that is central in the modulation of coagulation and inflammation (Levi and Van der Poll, *Minerva Anestesiol* Epub Dec 17, 2012). Administration of recombinant thrombomodulin is reported to have a beneficial effect on restoration of coagulation and improvement of organ failure (Levi and Van der Poll, *Minerva Anestesiol* Epub Dec 17, 2012). A recent retrospective study confirmed that treatment with recombinant thrombomodulin was associated with reduced mortality in hospitalized patients with sepsis-induced DIC (Yamakawa et al., 2013, *Intensive Care Med,* Epub January 30, 2013).

[0204] In other embodiments, the multispecific antibodies bind to a MHC class I, MHC class II or accessory molecule, such as CD40, CD54, CD80 or CD86. The multispecific antibody also may bind to a T-cell activation cytokine, or to a cytokine mediator, such as NF-κB.

Kits

[0205] Various embodiments may concern kits containing components suitable for treating or diagnosing glomerulonephritis in a patient. Exemplary kits may contain one or more histone-neutralizing agents, such as the anti-histone antibodies described herein. If the composition containing components for administration is not formulated for delivery via the alimentary canal, such as by oral delivery, a device capable of delivering the kit components through some other route may be included. One type of device, for applications such as parenteral delivery, is a syringe that is used to inject the composition into the body of a subject. Inhalation devices may also be used. In certain embodiments, a therapeutic agent may be provided in the form of a prefilled syringe or autoinjection pen containing a sterile, liquid formulation or lyophilized preparation.

[0206] The kit components may be packaged together or separated into two or more containers. In some embodiments, the containers may be vials that contain sterile, lyophilized formulations of a composition that are suitable for reconstitution. A kit may also contain one or more buffers suitable for reconstitution and/or dilution of other reagents. Other containers that may be used include, but are not limited to, a pouch, tray, box, tube, or the like. Kit components may be packaged and maintained sterilely within the containers. Another component that can be included is instructions to a person using a kit for its use.

EXAMPLES

Example 1. Effect of Histone-Neutralizing Agents on Vascular Necrosis in Severe Glomerulonephritis

[0207] Severe glomerulonephritis involves cell necrosis as well as NETosis, a programmed neutrophil death leading to expulsion of nuclear chromatin leading to neutrophil extracellular traps (NETs). We speculated on a role of the dying cell`s and NET`s histone component in necrotizing glomerulonephritis. Histones from calf thymus or histones released by neutrophils undergoing NETosis killed glomerular endothelial cells, podocytes, and parietal epithelial cells in a dose-dependent manner. As discussed below, this effect was prevented by histone-neutralizing agents such as anti-histone IgG, activated protein C, or heparin.

[0208] Histone toxicity on glomeruli *ex vivo* was TLR2/4-dependent. Lack of TLR2/4 attenuated intra-arterial histone injection-induced renal thrombotic microangiopathy and glomerular necrosis in mice. Anti-GBM glomerulonephritis involved NET formation and vascular necrosis. Pre-emptive anti-histone IgG administration significantly reduced all aspects of glomerulonephritis, i.e. vascular necrosis, podocyte loss, albuminuria, cytokine induction, recruitment and activation of glomerular leukocytes as well as glomerular crescent formation.

[0209] To evaluate the therapeutic potential of histone neutralization we treated mice with established glomerulonephritis with three different histone-neutralizing agents. Anti-histone IgG, recombinant activated protein C, and heparin all abrogated severe glomerulonephritis, suggesting that histone-mediated glomerular pathology is not an initial but rather a subsequent event in necrotizing glomerulonephritis. Together, histone release during glomerulonephritis elicits cytotoxic and immunostimulatory effects. Neutralizing extracellular histones is therapeutic in severe experimental glomerulonephritis.

Materials and methods

[0210] Mice and anti-GBM nephritis model - C57BL/6 mice were procured from Charles River (Sulzfeld, Germany). 6-8 week old mice received an intravenous injection of 100 µl of anti-GBM serum (sheep anti-rat glomeruli basement membrane serum procured from

Probetex INC, PTX-001). Urine samples were collected at different time points after antiserum injection to evaluate the functional parameters of kidney damage. On day 7 the mice were sacrificed by cervical dislocation to collect plasma and kidney tissue. Kidneys were kept at -80°C for protein isolation and in RNALATER® solution at -20°C for RNA isolation. A part of the kidney was also kept in formalin to be embedded in paraffin for histological analysis (Teixeira *et al.*, 2005, *Kidney Int* 67:514B). We treated groups of mice either with 20mg/kg, i.p. control IgG or anti-histone antibody (clone BWA-3) to neutralize the effects of extracellular histones.

[0211] Assessment of renal pathology - Renal sections of 2 μm were stained with periodic acid-Schiff reagent. Glomerular abnormalities were scored in 50 glomeruli per section by a blinded observer. The following criteria were assessed in each of the 50 glomeruli and scored as segmental or global lesions if less or more than 50% of the glomerular tuft were affected by focal necrosis and capsule adhesions. Cellular crescents were assessed separately when more than a single layer of PECs were present around the inner circumference of Bowman`s capsule. Immunostaining was performed as described using the following primary antibodies: for WT-1/nephrin, neutrophils (Serotec, Oxford, UK), Mac-2 (Cedarlane, Ontario, Canada), TNF-α (Abcam, Cambridge, UK) and fibrinogen (Abcam, Cambridge, UK). Stained glomerular cells were quantified in 50 glomeruli per section.

[0212] Electron microscopy - Kidney tissues and endothelial cell monolayers were fixed in 2.0% paraformaldehyde/ 2.0% glutaraldehyde, in 0.1M sodium phosphate buffer, pH 7.4 for 24h, followed by 3 washes x15 min in 0.1m sodium phosphate buffer, pH 7.4 and distilled water. For transmission EM kidneys were post-fixed, in phosphate cacodylate-buffered 2% OsO4 for 1h, dehydrated in graded ethanols with a final dehydration in propylene oxide and embedded in Embed-812 (Electron Microscopy Sciences, Hatfield, PA). Ultrathin sections (~90-nm thick) were stained with uranyl acetate and Venable's lead citrate. For scanning EM, after rinsing in distilled H_2O, cells on coverslips were treated with 1% thiocarbohydrazide, post-fixed with 0.1% osmium tetroxide, dehydrated in ethanol, mounted on stubs with silver paste and critical-point dried before being sputter coated with gold/palladium. Specimens were viewed with a JEOL model 1200EX electron microscope (JEOL, Tokyo, Japan).

[0213] Immunohistochemistry of human tissues - Formalin-fixed paraffin-embedded sections of renal biopsies from five subjects with ANCA-positive RPGN, newly diagnosed in 2013, were drawn from the files of the Institute of Pathology at the Ludwig-Maximilians-University of Munich. The renal biopsies were fixed in 4 % PBS-buffered formalin solution and embedded in paraffin. Biopsies contained normal glomeruli and glomeruli exhibiting cellular, fibrocellular or fibrous crescents. Controls consisted of normal kidney tissue from tumor nephrectomies. TLR2 and TLR4 expression was assessed by using specific antibodies (TLR2-LS Bio, Seattle, WA, TLR4- Novus, Littleton, CO).

In-vitro models

[0214] Cytotoxicity assay - Mouse glomerular endothelial cells (GEnC (*46*)), podocytes (*47*)), and parietal epithelial cells (PECs,(*48*)) were cultured in 96 well plates with RPMI media without FCS and PS and allowed to adhere overnight. The cells were stimulated with the different concentrations of total calf thymus histones (10, 20, 30, 40, 50 and 100μg/ml) with or without histone antibody for another 18-20h. Cytotoxicity assay was performed using Promega CELLTITER 96® non-radioactive cell proliferation assay (MTT Assay Kit, Mannheim, Germany). Glomerular cells were also incubated with histones with or without anti-histone IgG, heparin and/or aPC. LDH assay using cytotoxicity detection kit (Roche Diagnostics, Mannheim, Germany) was used to assess cell death.

[0215] Podocyte detachment assay - Podocytes were grown at 33^{0}C using modified RPMI media in the presence of IFN-γ in collagen coated 10 cm dishes and 8x10^4 cells were seeded and allowed to differentiate as podocytes at 37^{0}C for two weeks in collagen plates without IFN-γ. Once the monolayers of podocytes were differentiated, the cells were treated with either histones or GBM antiserum with or without histone antibody and allowed to sit for 18h. Detached cells which are present in supernatant were manually counted using an hemocytometer. Adhered cells were trypsinised and counted manually to calculate the percentage of cells detached.

[0216] In-vitro tube formation assay - Matrigel was thawed overnight at 4^{0}C to make it liquid. After 10 μl per well of μ-slide angiogenesis (IBIDI, Munich, Germany) was added, the gel was allowed to solidify at 37^{0}C. GEnCs were seeded at 1x10^4 cells/well and stimulated with VEGF and b-FGF as positive control or with histones with or without anti-histone antibody. Tube formation as a marker of angiogenesis was assessed by light microscopy by taking a series of pictures at 0 h, 4h 8h and 24h (*49*).

[0217] NETosis assay - Neutrophils were isolated from healthy mice by dextran sedimentation and hypotonic lysis of RBCs. Neutrophil extracellular traps (NETs) were induced *in-vitro* by adding TNF-α (Immunotools, Friesoythe, Germany) or phorbol 12-myristate 13-acetate (PMA, Sigma-Aldrich, MO, USA) for 12 h in with or without anti-histone antibody. Endothelial cell death was assessed by MTT assay and immunofluorescence staining for histones (BWA-3 clone), neutrophil elastase (ABCAM®, Cambridge, UK) and 4′,6-Diamidin-2-phenylindol (DAPI, Vector labs, Burlingame, CA) after fixing with acetone.

[0218] BMDCs and J774 macrophages - Bone marrow cells were isolated from healthy mouse and plated at $1x10^6$ cells per well and differentiated into BMDCs in the presence of GM-CSF (Immunotools). J774 macrophage cells were grown in RPMI media, plated at $1x10^6$ cells per well, and stimulated with different doses of histones with or without anit-histone antibody for 18 h. Supernatants were collected for TNF-α (Bio Legend, San Diego, CA) and IL-6 Elisa (BD Biosciences, San Diego, CA) determination. Flow cytometry for the activation markers MHC-II, CD40, CD103 and CD86 (BD) was also performed.

[0219] Flow cytometry - Flow cytometric analysis of cultured and renal immune cells was performed on a FACSCALIBUR™ flow cytometer (BD) as described (Lech *et al.*, 2009, *J Immunol* 183:4109). Every isolate was incubated with binding buffer containing either anti-mouse CD11c, CD11b, CD103, F4/80, and CD45 antibodies (BD) for 45 min at 4^0C in the dark were used to detect renal mononuclear phagocyte populations. Anti-CD86 (BD) was used as an activation marker. Anti-CD3 and CD4 (BD) were used to identify the respective T-cell populations.

[0220] RNA preparation and real-time RT-PCR - Reverse transcription and real time RT-PCR from total renal RNA was prepared as described (Patole *et al.*, 2007, *J Autoimmun* 29:52). SYBR Green Dye detection system was used for quantitative real-time PCR on a Light Cycler 480 (Roche, Mannheim, Germany). Gene-specific primers (300 nM, Metabion, Martinsried, Germany) were used as follows: Reverse and forward primers respectively 18s: AGGGCCTCACTAAACCATCC (SEQ ID NO:111) and GCAATTATTCCCCATGAACG (SEQ ID NO:112), TNF-α: CCACCACGCTCTTCTGTCTAC (SEQ ID NO:113) and AGGGTCTGGGCCATAGAACT (SEQ ID NO:114), Fibrinogen (FGL-2): AGGGGTAACTCTGTAGGCCC (SEQ ID NO:115) and GAACACATGCAGTCACAGCC (SEQ ID NO:116), WT-1: CATCCCTCGTCTCCCATTTA (SEQ ID NO:117) and TATCCGAGTTGGGGAAATCA (SEQ ID NO:118), CD44: AGCGGCAGGTTACATTCAAA (SEQ ID NO:119) and CAAGTTTTGGTGGCACACAG (SEQ ID NO:120). Controls consisting of ddH_2O were negative for target and housekeeping genes.

Statistical analysis

[0221] Data were expressed as mean ± standard error of the mean (SEM). Comparison between groups was performed by two-tailed *t*-test or ANOVA. A value of $p<0.05$ was considered to be statistically significant. All statistical analyses were calculated using Graph Pad Prism (GraphPad).

Example 2. Glomerular TLR2 and TLR4 expression in severe human glomerulonephritis

[0222] We first asked whether the TLR2 and TLR4 (Allam et al., 2012, *J Am Soc Nephrol* 23:1375) extracellular histones were expressed in the healthy and diseased glomeruli. TLR2/4 immunostaining of normal human kidney showed a weak granular positivity in all glomerular cells. TLR4 positivity was clearly noted in glomerular endothelial cells (**FIG. 1A**). In addition, TLR2 was strongly positive in the cytoplasm of epithelial cells of the proximal and distal tubule, while this was less prominent for TLR4 (**FIG. 1A**). Immunostaining of kidney biopsies of patients with ANCA-associated necrotizing and crescentic GN revealed prominent positivity also in PECs along the inner aspect of Bowman`s capsule (**FIG. 1B**). As glomerular crescents are largely formed by PECs (Smeets *et al.*, 2009, *J Am Soc Nephrol* 20:2593; Smeets *et al.*, 2009, *J Am Soc Nephrol* 20:2604), glomerular crescents displayed TLR2 and TLR4 positivity (**FIG. 1C**). Thus, the cells of the normal glomerulus express TLR2/4 and PECs induce these TLRs in crescentic GN.

Example 3. Anti-histone IgG prevents histone toxicity on glomerular cells

[0223] Histones were previously shown to be toxic to pulmonary endothelial cells *in vitro* and *in vivo* (Xu *et al.*, 2009, *Nat Med* 15:1318; Abrams *et al.*, 2013, *Am J Respir Crit Care Med* 187:160). We tested this effect on cultured glomerular endothelial cells and found that a total histone preparation was cytotoxic in a dose-dependent manner. Anti-histone IgG derived from the BWA-3 hybridoma is known to neutralize the toxic and immunostimulatory effect of extracellular histones (Xu *et al.*, 2009, *Nat Med* 15:1318; Xu *et al.*, 2011, *J Immunol* 187:2626; Monestier *et al.*, 1993, *Mol Immunol* 30:1069. Anti-histone IgG almost entirely prevented histone toxicity on glomerular endothelial cells up to a histone concentration of 30 μg/ml (**FIG. 2A**). Anti-histone IgG also prevented histone-induced GEnC microtubule destruction in angiogenesis assays (**FIG. 9A-9B**). Histone-induced toxicity was also evident in cultured podocytes and PECs albeit at much higher histone concentrations compared to the toxic dose required to kill endothelial cells (**FIG. 2A**). Anti-histone-IgG also significantly reduced histone-induced detachment of cultured podocytes (**FIG. 10**). Thus, extracellular histones are toxic to glomerular cells, which toxicity can be blocked by anti-histone IgG.

Example 4. Neutrophil extracellular traps kill glomerular endothelial cells through histone release

[0224] In severe GN neutrophils undergo NETosis, which deposits nuclear chromatin within the glomerular capillaries (Kessenbrock *et al.*, 2009, *Nat Med* 15:623). Immunohistochemical staining showed nuclear chromatin release from netting neutrophils, including the spread of histones outside the dying cells (**FIG. 2B**). Neutrophils undergoing TNF-α- or PMA-induced NETosis on monolayers of glomerular endothelial cells destroyed this monolayer by inducing endothelial cell death, while TNF or PMA alone did not (**FIG. 2C-2E**). This NETosis-related endothelial cell toxicity was entirely prevented by anti-histone IgG (**FIG. 2C-2E**). We conclude that netting neutrophils damage glomerular endothelial cells via the release of histones.

Example 5. Histones need TLR2/4 to trigger glomerular necrosis and microangiopathy

[0225] Whether glomerular toxicity of extracellular histones is TLR2/4-dependent is not clear. To answer this question we exposed glomeruli isolated from wild type and *Tlr2/4*-deficient mice to histones *ex vivo*. Histones exposure was cytotoxic to glomeruli, a process that was entirely prevented using glomeruli from *Tlr2/4*-deficient mice (**FIG. 3A**). Lack of TLR2/4 also prevented IL-6 and TNF expression in histone-exposed glomeruli (**FIG. 11**). We also studied the effects of extracellular histones on glomeruli *in vivo*. Because intravenous histone injection kills mice immediately by pulmonary microvascular injury (Xu *et al.*, 2009, *Nat Med* 15:1318), we injected histones directly into the left renal artery in anaesthetized mice. Unilateral histone injection caused glomerular lesions within 24 hours ranging from minor endothelial fibrinogen positivity to thrombotic microangiopathy and global glomerular necrosis (**FIG. 3B-3C**). The contralateral kidney remained unaffected (not shown). Histone injection into the renal artery of *Tlr2/4*-deficient mice showed significantly reduced glomerular lesions and fibrinogen positivity (**FIG. 3B**). These results demonstrate that extracellular histones induce glomerular injury in a TLR2/4-dependent manner.

Example 6. Extracellular histones contribute to severe glomerulonephritis

[0226] Based on these results we speculated that intrinsic histone release may also contribute to severe GN *in vivo*. To address this question we applied the same neutralizing anti-histone IgG as used *in vitro* that demonstrated the functional contribution of extracellular histones in lethal endotoxemia (Xu *et al.*, 2009, *Nat Med* 15:1318). Mice were injected i.p. with 20 mg/kg anti-histone IgG or with 20 mg/kg control IgG 24 hours before the intravenous injection of a GBM antiserum raised in sheep. At the end of the study at day 7 only sheep IgG but no mouse IgG deposits were found in glomeruli, excluding any autologous anti-sheep IgG response contributing to glomerulonephritis (**FIG. 12A**). Anti-histone IgG significantly reduced blood urea nitrogen (BUN) and serum creatinine levels following GBM antiserum injections (**FIG. 4A**). This was associated with a significant reduction in crescent formation and global glomerular pathology with less severe lesions 7 days after antiserum injection (**FIG. 4B-4C**). Myeloperoxidase (MPO) immunostaining visualized NETs inside glomeruli, which was associated with focal loss of endothelial CD31 positivity as a marker of glomerular vascular injury (**FIG. 4D**). Anti-histone IgG did not affect extracellular positivity but maintained CD31+ vasculature (**FIG. 4D**), indicating a protective effect on NET-related vascular injury.

[0227] Because histones were toxic to glomerular endothelial cells and podocytes *in vitro*, we assessed the glomerular capillary ultrastructure by transmission electron microscopy. In control mice with crescentic glomeruli there was severe glomerular damage with fibrin deposits replacing large glomerular segments (fibrinoid necrosis). The capillary loops showed extensive GBM splitting and thinning, prominent endothelial cell nuclei, massive subendothelial edema with closure of the endothelial fenestrae, and obliteration of the capillary lumina. Subendothelial transudates (leaked serum proteins) and luminal platelets and neutrophils were also noted. Severe podocyte injury with diffuse foot process effacement, reactive cytoplasmic changes and detachment from the GBM were apparent (**FIG. 5A**).

[0228] In contrast, glomeruli of mice injected with anti-histone IgG showed restored endothelial fenestrations, flat appearing endothelial cells and preserved podocytes with intact foot processes (**FIG. 5A**). WT-1/nephrin co-immunostaining revealed that anti-histone IgG largely prevented podocyte loss in antiserum-induced GN (**FIG. 5B-5C**). This was consistent with significant reduction of albuminuria on day 7 following antiserum injection as compared to control IgG-treated mice (**FIG. 5D**). These results demonstrate that extracellular histones induce severe GN by causing glomerular vascular injury and podocyte loss, accompanied by proteinuria. They also demonstrate the efficacy of anti-histone antibody in preventing glomerular damage in glomerulonephritis.

Example 7. Extracellular histones drive glomerular leukocyte recruitment and activation

[0229] Infiltrating leukocytes are not only a documented source of extracellular histones in severe GN (Kessenbrock *et al.*, 2009, *Nat Med* 15:623) but also important effector cells (Kurts *et al.*, 2013, *Nat Rev Immunol* 13:738). For example, in GBM antiserum-exposed glomerular endothelial cells, histone exposure triggered CXCL2 expression (**FIG. 12B**). *In vivo*, anti-histone IgG significantly reduced the numbers of glomerular neutrophils and macrophages as quantified by immunostaining (**FIG. 6A**). Flow cytometry of renal cell suspensions allowed us to better distinguish renal mononuclear phagocyte populations. Anti-histone IgG significantly reduced the numbers of activated (MHC II+) F4/80+ cells as well as of activated (CD86+) CD11b/CD103+ cells, and of CD4+ dendritic cells (**FIG. 6B**). In fact, histones dose-dependently induced activation markers like MHCII, CD40, CD80, and CD86 also in cultured bone marrow derived macrophages (BMDCs), which was entirely prevented with anti-histone IgG (**FIG. 6C**). Taken together, extracellular histones trigger glomerular leukocyte recruitment and activation, which can be blocked with anti-histone IgG *in vitro* and *in vivo*.

Example 8. Extracellular histones trigger intraglomerular TNF-α release and thrombosis

[0230] Activated mononuclear phagocytes are also an important source of pro-inflammatory cytokines in glomerular disease. Among these, TNF-α particularly contributes to podocyte loss, proteinuria, and glomerulosclerosis (Ryu *et al.*, 2012, *J Pathol* 226:120). Because anti-histone IgG entirely prevented histone-induced TNF-α secretion in cultured macrophages and dendritic cells (**FIG. 7A**), we next assessed glomerular TNF-α expression. Immunostaining displayed robust TNF-α positivity within the glomerular tuft, which not only localized in infiltrating cells but also in inner and outer aspect of the glomerular capillaries (**FIG. 7B**). Anti-histone IgG strongly reduced glomerular TNF-α positivity, which was consistent with the corresponding renal mRNA expression levels (**FIG. 7C**). TNF-α is not only an inducer of NETosis but also triggers a prothrombotic activation of (glomerular) endothelial cells and intravascular fibrin formation (*32-34*). Our GN model displayed global fibrinogen positivity within glomerular capillaries, which was almost entirely prevented with anti-histone IgG (**FIG. 7D**). Also fibrinogen mRNA levels were reduced in the anti-histone IgG group (**FIG. 7E**). These results show that extracellular histones trigger intraglomerular TNF-α production and microthrombi formation within glomerular capillaries.

Example 9. Extracellular histones activate parietal epithelial cells via TLR2/4

[0231] Mitogenic plasma proteins leaking from injured glomerular capillaries cause PEC hyperplasia and glomerular crescent formation (Ryu *et al.*, 2012, *J Pathol* 228:482; Smeets *et al.*, 2009, *J Am Soc Nephrol* 20:2593; Smeets *et al.*, 2009, *J Am Soc Nephrol* 20:2604). In fact, in antiserum-induced GN glomerular crescents were positive for claudin-1/WT-1 positive cells (**FIG. 7F**), where claudin-1 identifies PECs and WT-1 marks PEC activation (Shankland *et al.*, 2013, *Curr Opin Nephrol Hypertens* 22:302. PECs cultured in 10% serum started proliferating upon histone exposure (**FIG. 7G**). Having shown that TLR2 and -4 are upregulated in PECs during severe human GN, we questioned whether extracellular histones drive PEC activation in a TLR2/4-dependent manner.

[0232] The mitogenic effect of histones to serum exposed PECs was entirely blocked by TLR2/4 inhibition (**FIG. 7H**). TLR2/4 inhibition also blocked histone-induced expression of CD44 and WT-1 in PECs (**FIG. 7I**). Previous reports documented that heparin and recombinant activated protein C (aPC) also block histone toxicity (Xu *et al.*, 2009, *Nat Med* 15:1318; Wildhagen *et al.*, 2013, *Blood* 123:1098). As such, the protective effect on PEC activation was shared by anti-histone IgG, heparin or activated protein C (aPC) (**FIG. 7I**), the latter two suppressing histone cytotoxicity on glomerular endothelial cells just like anti-histone IgG (not shown). Thus, extracellular histones activate PECs in a TLR2/4-dependent manner, a process that may act synergistically with other triggers of PEC hyperplasia during crescent formation and that can be blocked by anti-histone IgG, aPC or heparin.

Example 10. Delayed onset of histone neutralization still improves severe GN

[0233] The results of pre-emptive histone neutralization proved their pathogenic contribution to severe GN. We mext examined whether histone neutralization could be therapeutic in established disease. Anti-histone IgG, heparin, and aPC all completely blocked histone toxicity on glomeruli *ex vivo* (**FIG. 8A**). In another series of experiments we initiated anti-histone IgG, heparin, and aPC treatments 24 hours after GBM antiserum injection, a time point where massive proteinuria and elevated BUN were already established (**FIG. 4A, FIG. 5D**). All these treatments consistently and significantly reduced plasma creatinine levels, proteinuria, and podocyte loss at day 7 (**FIG. 8B-D**). Histone blockade also significantly reduced the percentage of glomeruli with global lesions or halted damage (**FIG. 8E**). Glomerular crescents were reduced by 80% (**FIG. 8F**) and so were features of secondary tubular injury (**FIG. 8G**). This was associated with less glomerular neutrophil and macrophage infiltrates as well as a significant reduction of intrarenal leukocyte subpopulations as well as their activation, as identified by flow cytometry (**FIG. 14**). Thus, delayed onset of histone blockade with anti-histone IgG, heparin or aPC protects from renal dysfunction and structural injury during severe GN.

Example 10. Summary of effects of histone neutralization on necrosis in glomerulonephritis

[0234] We hypothesized that extracellular histones elicit toxic and immunostimulatory effects on glomerular cells during necrotizing and crescentic GN. The data reported in the Examples above confirm this concept and also demonstrate that histone neutralization continues to be protective when it commences after disease onset, which implies a potential therapeutic use of histone neutralizing agents in severe GN.

[0235] Necrotizing and crescentic GN, such as seen in ANCA-associated renal vasculitis or anti-GBM disease, is associated with neutrophil-induced glomerular injury. First discovered in 2004, NETosis is a regulated form of neutrophil death that supports killing of extracellular bacteria (Brinkmann *et al.*, 2004, *Science* 303:1532). NETosis is not limited to antibacterial host defence but also occurs in sterile forms of inflammation, because it can be triggered by pro-inflammatory cytokines such as TNF-α. Our *in vitro* studies show that TNF-α is a sufficient stimulus to trigger NETosis-driven injury of glomerular endothelial cells. NETosis releases many aggressive proteases, oxygen radicals, and potential DAMPs into the extracellular space that have the potential to drive vascular injury in the glomerulus.

[0236] Our data demonstrate an essential role of histones in this context. The endothelial toxicity of extracellular histones was first described in a seminal paper on sepsis, where early lethality was due to microvascular endothelial cell injury in the lung (Xu *et al.*, 2009, *Nat Med* 15:1318). Subsequent reports further explored the thrombogenic potential of extracellular histones via direct activation of endothelial cells as well as of platelets (Abrams *et al.*, 2013, *Am J Respir Crit Care Med* 187:160; Saffarzadeh *et al.*, 2012, *PLoS One* 7:e32366; Semeraro *et al.*, 2011, *Blood* 118:1952; Ammollo *et al.*, 2011, *J Thromb Haemost* 9:1795; Fuchs *et al.*, 2011, *Blood* 118:3708;
Fuchs *et al.*, 2010, *Proc Natl Acad Sci U S A* 107:15880).

[0237] In infection and sepsis models, NETosis is the most likely source of extracellular histones. However, in mechanical trauma, toxic liver injury, cerebral stroke, and post-ischemic renal tubular necrosis histones are also released from dying tissue cells (Allam *et al.*, 2014, *J Mol Med*, 92:465; Allam *et al.*, 2012, *J Am Soc Nephrol* 23:1375). The source of extracellular histones in our *in vivo* model could be dying glomerular cells as well as netting neutrophils, which we identified by MPO staining *in situ*. Histone blockade had no effect on NETosis per se but rather worked on the related vascular injury inside the glomerulus.

[0238] Our *in vitro* and *in vivo* data clearly demonstrate that extracellular histones are toxic to glomerular cells and promote glomerular injury in healthy mice upon intra-arterial injection or during severe antiserum-induced GN. The mechanisms of histone toxicity are not entirely clear but are thought to be due to their strong basic charge (Gillrie *et al.*, 2012, *Am J Pathol* 180:1028). While histones basic charge is needed inside the nucleus to neutralize acidic residues of the DNA, outside the cell, it has the capacity to damage cell membranes (Gillrie *et al.*, 2012, *Am J Pathol* 180:1028). The polyanion heparin blocks this charge effect of histones, which may explain its antagonistic effect on histone toxicity *in vitro* and *in vivo*.

However, we and others discovered that histones elicit also DAMP-like activity by activating TLR2, TLR4, and NLRP3 (Semeraro *et al.*, 2011, *Blood* 118:1952; Allam *et al.*, 2012, *J Am Soc Nephrol* 23:1375; Allam *et al.*, 2013, *Eur J Immunol* 43:3336; Huang *et al.*, 2013, *J Immunol* 191:2665; Xu *et al.*, 2011, *J Immunol* 187:2626), which is another pathway of how extracellular histones trigger sterile inflammation.

[0239] Because TLR2 and TLR4 (but not NLRP3) are known to induce glomerular injury in the heterologous anti-GBM GN model (Brown *et al.*, 2006, *J Immunol* 177:1925; Brown *et al.*, 2007, *J Am Soc Nephrol* 18:1732; Lichtnekert *et al.*, 2011, *PLoS One* 6:e26778; Lichtnekert *et al.*, 2009, *Am J Physiol Renal Physiol* 296:F867), we further explored the histone-TLR2/4 axis. *Tlr2/4*-deficient glomeruli were protected from histone-induced injury *ex vivo* and *in vivo*, implying that the histone-related glomerular injury relates to the TLR2/4-dependent DAMP effect. In particular the presence of serum turned the cytotoxic effect of histones on PECs into PEC proliferation, which was entirely TLR2/4 dependent. Although PEC necrosis can be followed by excessive PEC recovery leading to PEC hyperplasia and crescent formation (Sicking *et al.*, 2012, *J Am Soc Nephrol* 23:629), concomitant plasma leakage and histone release provide additional mitogenic stimuli during severe GN (Ryu *et al.*, 2012, *J Pathol* 228:382).

[0240] Our proof-of-concept experiments were based on pre-emptive histone neutralization with anti-histone IgG. To explore a potential efficacy of histone blockade in severe GN we also applied three different modes of histone inactivation following GN induction. Delayed onset of anti-histone IgG was equally protective as pre-emptive therapy in terms of glomerular injury, proteinuria, and serum creatinine levels. The same applies to heparin treatment, which confirms previously published results in GN models (Floege *et al.*, 1993, *Kidney Int* 43:369). Our data clearly show that heparin inhibits the direct toxic effects of histones on glomerular endothelial cells, which is consistent with the results of other investigators in other cell types (Hirsch, 1958, *J Exp Med* 108:925; Ammollo *et al.*, *J Thromb Haemost* 9:1795; Fuchs *et al.*, 2010, *Proc Natl Acad Sci U S A* 107:15880). As previously reported aPC degrades extracellular histones (Xu *et al.*, 2009, *Nat Med* 15:1318. In the current studies it was equally effective as anti-histone IgG and heparin in abrogating extracellular histone toxicity *in vitro* and severe GN *in vivo*.

[0241] Together, NETosis releases histones into the extracellular space where they have toxic effects on glomerular endothelial cells and podocytes. Extracellular histone-induced glomerular injury is partially due to TLR2/4. Pre-emptive as well as delayed onset of histone neutralization either by anti-histone IgG, recombinant aPC or heparin abrogates all aspects of

GBM antiserum-induced severe GN. We conclude that extracellular histones represent a novel therapeutic target in severe GN.

* * *

[0242] One skilled in the art would readily appreciate that the present invention is well adapted to obtain the ends and advantages mentioned, as well as those inherent therein. The methods, variances, and compositions described herein as presently representative of preferred embodiments are exemplary and are not intended as limitations on the scope of the invention. Changes therein and other uses will occur to those skilled in the art, which are encompassed within the invention.

CLAIMS:

1. Use of an anti-histone agent for treating rapidly-progressive glomerulonephritis (RPGN) in a subject, wherein the agent is selected from the group consisting of an anti-histone antibody or antigen-binding fragment thereof, activated protein C (APC), and heparin.

2. Use of an anti-histone agent for treating anti-neutrophil cytoplasmic antibody (ANCA) associated glomerulonephritis in a subject, wherein the agent is selected from the group consisting of an anti-histone antibody or antigen-binding fragment thereof, activated protein C (APC), and heparin.

3. The use of claim 1 or 2, wherein the anti-histone agent inhibits activity of toll-like receptor 2 (TLR-2) and TLR-4.

4. The use of any one of claims 1 to 3, wherein administration of the anti-histone agent is effective to prevent vascular necrosis in severe glomerulonephritis.

5. The use of any one of claims 1 to 4, wherein the anti-histone antibody or fragment thereof binds to a human histone selected from the group consisting of histone H1/H5, histone H2A, histone H2B, histone H3 and histone H4.

6. The use of claim 5, wherein the anti-histone antibody is an anti-histone H4 antibody.

7. The use of claim 5, wherein the anti-histone antibody is selected from the group consisting of BWA-3, LG2-1 and LG2-2.

8. The use of any one of claims 1 to 7, wherein the anti-histone antibody is a chimeric, humanized or human antibody.

9. The use of any one of claims 1 to 7, wherein the antigen-binding fragment is selected from the group consisting of $F(ab')_2$, Fab', $F(ab)_2$, Fab, Fv, sFv, scFv and single domain antibody (nanobody).

10. The use of any one of claims 1 to 7, wherein the anti-histone antibody is a bispecific antibody comprising a first binding site for a histone and a second binding site for a non-histone antigen.

11. The use of any one of claims 1 to 7 wherein the anti-histone antibody or fragment thereof is a fusion protein.

12. The use of any one of claims 1 to 11, wherein the anti-histone antibody or fragment thereof is not conjugated to a therapeutic agent.

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13. The use of claim 12, further comprising use of an immunomodulator selected from the group consisting of a cytokine, a stem cell growth factor, a lymphotoxin, a hematopoietic factor, a colony stimulating factor (CSF), an interleukin (IL), erythropoietin, thrombopoietin, tumor necrosis factor (TNF), granulocyte-colony stimulating factor (G-CSF), granulocyte macrophage-colony stimulating factor (GM-CSF), interferon-α, interferon-β, interferon-γ, interferon-λ, TGF-α, TGF-ß, interleukin-1 (IL-1), IL-1α, IL-2, IL-3, IL-4, IL-5, IL-6, IL-7, IL-8, IL-9, IL-10, IL-11, IL-12; IL-13, IL-14, IL-15, IL-16, IL-17, IL-18, IL-21, IL-23, IL-25, LIF, FLT-3, angiostatin, thrombospondin, endostatin and lymphotoxin.

14. The use of claim 13, wherein the immunomodulator is selected from the group consisting of human growth hormone, N-methionyl human growth hormone, bovine growth hormone, parathyroid hormone, thyroxine, insulin, proinsulin, relaxin, prorelaxin, follicle stimulating hormone (FSH), thyroid stimulating hormone (TSH), luteinizing hormone (LH), hepatic growth factor, prostaglandin, fibroblast growth factor, prolactin, placental lactogen, OB protein, tumor necrosis factor-α, tumor necrosis factor-ß, mullerian-inhibiting substance, mouse gonadotropin-associated peptide, inhibin, activin, vascular endothelial growth factor, integrin, thrombopoietin (TPO), NGF-ß, platelet-growth factor, TGF-α, TGF-ß, insulin-like growth factor-I, insulin-like growth factor-II, erythropoietin (EPO), osteoinductive factors, interferon-α, interferon-β, interferon-γ, macrophage-CSF (M-CSF), IL-1, IL-1α, IL-2, IL-3, IL-4, IL-5, IL-6, IL-7, IL-8, IL-9, IL-10, IL-11, IL-12, IL-13, IL-14, IL-15, IL-16, IL-17, IL-18, IL-21, IL-25, LIF, FLT-3, angiostatin, thrombospondin, endostatin, tumor necrosis factor and lymphotoxin.

15. The use of any one of claims 1 to 11, wherein the anti-histone antibody or fragment thereof is conjugated to at least one therapeutic agent.

16. The use of claim 15, wherein the therapeutic agent is selected from the group consisting of a second antibody, a second antibody fragment, a radionuclide, an immunomodulator, an anti-angiogenic agent, a pro-apoptotic agent, a cytokine, a chemokine, a drug, a toxin, a hormone, an siRNA and an enzyme.

17. The use of any one of claims 1 to 16, wherein administration of the anti-histone antibody or fragment thereof reduces vascular necrosis, podocyte loss, albuminuria, cytokine induction, recruitment and activation of glomerular leukocytes and glomerular crescent formation.

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18. The use of any one of claims 1 to 17, comprising use of two or more anti-histone agents.

19. The use of any one of claims 1 to 18, further comprising use of an anti-TNF-α antibody.

20. The use of any one of claims 1 to 19, further comprising use of an antibody against toll-like receptor 2 (TLR-2) or TLR-4.

21. The use of any one of claims 1 to 20, further comprising use of a second antibody or antigen-binding fragment thereof, wherein the second antibody binds to an antigen selected from the group consisting of histone H2B, histone H3, histone H4, a proinflammatory effector of the innate immune system, a proinflammatory effector cytokine, a proinflammatory effector chemokine, TNF-α, MIF, CD74, HLA-DR, IL-1, IL-3, IL-4, IL-5, IL-6, IL-8, IL-12, IL-15, IL-17, IL-18, IL-23, IL-4R, IL-6R, IL-13R, IL-15R, IL-17R, IL-18R, CD40L, CD44, CD46, CD55, CD59, CCL19, CCL21, mCRP, MCP-19, MIP-1A, MIP-1B, RANTES, ENA-78, IP-10, GRO-β, lipopolysaccharide, lymphotoxin, HMGB-1, tissue factor, a complement regulatory protein, a coagulation factor, thrombin, a complement factor, C3, C3a, C3b, C4a, C4b, C5, C5a, C5b, Flt-1 and VEGF.

22. The use of any one of claims 1 to 21, wherein the subject is a human subject.

23. Use of an anti-histone agent for treating vascular necrosis in severe glomerulonephritis in a subject, wherein the agent is selected from the group consisting of an anti-histone antibody or antigen-binding fragment thereof, activated protein C (APC), and heparin.

Date Reçue/Date Received 2022-05-19

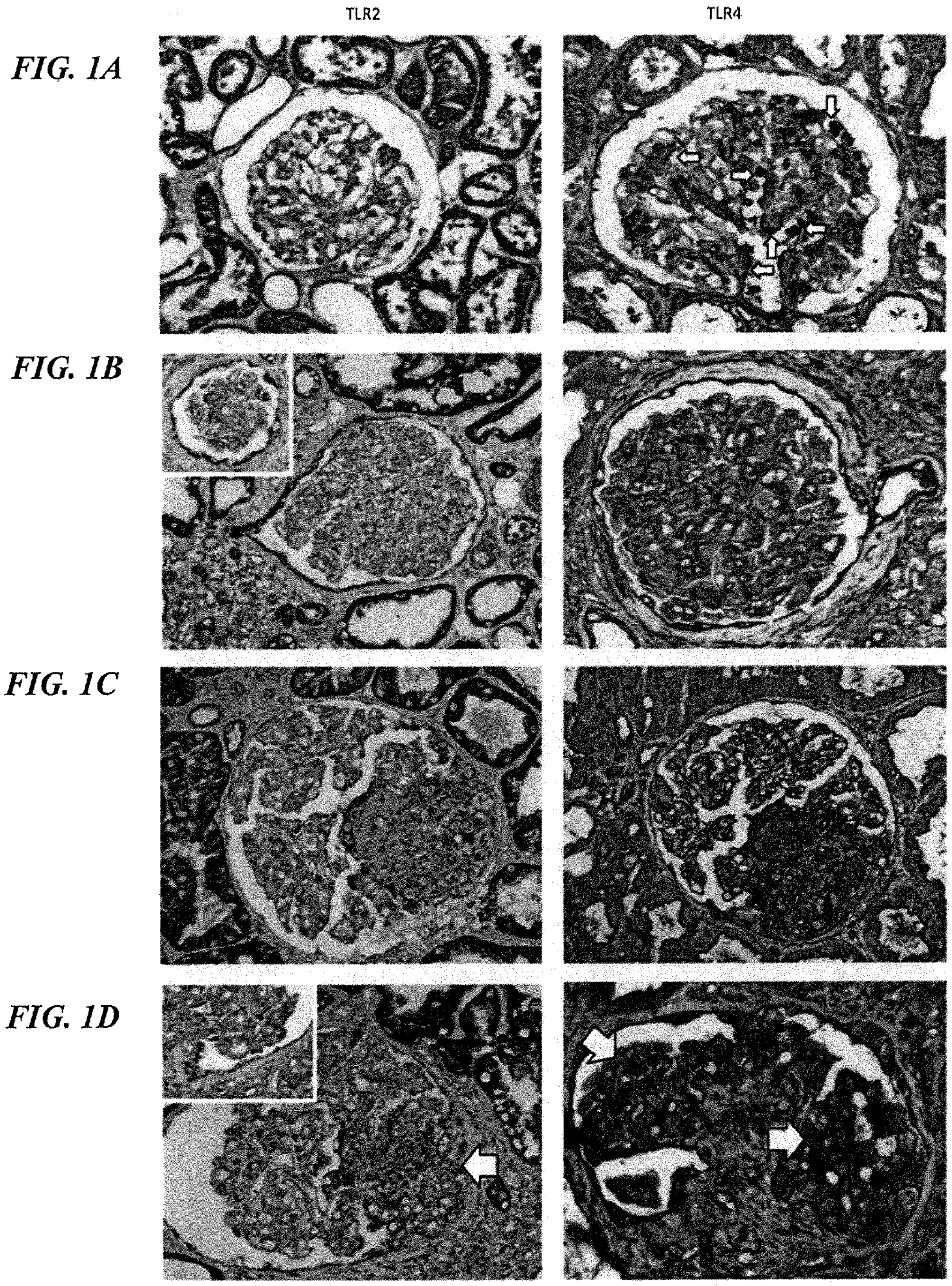
TLR2
TLR4
FIG. 1A
FIG. 1B
FIG. 1C
FIG. 1D

FIG. 2A

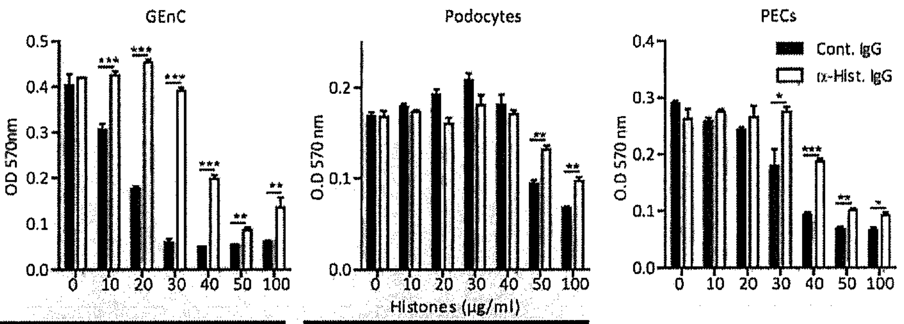

FIG. 2B

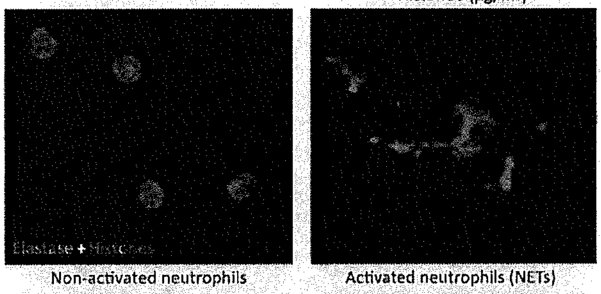

FIG. 2C

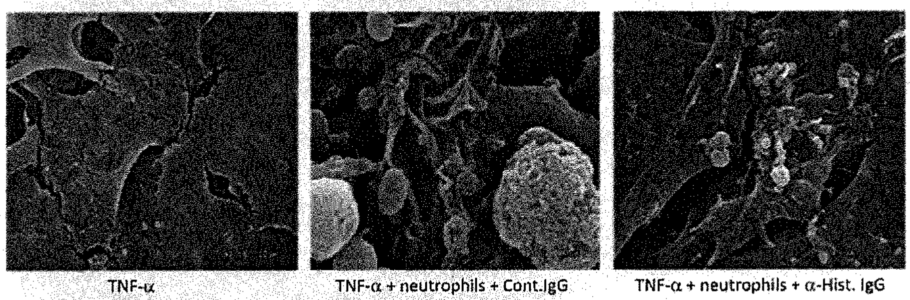

FIG. 2D

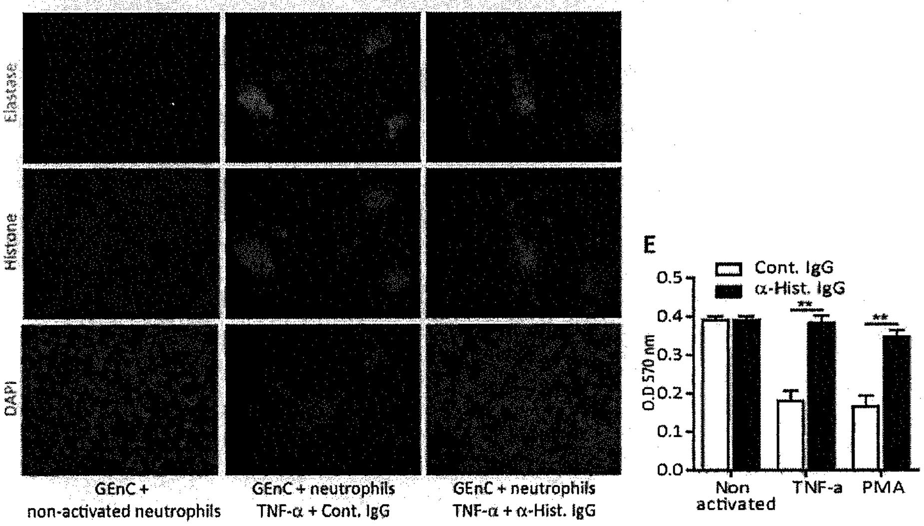

FIG. 3A

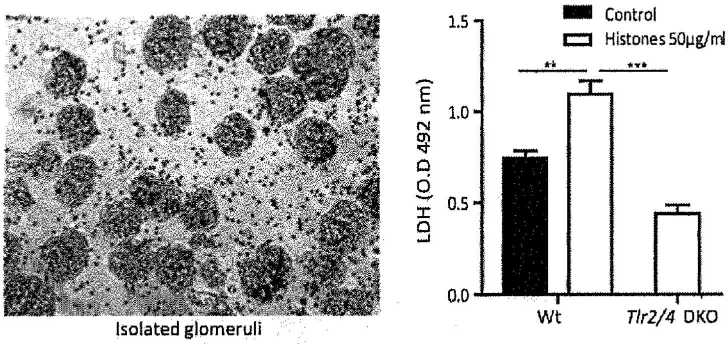

FIG. 3B

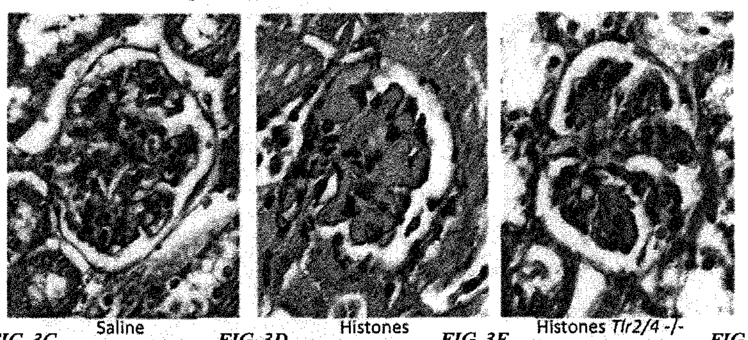

FIG. 3C

FIG. 3D

FIG. 3E

FIG. 3F

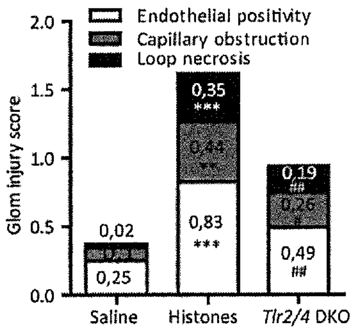

FIG. 4A

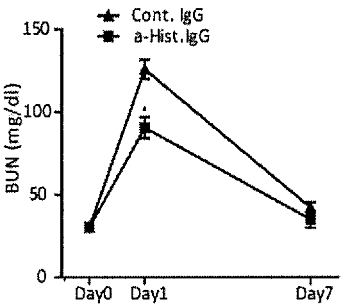

FIG. 4B

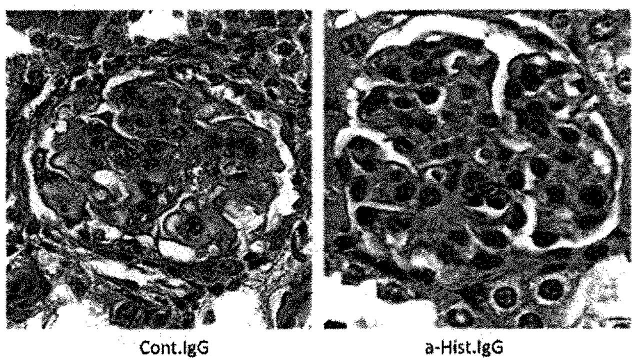

FIG. 4C

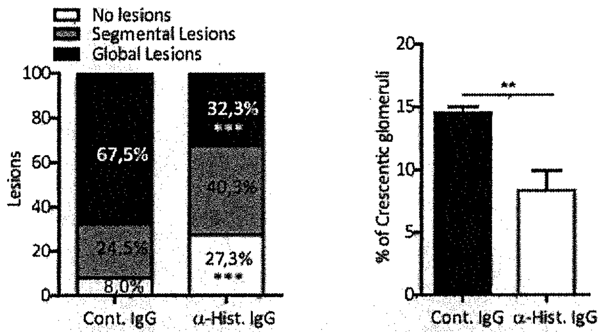

FIG. 4D

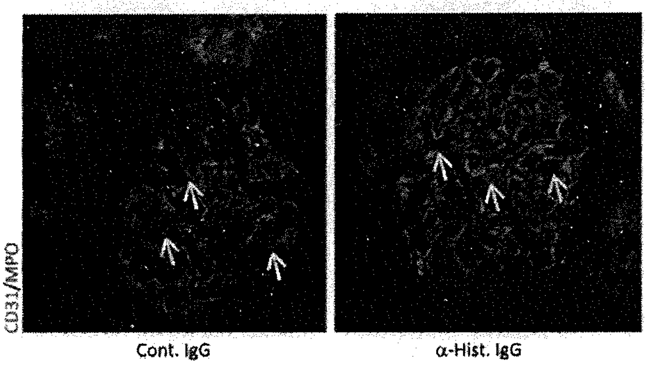

FIG. 5A

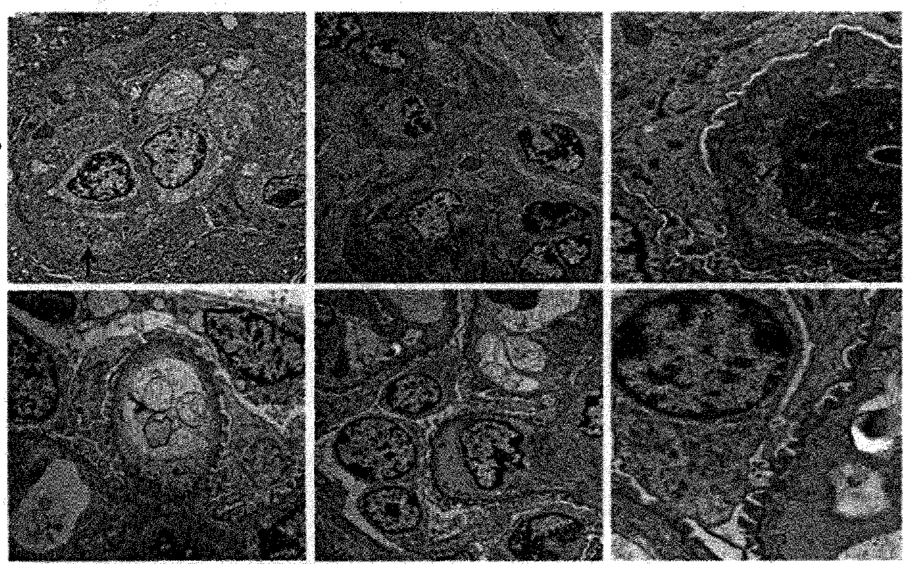

FIG. 5B

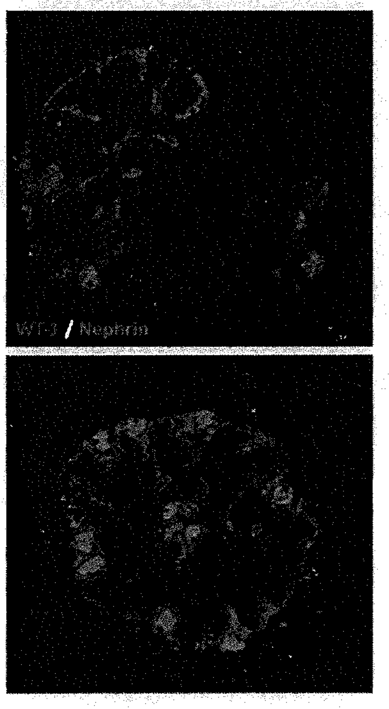

FIG. 5C

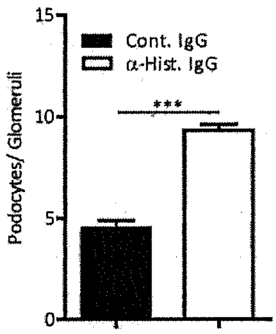

FIG. 5D

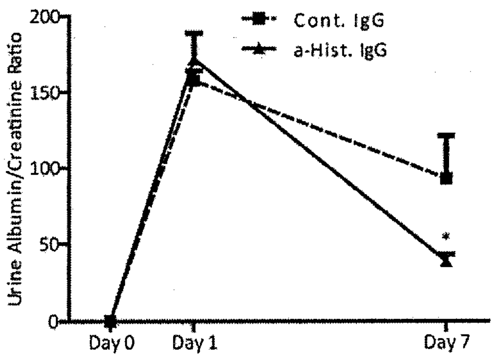

FIG. 6A

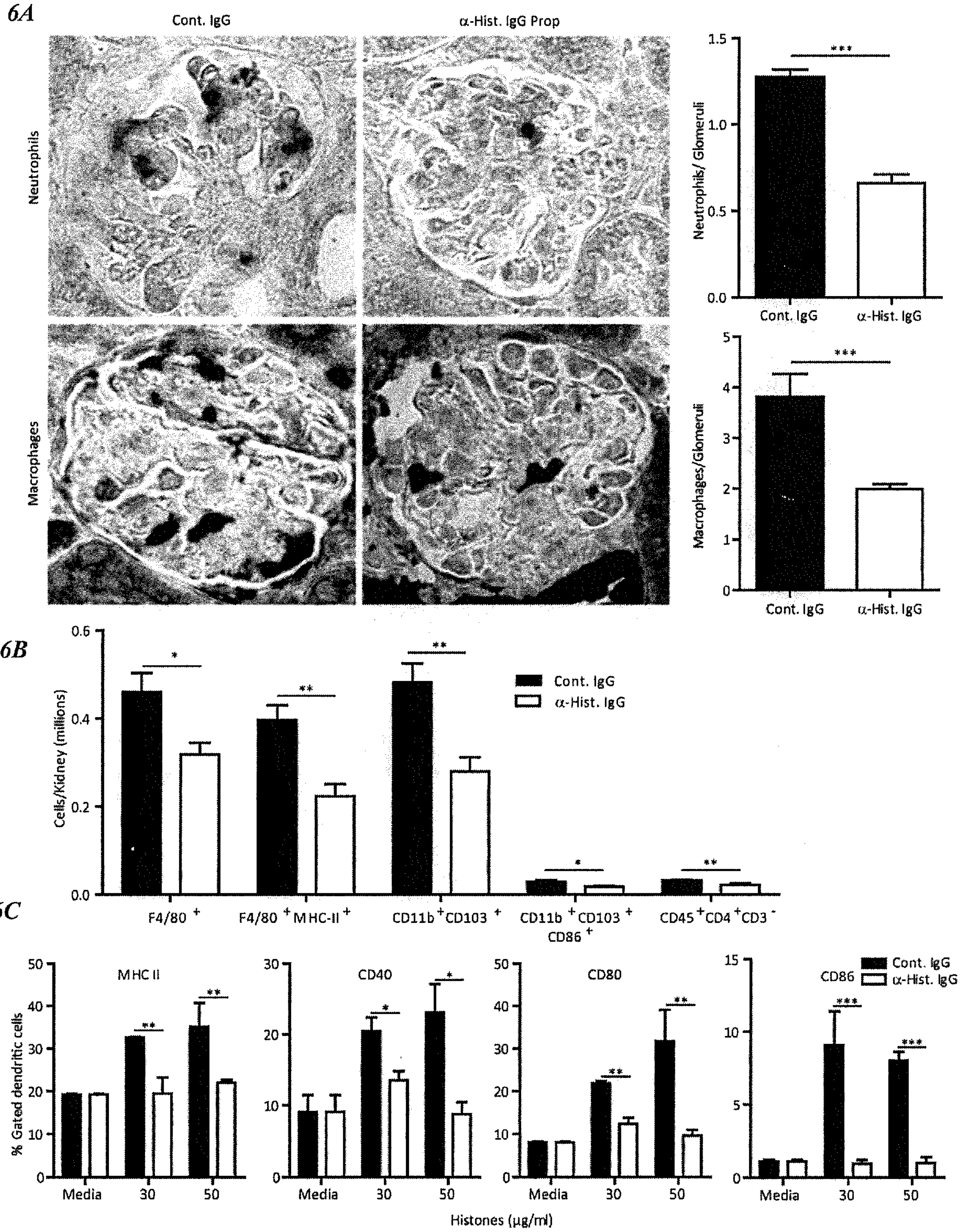

FIG. 6B

FIG. 6C

FIG. 7A

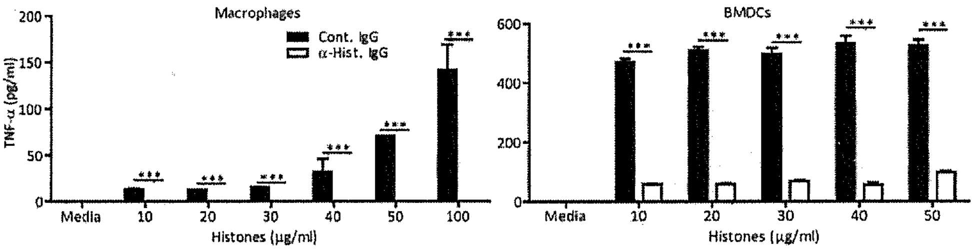

FIG. 7B

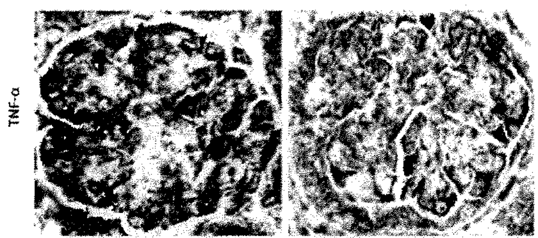

FIG. 7C

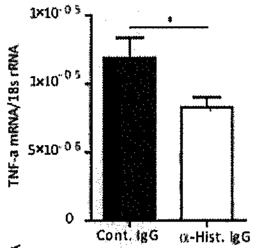

FIG. 7D

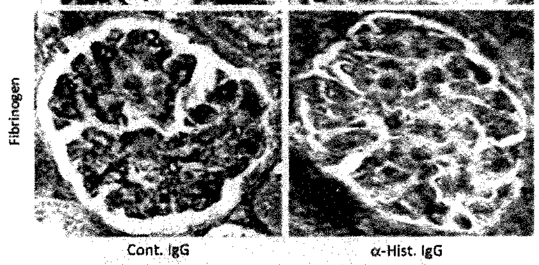

FIG. 7E

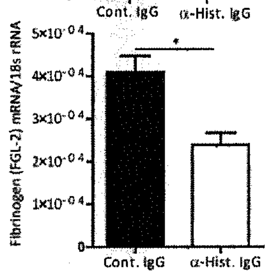

FIG. 7F

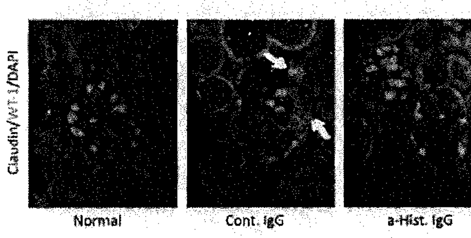

FIG. 7G

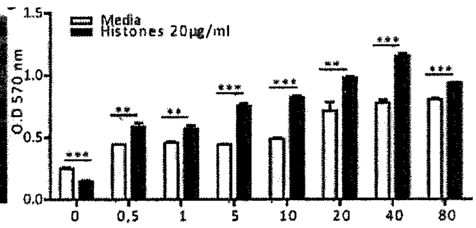

FIG. 7H

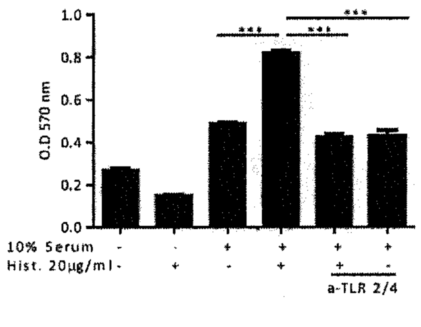

FIG. 7I

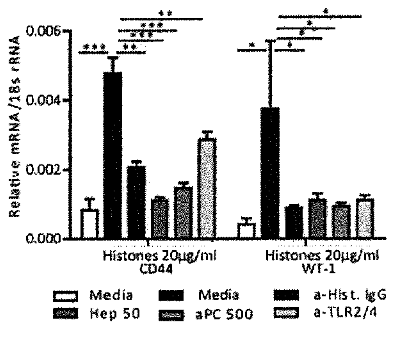

FIG. 8A

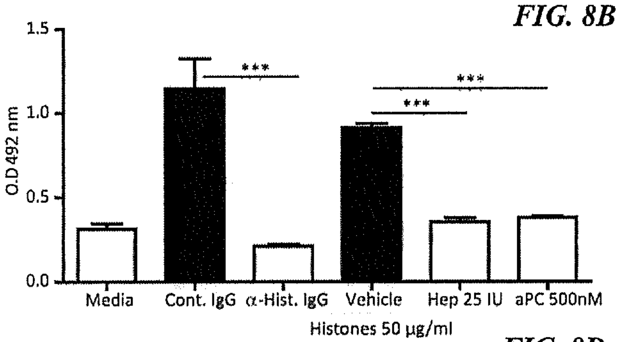

FIG. 8B

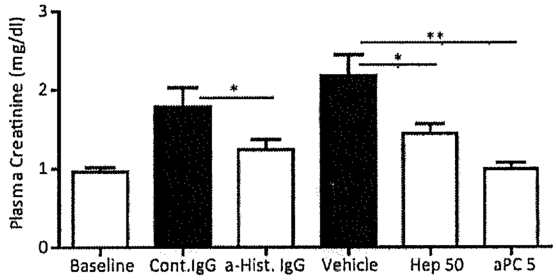

FIG. 8C

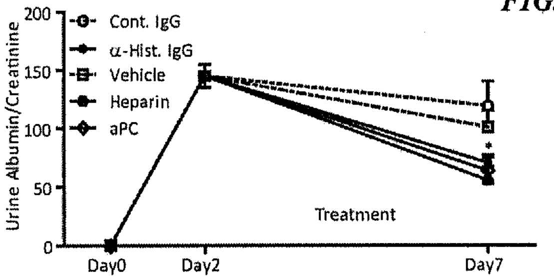

FIG. 8D

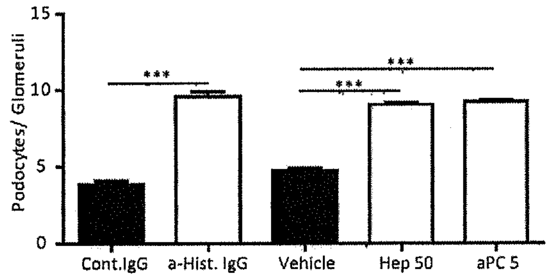

FIG. 8E

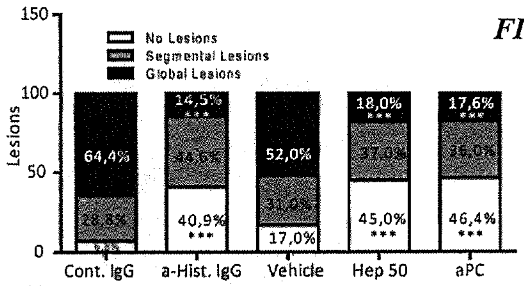

FIG. 8F

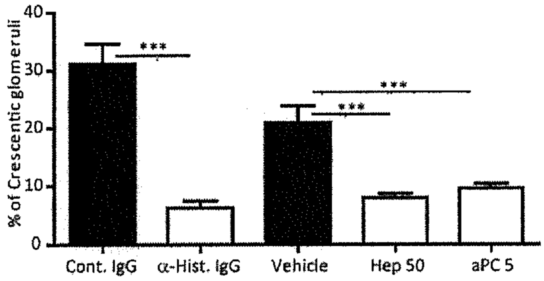

FIG. 8G

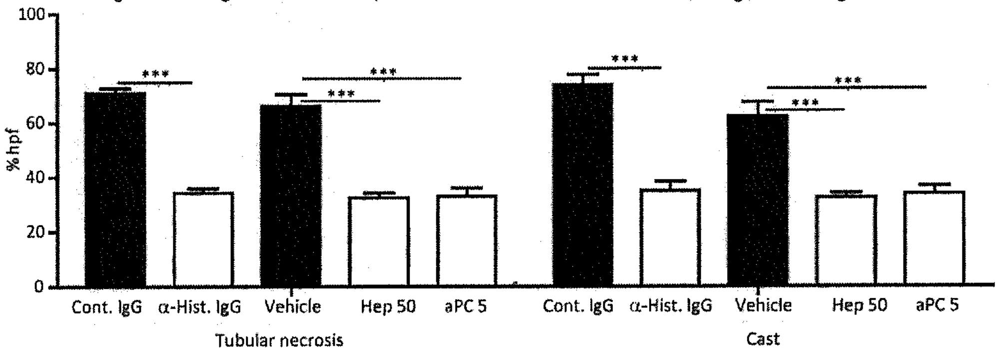

FIG. 9A

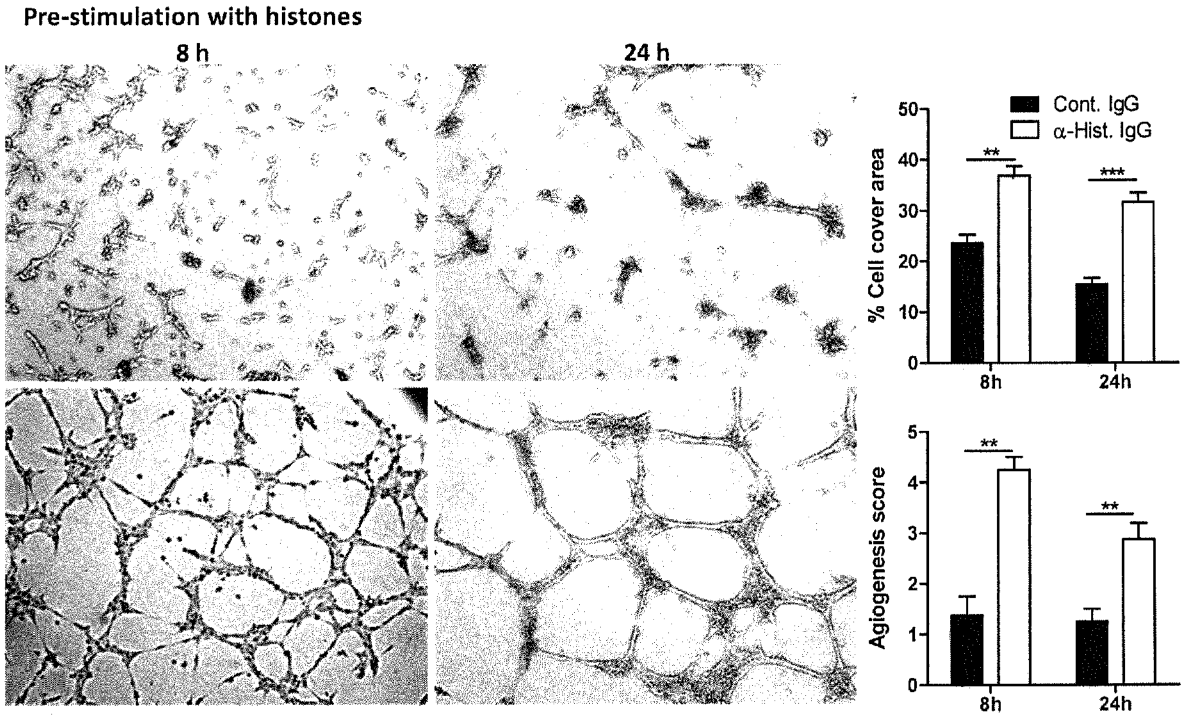
Pre-stimulation with histones
8 h
24 h
Cont. IgG
A-Hist. IgG
Cont. IgG
α-Hist. IgG
% Cell cover area
8h
24h
Agiogenesis score
8h
24h

FIG. 9B

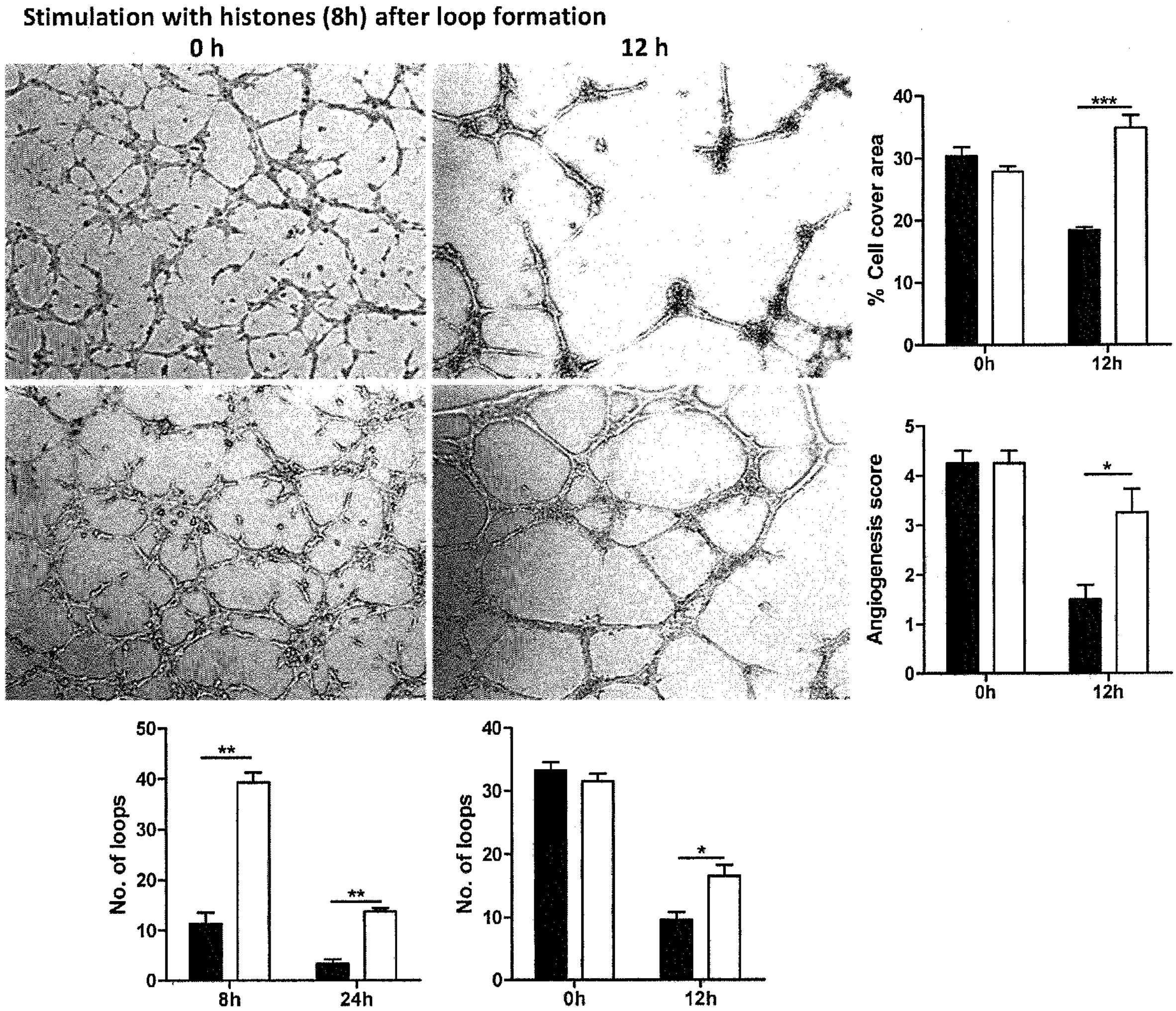
Stimulation with histones (8h) after loop formation
0 h
12 h
Cont. IgG
A-Hist. IgG
% Cell cover area
0h
12h
Angiogenesis score
0h
12h
No. of loops
8h
24h
No. of loops
0h
12h

FIG. 10

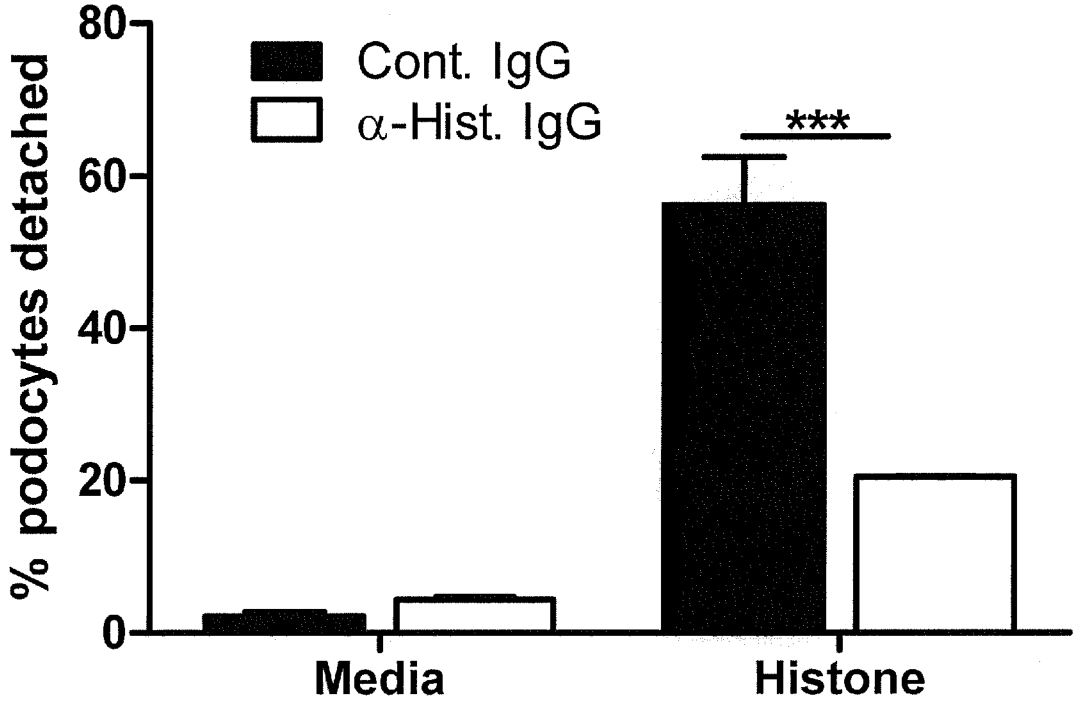
80
60
40
20
0
% podocytes detached
Cont. IgG
α-Hist. IgG
***
Media
Histone

FIG. 11A

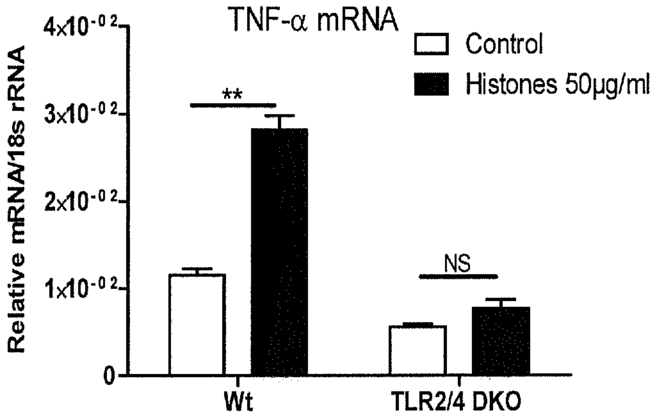

FIG. 11B

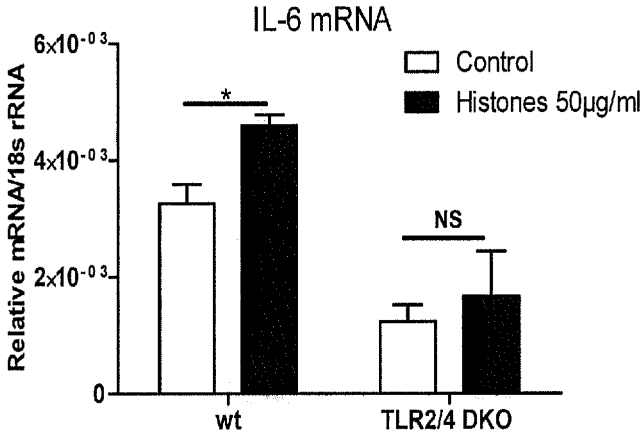

FIG. 11C

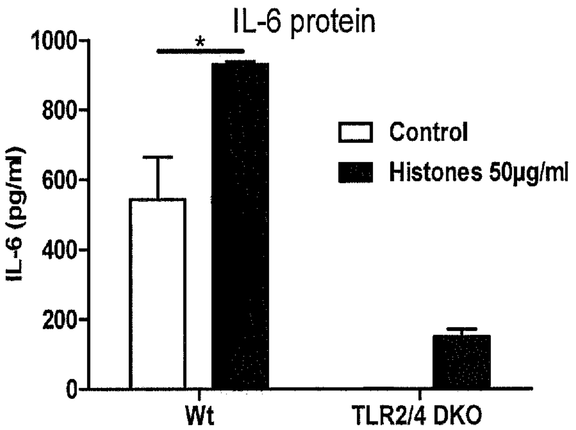

FIG. 12A

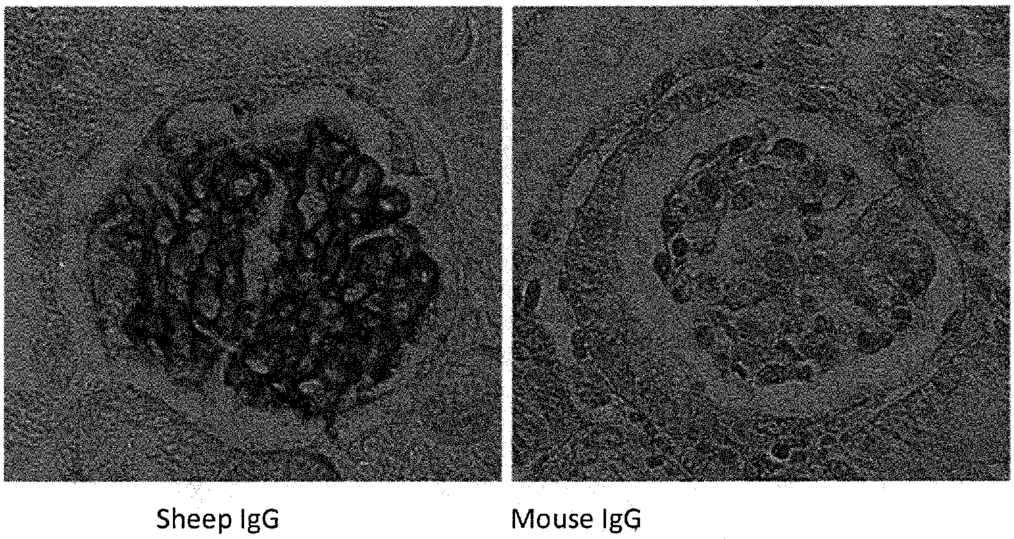

FIG. 12B

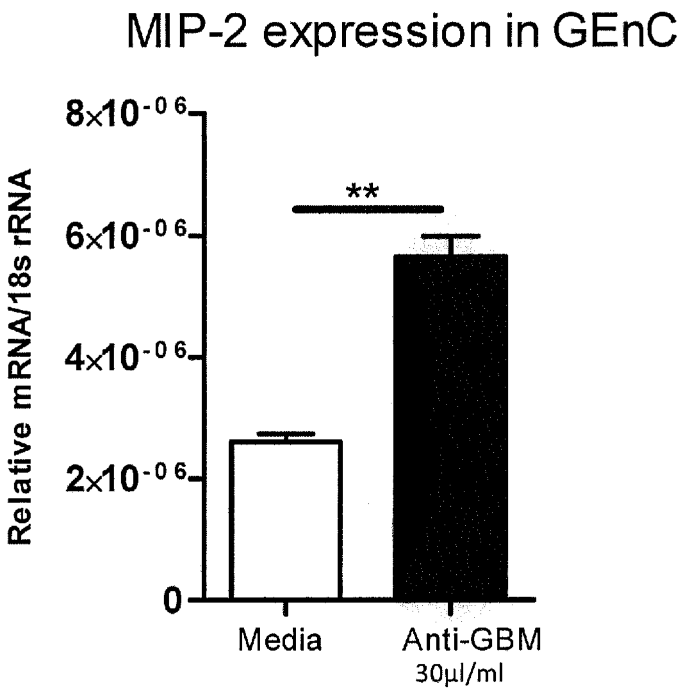

FIG. 13A

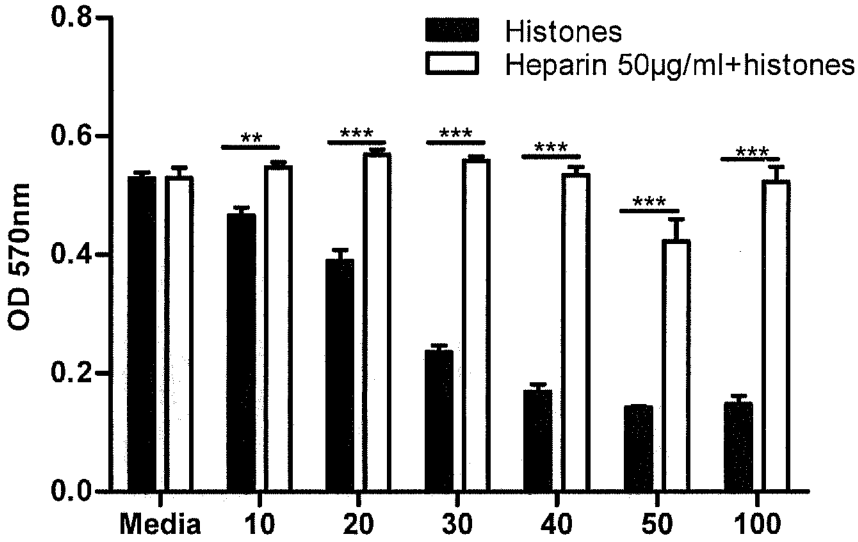

FIG. 13B

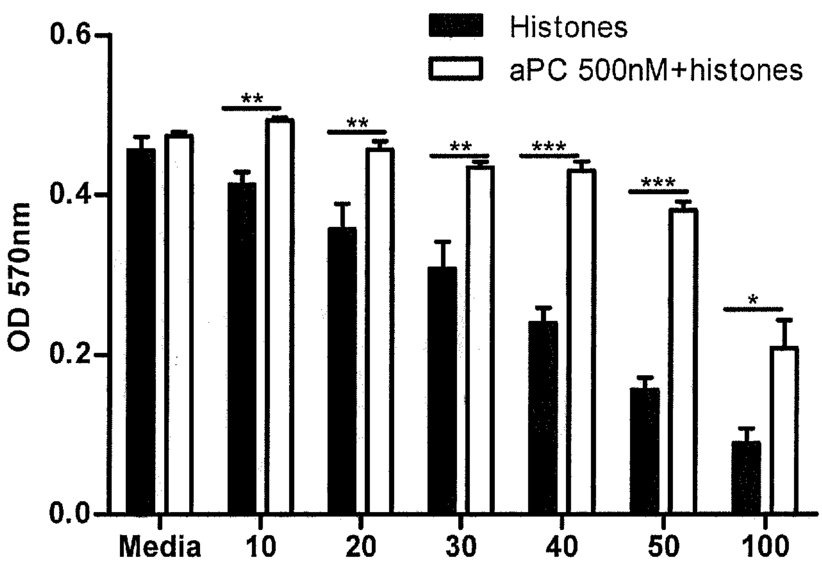

FIG. 14A

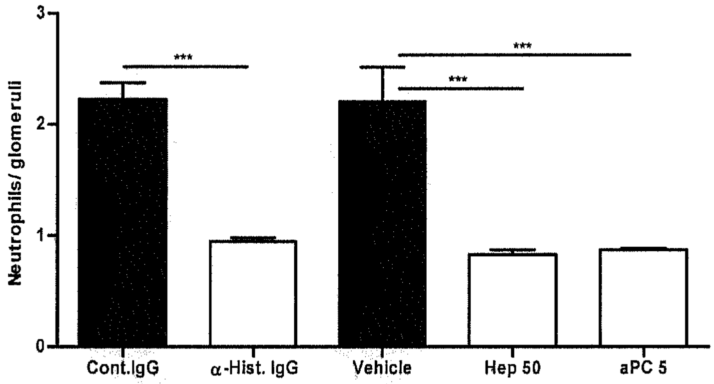

FIG. 14B

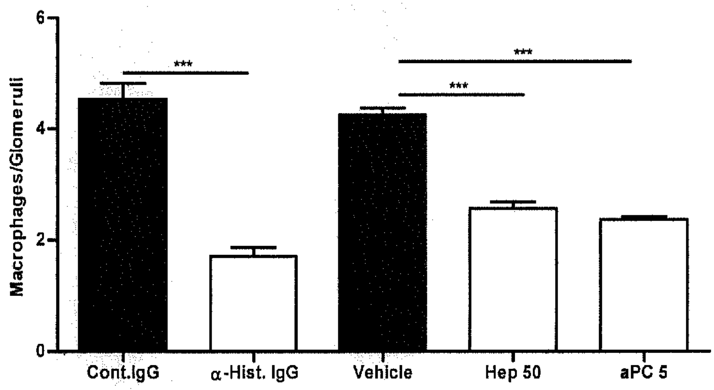

FIG. 14C

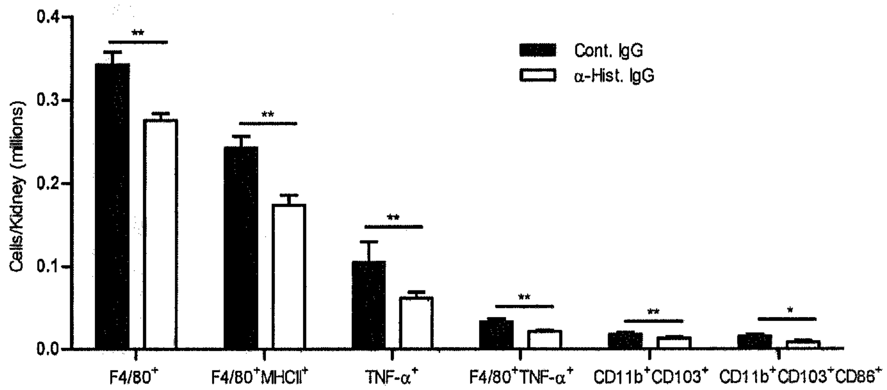

FIG. 14D