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(54) Title: HEMATOPOIETIC STEM CELLS FOR USE IN THE TREATMENT OF A KIDNEY INJURY

(57) Abstract: Provided herein are methods of treating a kidney injury in a patient, comprising administering to the patient hematopoietic stem cells (HSCs) in an amount effective to treat the kidney injury. In some embodiments, administration of the HSCs is delayed, such that the HSCs are not administered immediately after the kidney injury. In certain aspects, the HSCs are administered to the patient during the beginning of the repair phase of the kidney. Further embodiments and aspects of the invention, including related methods and compositions for use therein, are described herein.



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**HEMATOPOIETIC STEM CELLS FOR USE IN THE TREATMENT OF A KIDNEY INJURY****CROSS-REFERENCE TO RELATED APPLICATIONS**

**[0001]** This application claims priority to U.S. Provisional Patent Application No. 61/248,316, filed on October 2, 2009, which is incorporated by reference in its entirety.

**BACKGROUND**

**[0002]** Although the kidney has tremendous capacity for regeneration, chronic kidney disease and kidney failure following acute kidney injury or following both repetitive and chronic kidney injuries are now leading causes of morbidity and mortality in the world [1-3]. Furthermore chronic kidney disease has been identified as a leading independent risk factor for cardiovascular diseases and cardiovascular mortality [4]. Chronic kidney diseases may represent unsuccessful or inadequate renal repair following injury, and currently there are few therapies that promote repair and regeneration of the kidney [5].

**[0003]** The kidney peritubular microvasculature has received increasing attention recently, since this fragile vasculature may not regenerate normally following injury. This may predispose to chronic ischemia of the kidney [12-15], triggering chronic inflammation, tubular atrophy, and interstitial fibrosis, hallmarks of chronic kidney disease [12, 13]. It has been proposed that unsuccessful regeneration of peritubular capillaries following injury is central to progression to chronic kidney diseases [12-14].

**[0004]** There has been much interest in the reparative and angiogenic properties of stem cells from bone marrow [6-8], and several studies in mouse models of kidney disease have shown that mouse mesenchymal stromal cells of bone marrow (MSCs) can prevent or attenuate kidney injury, possibly by paracrine or systemic secretory mechanisms [6, 9, 10]. However the possible angiogenic role of hematopoietic stem cells (HSCs) in kidney repair has been little explored and no studies have ascertained the practicability of harvesting human HSCs in cell therapy to promote organ repair and regeneration [11].

**[0005]** Thus there exists a need in the art to develop methods for the treatment of a kidney injury.

**BRIEF SUMMARY OF THE INVENTION**

**[0006]** The studies described herein demonstrate for the first time that human CD34+ stem cells are recruited to the injured kidney and promote survival, vascular regeneration and functional recovery. The capacity of human CD34+ hematopoietic stem cells to promote repair and regeneration of the kidney was studied using an established ischemia reperfusion

injury model in mice. Human HSCs administered, e.g., systemically following kidney injury, were selectively recruited to injured kidneys of the mice and localized prominently in and around vasculature. This recruitment was associated with enhanced repair of the kidney microvasculature, tubule epithelial cells, enhanced functional recovery and increased survival. In some instances, HSCs acquired early myeloid and lymphoid differentiation markers in the kidney and also showed acquisition of endothelial progenitor cell markers, but retained synthesis of high levels of pro-angiogenic transcripts following recruitment to the kidney. Although infused purified HSCs contained small numbers of circulating endothelial progenitors and occasional endothelial cells, only rare human endothelial cells were identified in the mouse capillary walls, suggesting HSC-mediated renal repair is by paracrine mechanisms rather than replacement of vasculature. These studies advance human HSCs as a promising therapeutic strategy for promoting renal repair following injury.

**[0007]** Accordingly, the invention provides a method of treating a kidney injury in a patient, comprising administering to the patient hematopoietic stem cells (HSCs). The HSCs are administered to the patient in an amount effective to treat the kidney injury, which amount is further described herein. In certain embodiments of the invention, administration of the HSCs is delayed; that is, the HSCs are not administered immediately after the kidney injury. In some aspects of the invention, the HSCs are administered to the patient at the beginning of the repair phase of the kidney, e.g., at least about 12 hours, 14 hours, 16 hours, 18 hours, 20 hours, 22 hours, or 24 hours post-injury. In further embodiments, the HSCs are administered to the patient at about 24 hours post-injury, or some time thereafter, but before about 14 days post-injury. Further embodiments with regard to the time of administration of the HSCs are detailed herein.

**[0008]** Further provided herein are related methods comprising the administration of HSCs. For example, a method of preventing a renal disease or renal medical condition in a patient comprising a kidney injury, a method of increasing survival of a patient comprising a kidney injury, and a method of preventing a non-renal disease or non-renal medical condition which is caused by or associated with a renal disease or renal medical condition in a patient comprising a kidney injury.

**[0009]** In some embodiments of the invention, the HSCs used in the inventive methods are formulated with a pharmaceutically acceptable carrier. Accordingly, the invention provides a pharmaceutical composition comprising a population of HSCs and a pharmaceutically acceptable carrier. In certain embodiments, the pharmaceutical composition comprises additional therapeutic agents or diagnostic agents, optionally, conjugated to the HSCs. Such

pharmaceutical compositions can be used to deliver the therapeutic agent or diagnostic agent to an injured kidney. Therefore, the invention further provides a method of delivering a therapeutic agent or a diagnostic agent to an injured kidney in a patient, comprising administering to the patient HSCs conjugated to the therapeutic agent or diagnostic agent.

**[0010]** In some aspects, the pharmaceutical composition comprises a heterogeneous population of cells, wherein the HSCs (e.g., the CD34+ HSCs) constitute at least about 25% (e.g., at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, at least about 90%, at least about 95%, or at least about 98%) of the cells of the population. Further embodiments of the inventive pharmaceutical compositions and uses thereof are provided herein.

### BRIEF DESCRIPTION OF THE DRAWINGS

**[0011]** Figure 1 demonstrates that human hematopoietic stem cells are recruited to post ischemia reperfusion injury kidneys, spleen and bone marrow of NOD/SCID mice. (A) Representative confocal image of day 3 post IRI kidney of NOD/SCID mice that received adoptively transferred human HSCs on d1 post IRI showing CMFDA labeled human cells (arrows) in peritubular capillaries denoted by mouse CD31 labeling. (B) Graph indicating the number of human HSCs identified in post IRI and control kidneys on days 3, 5 and 7 after IRI. (C) Representative confocal image detecting human HLA class I (green, arrow) of day 7 post IRI kidney of NOD/SCID mice treated with human HSCs 24h after IRI. (D) Graph indicating the number of human HLA class I cells per section in post IRI and control kidneys on days 7, 14 and 28 after IRI. (E) Representative confocal image of CMFDA labeled human HSCs in spleen 3d following IRI, adoptively transferred 1d after kidney IRI. (F) Graph indicating the number of CMFDA positive cells per section in the spleen on days 3, 5 and 7 after IRI. (G) Representative flow cytometric plot for CD11b (detects mouse and human antigens) and human CD45 of whole bone marrow from d7 post kidney IRI mouse that received adoptively transferred human HSCs d1 after IRI. (H) Graph indicating proportion of human CD45+ cells in mouse bone HSCs (E) on d1 and d2. Note prominent debris in severely injured tubules in (D), present to a much lower extent in (E). (F) Graph showing tubular injury index for mice following vehicle or HSCs (n=3 per timepoint). (G-H) Representative images of Sirius red-stained kidneys d28 post IRI that received either vehicle (G) or HSCs (H) on d1 and d2 post IRI. (I) Graph showing fibrosis area for mice following vehicle or HSCs (n=3 per timepoint). Mean  $\pm$  SD. \* $P < 0.05$ , vs. vehicle group. (Bars = 50 $\mu$ m).

**[0012]** Figure 2 demonstrates that adoptive transfer of human HSCs to NOD/SCID mice following kidney ischemia reperfusion injury decreases mortality and improves kidney function. (A) Plasma creatinine levels on days 1, 2 and 7 following bilateral IRI followed IV injection with PBS (Vehicle, n=16) or  $2.5 \times 10^6$  (HSC, n=10) 1 day following injury. Data are mean  $\pm$  SD. *P* value <0.01. (B) Survival curves and number at each time point, for mice undergoing bilateral IRI followed IV injection with PBS (vehicle) or  $2.5 \times 10^6$  human HSCs (HSC) 1 day following injury. *P* value = 0.039.

**[0013]** Figure 3 demonstrates that adoptive transfer of Human HSCs attenuates peritubular capillary loss and reduces tubular epithelial injury following kidney ischemia reperfusion injury. (A-B) Representative images of mouse CD31-labeled peritubular capillaries (PTC) of outer medulla of d7 post IRI kidney that received vehicle (A) or HSCs (B) on d1 and d2. Note marked PTC loss in (A). (C) Graph showing PTC index for mice following vehicle or HSCs (n=3 per timepoint). (D-E) Representative light images of PAS stained kidney sections of outer medulla d5 post IRI kidney from mice that received vehicle (D) or HSCs (E) on d1 and d2. Note prominent debris in severely injured tubules in (D), present to a much lower extent in (E). (F) Graph showing tubular injury index for mice following vehicle or HSCs (n=3 per timepoint). (G-H) Representative images of Sirius red-stained kidneys d28 post IRI that received either vehicle (G) or HSCs (H) on d1 and d2 post IRI. (I) Graph showing fibrosis area for mice following vehicle or HSCs (n=3 per timepoint). Mean  $\pm$ SD. \**P* <0.05, vs. vehicle group. (Bars = 50 $\mu$ m).

**[0014]** Figure 4 demonstrates the differentiation of human HSCs in kidneys. Representative confocal images (A, C) and epifluorescence image (E) of kidney outer medulla showing expression of human CD45 (A), human CD68 (C), and human CD3 (E) in cells (arrowheads) in d5 post IRI kidneys that received IV injection of HSCs 1 day following injury, colabeled to show mCD31 (red) of the mouse vasculature. Graphs showing the number of human CD45 (B), human CD68 (D), and human CD3 (F) cells identified in post IRI kidneys and control kidneys. Data are mean  $\pm$  SD. n = 6/ timepoint. (G-H) Representative epifluorescence images of day 3 post IRI kidney of NOD/SCID mice that received human HSCs on d1-d2 labeled with CMFDA (arrowheads) co-labeled with antibodies against human CD133 (G), CD146 (H) and KDR (I). Note anti-KDR antibodies also detected mouse endothelium (arrows) (Bars = 50 $\mu$ m).

**[0015]** Figure 5 demonstrates that rare human endothelial cells can be detected in the kidney after ischemic injury and HSC infusion. (A-B) Confocal images of d28 post IRI kidneys showing the presence of human CD31 expressing cells some of which appear to be

integrated into capillaries (arrowhead) (A) but the majority are morphologically monocytic and co-express hCD45 (arrowheads) (B). (C) Graph showing the number of human CD31 expressing cells in the post IRI kidneys with time following adoptive transfer of HSCs 1day following injury. (D) Specific expression of human von Willebrand factor (vWF) (arrowheads) and not mouse vWF in cells that lack expression of human CD45 in the post IRI kidney (Bar = 50 $\mu$ m).

**[0016]** Figure 6 demonstrates human HSCs generate angiogenic paracrine factors in the kidney after kidney ischemic injury. Relative gene expression compared with GAPDH of pro-angiogenic transcripts in HSCs (white) and HSCs prior to adoptive transfer and, purified from post IRI kidney 48h following adoptive transfer. Note that HSCs recruited to the kidney retain high-level expression of pro-angiogenic transcripts. Mean  $\pm$  SD. n = 6/group. (Bars = 50 $\mu$ m).

**[0017]** Figure 7 demonstrates a model of functions of HSCs in repair of the kidney following injury. HSCs are recruited to the injured kidney where they acquire the CEP marker CD146 and localize within injured capillaries and in the interstitium. Local production of cytokines including Angiopoietins, Vascular endothelial growth factors, hepatocyte growth factor and insulin like growth factors are generated promoting cellular repair by paracrine mechanisms.

#### DETAILED DESCRIPTION OF THE INVENTION

**[0018]** Data described herein demonstrate for the first time the specific localization of administered HSCs to a mammal with an injured kidney and subsequent repair of the injured kidney tissues, including, but not limited to the peritubular microvasculature, which repair is mediated by the HSCs. The invention accordingly provides a method of treating a kidney injury in a patient, comprising administering to the patient hematopoietic stem cells (HSCs) in an amount effective to treat the kidney injury in the patient.

**[0019]** The term "treat," as well as words stemming therefrom, as used herein, does not necessarily imply 100% or complete amelioration of a targeted condition. Rather, there are varying degrees of a therapeutic effect which one of ordinary skill in the art recognizes as having a benefit. In this respect, the methods described herein provide any amount or any level of therapeutic benefit of a kidney injury and therefore "treat" the injury. For example, in various aspects, the method of treating a kidney injury includes one or more of: promoting repair or regeneration of the injured kidney tissue of the patient, increasing survival of the patient, enhancing functional recovery of the kidney, or restoring function to the kidney. In

another aspect, the treatment provided by the method includes amelioration of one or more conditions or symptoms caused by the injured kidney. By way of example and without limitation, the inventive methods described herein achieve one or more of the following: enhanced repair or regeneration of the kidney peritubular microvasculature (e.g., the peritubular capillaries), creation or stabilization of blood vessels (e.g., peritubular microvasculature (e.g., the peritubular capillaries)) in the kidney, inducement of angiogenesis in the injured kidney, or enhanced repair of the tubule epithelial cells, reducing the occurrence of negative remodeling of the kidney.

**[0020]**    *Kidney Injuries*

**[0021]**    In various aspect of the invention, methods provided are intended to treat kidney injury in the patient which is any injury to the kidney caused by any one or more of: ischemia, exposure to a toxin, use of an angiotensin-converting enzyme inhibitor (ACEI) or angiotensin II receptor blocker, a blood transfusion reaction, an injury or trauma to muscle, surgery, shock, hypotension, or any of the causes of ARF or chronic kidney disease, as further described herein.

**[0022]**    The targeted kidney injury comprises injury to any tissue found within the kidney, including, but not limited to, a tissue of the medulla, cortex, renal pyramid, interlobar artery, renal artery, renal vein, renal hilum, renal pelvis, ureter, minor calyx, renal capsule, inferior renal capsule, superior renal capsule, interlobar vein, nephron, major calyx, renal papilla, glomerulus, Bowman's capsule, and renal column, which tissue is sufficiently damaged to result in a partial or complete loss of function. The injured kidney tissue comprises any one or more of distinct cell types which occur in the kidney, including, but not limited to, kidney glomerulus parietal cells, kidney glomerulus podocytes, intraglomerular mesangial cells, endothelial cells of the glomerulus, kidney proximal tubule brush border cells, loop of Henle thin segment cells, thick ascending limb cells, kidney distal tubule cells, kidney collecting duct cells, and interstitial kidney cells. In certain embodiments of the invention, the kidney injury comprises injury to a kidney peritubular microvasculature. In certain aspects, the kidney injury comprises injury to a peritubular capillary. In some embodiments, the kidney injury comprises injury to tubule (tubular) epithelial cells.

**[0023]**    *Prevention of Renal disease and Renal Medical Conditions*

**[0024]**    While the kidney has tremendous capacity for self-repair or self-regeneration, a kidney injury often leads to an increased predisposition to a renal disease or renal medical condition. It is theorized that the method of treating a kidney injury in a patient provided

herein allows for successful repair and regeneration of the kidney, so that the patient does not have an increased predisposition to a renal disease or renal medical condition. Therefore, the invention further provides a method of preventing a renal disease or renal medical condition in a patient comprising a kidney injury. The method comprises administering to the patient HSCs in an amount effective to prevent the renal disease or renal medical condition. In some embodiments, the amount is effective to treat the kidney injury, e.g., an amount effective to restore kidney function, to regenerate kidney peritubular microvasculature.

**[0025]** As used herein, the term "prevent" as well as words stemming therefrom, does not necessarily imply 100% or complete prevention. Rather, there are varying degrees of prevention of which one of ordinary skill in the art recognizes as having a potential benefit. In this respect, the methods of preventing described herein provide any amount or any level of prevention of renal disease or renal medical condition. In various aspects, the method of preventing is a method of delaying, slowing, reducing, or attenuating the onset, development, occurrence, or progression of the renal disease or renal medical condition, or a symptom or condition thereof.

**[0026]** In some embodiments, the renal disease or renal medical condition prevented is acute renal failure, chronic kidney disease, renal interstitial fibrosis, diabetic nephropathy, glomerulonephritis, hydronephrosis, interstitial nephritis, kidney stones (nephrolithiasis), kidney tumors (e.g., Wilms tumor, renal cell carcinoma), lupus nephritis, minimal change disease, nephrotic syndrome, pyelonephritis, renal failure (e.g., other than acute renal failure and chronic kidney disease).

**[0027]** *Acute Renal Failure*

**[0028]** The term "acute renal failure" as used herein is synonymous with "acute kidney injury" or "ARF" and refers to a rapid loss of renal function due to damage to the kidneys. ARF is a complex syndrome marked by abrupt changes in the levels of nitrogenous (e.g., serum creatine and/or urine output) and non-nitrogenous waste products that are normally excreted by the kidney. The symptoms and diagnosis of ARF are known in the art. See, for example, *Acute Kidney Injury, Contributions to Nephrology*, Vol. 156, vol. eds. Ronco et al., Karger Publishers, Basel, Switzerland, 2007, and Bellomo et al., *Crit Care* 8(4): R204-R212, 2004.

**[0029]** In various aspects, the ARF is a pre-renal ARF, an intrinsic ARF, or a post-renal ARF, depending on the cause. In this regard, the pre-renal ARF may be caused by one or more of: hypovolemia (e.g., due to shock, dehydration, fluid loss, or excessive diuretic use),



hepatorenal syndrome, vascular problems (e.g., atheroembolic disease, renal vein thrombosis, relating to nephrotic syndrome), infection (e.g., sepsis), severe burns, sequestration (e.g., due to pericarditis, pancreatitis), and hypotension (e.g., due to antihypertensiveness, vasodilator use).

**[0030]** The intrinsic ARF may be caused by one or more of: toxins or medications (e.g., NSAIDs, aminoglycoside antibiotics, iodinated contrast, lithium, phosphate nephropathy (e.g., associated with colonoscopy bowel preparation with sodium phosphates), rhabdomyolysis (e.g., caused by injury (e.g., crush injury or extensive blunt trauma), statins, stimulant use), hemolysis, multiple myeloma, acute glomerulonephritis.

**[0031]** The post-renal ARF may be caused by one or more of: medication (e.g., anticholinergics), benign prostatic hypertrophy or prostate cancer, kidney stones, abdominal malignancy (e.g., ovarian cancer, colorectal cancer), obstructed urinary catheter, and drugs that cause crystalluria or myoglobulinuria, or cystitis.

**[0032]** ARF may be caused by ischemia, a toxin, use of an angiotensin-converting enzyme inhibitor (ACEI) or angiotensin II receptor blocker, a blood transfusion reaction, an injury or trauma to muscle, surgery, shock, and hypotension in the patient. The toxin which causes ARF can be an antifungal or a radiographic dye. Also, in some embodiments, ARF involves acute tubular necrosis or renal ischemia reperfusion injury.

**[0033]** *Chronic Kidney Disease*

**[0034]** In some embodiments of the methods of preventing a renal disease or renal medical condition, the renal disease is chronic kidney disease (CKD). As used herein, “chronic kidney disease,” which is also known as “chronic renal disease,” refers to a progressive loss of renal function over a period of months or years. The CKD being treated is any stage, including, for example, Stage 1, Stage 2, Stage 3, Stage 4, or Stage 5 (also known as established CKD, end-stage renal disease (ESRD), chronic kidney failure (CKF), or chronic renal failure (CRF)).

**[0035]** The CKD may be caused by any one of a number of factors, including, but not limited to, acute kidney injury, causes of acute kidney injury, Type 1 and Type 2 diabetes mellitus leading to diabetic nephropathy, high blood pressure (hypertension), glomerulonephritis (inflammation and damage of the filtration system of the kidneys), polycystic kidney disease, use (e.g., regular and over long durations of time) of analgesics (e.g., acetaminophen, ibuprofen) leading to analgesic nephropathy, atherosclerosis leading to ischemic nephropathy, obstruction of the flow of urine by stones, an enlarged prostate,

strictures (narrowings), HIV infection, sickle cell disease, heroin abuse, amyloidosis, kidney stones, chronic kidney infections, and certain cancers.

**[0036]** *Prevention of Non-Renal Diseases and Non-Renal Medical Conditions*

**[0037]** Chronic kidney disease has been identified as a leading independent risk factor for cardiovascular diseases and cardiovascular mortality. It is theorized that the administration of HSCs as described herein is furthermore useful for preventing diseases or medical conditions other than renal diseases and renal medical conditions. Accordingly, a method of preventing a non-renal disease or non-renal medical condition which is caused by or associated with a renal disease or renal medical condition in a patient comprising a kidney injury is further provided herein. The method comprises administering to the patient HSCs in an amount effective to prevent the non-renal disease or non-renal medical condition. In certain embodiments, the non-renal disease or non-renal medical condition is cardiovascular disease.

**[0038]** *Increasing Survival*

**[0039]** Chronic kidney disease and kidney failure following acute kidney injury or following both repetitive and chronic kidney injuries are now leading causes of morbidity and mortality in the world. It is theorized herein that the administration of HSCs as described herein is furthermore useful for preventing mortality (increasing survival) of a patient comprising a kidney injury. Accordingly, a method of increasing survival of a patient comprising a kidney injury is furthermore provided herein. The method comprises administering to the patient HSCs in an amount effective to increase survival of the patient.

**[0040]** *Hematopoietic Stem Cells (HSCs)*

**[0041]** For purposes herein, the term "hematopoietic stem cells" or "HSCs" refer to multipotent stem cells that give rise to the blood cell types, including, for example, myeloid (monocytes and macrophages, neutrophils, basophils, eosinophils, erythrocytes, megakaryocytes, platelets, dendritic cells), and lymphoid lineages (T-cells, B-cells, natural killer (NK) cells). The HSCs may be multipotent, oligopotent, or unipotent HSCs.

**[0042]** *Methods of Obtaining HSCs and Sources of HSCs*

**[0043]** The HSCs may be obtained by any means known in the art. In some embodiments, the HSCs are isolated from a donor. The term "isolated" as used herein means having been removed from its natural environment. The HSCs are isolated from any adult, fetal or embryonic tissue comprising HSCs, including in various aspects, but not limited to, bone

marrow, adipose tissue, blood, yolk sac, myeloid tissue (e.g., in the liver, spleen, in fetuses, e.g., fetal liver, fetal spleen), umbilical cord blood, placenta, and aorta-gonad-mesonephros.

**[0044]** The donor of the HSCs is any of the hosts described herein with regard to patients. In some aspects, the donor is a mammal. In specific aspects, the donor is a human. In other aspects, the donor of HSCs is the same as the patient. In this regard, the HSCs are considered “autologous” to the patient. In some embodiments, the donor of the HSCs is different from the patient, but the donor and patient are of the same species. In this regard, the HSCs are considered as “allogeneic.”

**[0045]** In some embodiments, the HSCs are isolated from bone marrow of a donor, e.g., the hip of a donor, using a syringe and needle. In other embodiments, HSCs are isolated from the blood (e.g., peripheral blood). In certain aspects, the HSCs are isolated from the blood following pre-treatment of the donor with cytokines which induce or promote mobilization of the HSCs from the bone marrow into the blood, e.g., peripheral blood. The cytokine in some instances is granulocyte-colony stimulating factor (G-CSF), granulocyte macrophage colony stimulating factor (GM-CSF), or AMD-3100.

**[0046]** In some embodiments, the HSCs are primary cells or freshly isolated cells. Alternatively, the HSCs are cultured cells, cells of an established cell line, and/or thawed from frozen stocks of HSCs. HSCs can be obtained through cell repositories, such as, for example, the American Tissue Culture Collection (ATCC), the National Stem Cell Resource (NSCR), National Stem Cell Bank (NSCB), as well as other commercial vendors.

**[0047]** In other aspects, further steps to obtain a particular population of HSCs are performed. The HSCs in some embodiments are purified. The term “purified” as used herein means having been increased in purity, wherein “purity” is a relative term, and not to be necessarily construed as absolute purity. In various aspect, for example, the purity is at least about 50%, can be greater than 60%, 70% or 80%, or can be 100%. Accordingly, in some embodiments the HSCs of the invention are part of a heterogeneous population of cells or part of a substantially homogeneous population of cells. For example, in some aspects the HSCs are a clonal population of HSCs, wherein each cell of the population is genetically indistinct from another cell of the population. The heterogeneous population of cells comprise other types of cells, cells other than HSCs. For example, in some aspects the heterogeneous population of cells comprise, in addition to the HSCs, a white blood cells (a white blood cells of myeloid lineage or lymphoid lineage), a red blood cell, an endothelial cell, circulating endothelial precursor cells, an epithelial cell, a kidney cell, a lung cell, an osteocyte, a

myelocyte, a neuron, smooth muscle cells. Alternatively or additionally, the heterogeneous population of cells comprises only HSCs, but the HSCs are not clonal, e.g., not genetically indistinct from each other. The HSCs of the heterogeneous population have different phenotypes as discussed further herein. Suitable methods of isolating cells, e.g., HSCs, having a particular phenotype are known in the art and include, for instance, methods using optical flow sorters (e.g., fluorescence-activated cell sorting (FACS)) and methods using non-optical flow sorters (e.g., magnetic-activated cell sorting).

**[0048]** *Markers Expressed by HSCs*

**[0049]** The HSCs have any phenotype characteristic of a HSC. In some embodiments, the HSCs is negative for (expression of) lineage markers (i.e., lin-). In some instances, the HSCs are positive for (expression of) one or more of: CD34, CD38, CD90, CD133, CD105, CD45, and c-kit. In some instances, the HSCs are CD34+ and in other instances, the HSCs are CD45+. In still other aspect, the HSCs are CD34+ and CD45+. In certain embodiments, the phenotype of the HSCs changes once administered to the patient. Accordingly, in some embodiments, the HSCs are ones which become positive for expression of markers, e.g., circulating endothelial progenitor cell (CEP) markers (markers expressed on CEPs, e.g., CD146, CD133, CD34, CD117, CD31).

**[0050]** The HSCs are optionally part of a heterogeneous cell population, wherein at least 25% (e.g., at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, at least 90%, at least 95%) of the cells in the population have a particular phenotype. In some embodiments of the invention, the HSCs are part of a heterogeneous population of cells, wherein at least at least 25% (e.g., at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, at least 90%, at least 95%) of the cells are CD34+ HSCs. In some embodiments of the invention, the HSCs are part of a heterogeneous population of cells, wherein at least at least 25% (e.g., at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, at least 90%, at least 95%) of the cells are CD45+ HSCs. In some embodiments of the invention, the HSCs are part of a heterogeneous population of cells, wherein at least at least 25% (e.g., at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, at least 90%, at least 95%) of the cells are HSCs which become CD146+ HSCs after administration to the patient.

**[0051]** *Further Modifying Steps of HSCs*

**[0052]** In some aspects, the HSCs are further modified after being isolated and/or purified. In one alternative, the cells are cultured *in vitro* for purposes of expanding the population of

HSCs, delivering genes into the HSCs, differentiating the HSCs, or conjugating a compound, such as a therapeutic agent or a diagnostic agent, to the HSCs. Methods of carrying out these further steps are well known in the art. See, for example, Sambrook et al., *Molecular Cloning: A Laboratory Manual*, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, NY, 2001; Ogawa et al., *Blood* 81: 2844-2853 (1993); U.S. Patent 7,144,731; Li et al, *FASEB J* 15: 586 (2001); Norol et al., *Experimental Hematology* 35(4): 653-661 (2007); Verhoeven and Cosset, *Gene Transfer: Delivery and Expression of DNA and RNA*, eds. Friedmann and Rossi, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, NY, 2007.

**[0053]** *Pharmaceutical compositions*

**[0054]** The HSCs described herein are optionally formulated into a composition, such as a pharmaceutical composition. In this regard, the invention provides a pharmaceutical composition comprising the HSCs and a pharmaceutically acceptable carrier. The carrier is any of those conventionally used and is limited only by chemico-physical considerations, such as solubility and lack of reactivity with the active compound(s), and by the route of administration. The pharmaceutically acceptable carriers described herein, for example, vehicles, adjuvants, excipients, and diluents, are well-known to those skilled in the art and are readily available to the public. In one aspect the pharmaceutically acceptable carrier is one which is chemically inert to the active agent(s), e.g., the hematopoietic stem cells, and one which has no detrimental side effects or toxicity under the conditions of use. The choice of carrier will be determined in part by the particular agents comprising the pharmaceutical composition, as well as by the particular route used to administer the pharmaceutical composition. Accordingly, there are a variety of suitable formulations of the pharmaceutical composition of the invention.

**[0055]** *Routes of Administration*

**[0056]** In some embodiments, the pharmaceutical composition comprising the HSCs is formulated for parenteral administration, subcutaneous administration, intravenous administration, intramuscular administration, intraarterial administration, intrathecal administration, or interperitoneal administration. In other embodiments, the pharmaceutical composition is administered via nasal, spray, oral, aerosol, rectal, or vaginal administration.

**[0057]** Methods of administering HSCs are known in the art. See, for example, any of U.S. Patents 5423778, 5550050, 5662895, 5800828, 5800829, 5811407, 5833979, 5834001, 5834029, 5853717, 5855619, 5906827, 6008035, 6012450, 6049026, 6083523, 6206914, 6303136, 6306424, 6322804, 6352555, 6368612, 6479283, 6514522, 6534052, 6541024,

6551338, 6551618, 6569147, 6579313, 6599274, 6607501, 6630457, 6648849, 6659950, 6692738, 6699471, 6736799, 6752834, 6758828, 6787357, 6790455, 6805860, 6852534, 6863900, 6875441, 6881226, 6884427, 6884428, 6886568, 6918869, 6933281, 6933286, 6949590, 6960351, 7011828, 7031775, 7033345, 7033603, 7049348, 7070582, 7074239, 7097832, 7097833, 7135172, 7145055, 7157080, 7166280, 7176256, 7244242, 7452532, 7470425, and 7494644.

**[0058]** *Parenteral*

**[0059]** In some embodiments, the pharmaceutical composition described herein is formulated for parenteral administration. For purposes of the invention, parenteral administration includes, but is not limited to, intravenous, intraarterial, intramuscular, intracerebral, intracerebroventricular, intracardiac, subcutaneous, intraosseous, intradermal, intrathecal, intraperitoneal, intravesical, and intracavernosal injections or infusions.

**[0060]** Formulations suitable for parenteral administration include aqueous and non-aqueous, isotonic sterile injection solutions, which can contain anti-oxidants, buffers, bacteriostats, and solutes that render the formulation isotonic with the blood of the intended recipient, and aqueous and non-aqueous sterile suspensions that can include suspending agents, solubilizers, thickening agents, stabilizers, and preservatives. The pharmaceutical composition are in various aspects administered via a physiologically acceptable diluent in a pharmaceutical carrier, such as a sterile liquid or mixture of liquids, including water, saline, aqueous dextrose and related sugar solutions, a glycol, such as propylene glycol or polyethylene glycol, glycerol, ethers, poly(ethyleneglycol) 400, oils, fatty acids, fatty acid esters or glycerides, or acetylated fatty acid glycerides with or without the addition of a pharmaceutically acceptable surfactant, such as a soap or a detergent, suspending agent, such as pectin, carbomers, methylcellulose, hydroxypropylmethylcellulose, or carboxymethylcellulose, or emulsifying agents and other pharmaceutical adjuvants.

**[0061]** Oils, which are optionally used in parenteral formulations include petroleum, animal, vegetable, or synthetic oils. Specific examples of oils include peanut, soybean, sesame, cottonseed, corn, olive, petrolatum, and mineral. Suitable fatty acids for use in parenteral formulations include oleic acid, stearic acid, and isostearic acid. Ethyl oleate and isopropyl myristate are examples of suitable fatty acid esters.

**[0062]** The parenteral formulations in some embodiments contain preservatives or buffers. In order to minimize or eliminate irritation at the site of injection, such compositions optionally contain one or more nonionic surfactants having a hydrophile-lipophile balance

(HLB) of from about 12 to about 17. The quantity of surfactant in such formulations will typically range from about 5% to about 15% by weight. Suitable surfactants include polyethylene glycol sorbitan fatty acid esters, such as sorbitan monooleate and the high molecular weight adducts of ethylene oxide with a hydrophobic base, formed by the condensation of propylene oxide with propylene glycol. The parenteral formulations are in various aspects presented in unit-dose or multi-dose sealed containers, such as ampoules and vials, and can be stored in a freeze-dried (lyophilized) condition requiring only the addition of the sterile liquid excipient, for example, water, for injections, immediately prior to use. Extemporaneous injection solutions and suspensions are in certain aspects prepared from sterile powders, granules, and tablets of the kind previously described.

**[0063]** Injectable formulations are in accordance with the invention. The requirements for effective pharmaceutical carriers for injectable compositions are well-known to those of ordinary skill in the art (see, e.g., *Pharmaceutics and Pharmacy Practice*, J. B. Lippincott Company, Philadelphia, PA, Banker and Chalmers, eds., pages 238-250 (1982), and *ASHP Handbook on Injectable Drugs*, Toissel, 4th ed., pages 622-630 (1986)).

**[0064]** *Cell Delivery Matrices*

**[0065]** In some embodiments, the HSCs are administered via a cell delivery matrix. The cell delivery matrix in certain embodiments comprises any one or more of polymers and hydrogels comprising collagen, fibrin, chitosan, MATRIGEL, polyethylene glycol, dextrans including chemically crosslinkable or photocrosslinkable dextrans, and the like. In certain embodiments, the cell delivery matrix comprises one or more of: collagen, including contracted and non- contracted collagen gels, hydrogels comprising, for example, but not limited to, fibrin, alginate, agarose, gelatin, hyaluronate, polyethylene glycol (PEG), dextrans, including dextrans that are suitable for chemical crosslinking, photocrosslinking, or both, albumin, polyacrylamide, polyglycolic acid, polyvinyl chloride, polyvinyl alcohol, poly(n-vinyl-2-pyrrolidone), poly(2- hydroxy ethyl methacrylate), hydrophilic polyurethanes, acrylic derivatives, pluronics, such as polypropylene oxide and polyethylene oxide copolymer, 35/65 Poly(epsilon-caprolactone)(PCL)/Poly(glycolic acid) (PGA), Panacryl® bioabsorbable constructs, Vicryl® polyglactin 910, and self-assembling peptides and non-resorbable materials such as fluoropolymers (e.g., Teflon® fluoropolymers), plastic, and metal.

**[0066]** The matrix in some instances comprises non- degradable materials, for example, but not limited to, expanded polytetrafluoroethylene (ePTFE), polytetrafluoroethylene (PTFE), polyethyleneterephthalate (PET), poly(butylenes terephthalate (PBT), polyurethane,

polyethylene, polycarbonate, polystyrene, silicone, and the like, or selectively degradable materials, such as poly (lactic-co-glycolic acid; PLGA), PLA, or PGA. (See also, Middleton et al., *Biomaterials* 21:2335-2346, 2000; Middleton et al., *Medical Plastics and Biomaterials*, March/ April 1998, at pages 30-37; *Handbook of Biodegradable Polymers*, Domb, Kost, and Domb, eds., 1997, Harwood Academic Publishers, Australia; Rogalla, *Minim. Invasive Surg. Nurs.* 11:6769, 1997; Klein, *Facial Plast. Surg. Clin. North Amer.* 9:205-18, 2001; Klein et al., *J. Dermatol. Surg. Oncol.* 11:337-39, 1985; Frey et al., *J. Urol.* 154:812-15, 1995; Peters et al., *J. Biomed. Mater. Res.* 43:422-27, 1998; and Kuijpers et al., *J. Biomed. Mater. Res.* 51:13645, 2000).

**[0067]** The matrix in some embodiments includes biocompatible scaffolds, lattices, self-assembling structures and the like, whether bioabsorbable or not, liquid, gel, or solid. Such matrices are known in the arts of therapeutic cell treatment, surgical repair, tissue engineering, and wound healing. In certain aspects, the matrix is pretreated with the HSCs. In other embodiments, the matrix is populated with HSCs in close association to the matrix or its spaces. The HSCs can adhere to the matrix or can be entrapped or contained within the matrix spaces. In certain aspects, the matrix-HSCs complexes in which the cells are growing in close association with the matrix and when used therapeutically, growth, repair, and/or regeneration of the patient's own kidney cells is stimulated and supported, and proper angiogenesis is similarly stimulated or supported. The matrix-cell compositions can be introduced into a patient's body in any way known in the art, including but not limited to implantation, injection, surgical attachment, transplantation with other tissue, and the like. In some embodiments, the matrices form in vivo, or even more preferably in situ, for example in situ polymerizable gels can be used in accordance with the invention. Examples of such gels are known in the art or the like.

**[0068]** The HSCs in some embodiments are seeded on a three-dimensional framework or matrix, such as a scaffold, a foam or hydrogel and administered accordingly. The framework in certain aspects are configured into various shapes such as substantially flat, substantially cylindrical or tubular, or can be completely free-form as may be required or desired for the corrective structure under consideration. Two or more substantially flat frameworks in some aspects are laid atop another and secured together as necessary to generate a multilayer framework.

**[0069]** Examples of matrices, for example scaffolds which may be used for aspects of the invention include mats (woven, knitted, and more preferably nonwoven) porous or semiporous foams, self-assembling peptides and the like. Nonwoven mats may, for example,



be formed using fibers comprised of natural or synthetic polymers. In some embodiments, absorbable copolymers of glycolic and lactic acids (PGA/PLA), sold under the tradename VICRYL® (Ethicon, Inc., Somerville, N.J.) are used to form a mat. Foams, composed of, for example, poly(epsilon-caprolactone)/poly(glycolic acid) (PCL/PGA) copolymer, formed by processes such as freeze-drying, or lyophilization, as discussed in U.S. Pat. No. 6,355,699, can also serve as scaffolds. Gels also form suitable matrices, as used herein. Examples include in situ polymerizable gels, and hydrogels, for example composed of self-assembling peptides. These materials are used in some aspects as supports for growth of tissue. In situ-forming degradable networks are also suitable for use in the invention (see, e.g., Anseth, K. S. et al., 2002, *J. Controlled Release* 78: 199-209; Wang, D. et al., 2003, *Biomaterials* 24: 3969-3980; U.S. Patent Publication 2002/0022676 to He et al.). These materials are formulated in some aspects as fluids suitable for injection, then may be induced by a variety of means (e.g., change in temperature, pH, exposure to light) to form degradable hydrogel networks in situ or in vivo.

**[0070]** In some embodiments, the framework is a felt, which can be comprised of a multifilament yarn made from a bioabsorbable material, e.g., PGA, PLA, PCL copolymers or blends, or hyaluronic acid. The yarn in certain aspects is made into a felt using standard textile processing techniques consisting of crimping, cutting, carding and needling. The HSCs in certain aspects are seeded onto foam scaffolds that may be composite structures. In addition, the three-dimensional framework are molded in some aspects into a useful shape, such as a specific structure in or around the kidney to be repaired, replaced, or augmented.

**[0071]** The framework can be treated prior to inoculation of the HSCs in order to enhance cell attachment. For example, prior to inoculation with the HSCs, nylon matrices are treated with 0.1 molar acetic acid and incubated in polylysine, PBS, and/or collagen to coat the nylon. Polystyrene in some aspects is similarly treated using sulfuric acid.

**[0072]** In additional embodiments, the external surfaces of the three-dimensional framework is modified to improve the attachment or growth of cells and differentiation of tissue, such as by plasma coating the framework or addition of one or more proteins (e.g., collagens, elastic fibers, reticular fibers), glycoproteins, glycosaminoglycans (e.g., heparin sulfate, chondroitin-4-sulfate, chondroitin-6-sulfate, dermatan sulfate, keratin sulfate), a cellular matrix, and/or other materials such as, but not limited to, gelatin, alginates, agar, agarose, and plant gums, among others.

**[0073]** The scaffold in some embodiments comprises materials that render it non-thrombogenic. These materials in certain embodiments promote and sustain endothelial growth, migration, and extracellular matrix deposition. Examples of such materials include but are not limited to natural materials such as basement membrane proteins such as laminin and Type IV collagen, synthetic materials such as ePTFE, and segmented polyurethaneurea silicones, such as PURSPAN® (The Polymer Technology Group, Inc., Berkeley, Calif.). These materials can be further treated to render the scaffold non-thrombogenic. Such treatments include anti-thrombotic agents such as heparin, and treatments which alter the surface charge of the material such as plasma coating.

**[0074]** The pharmaceutical composition comprising the HSCs in certain embodiments comprises any of the components of a cell delivery matrix, including any of the components described herein.

**[0075]** *Dose*

**[0076]** For purposes herein, the amount or dose of the pharmaceutical composition administered are sufficient to effect, e.g., a therapeutic or prophylactic response, in the subject or animal over a reasonable time frame. For example, the dose of the pharmaceutical composition is sufficient to treat or prevent renal ischemia reperfusion injury in a period of from about 1 to 4 days or longer, e.g., 5 days, 6 days, 1 week, 10 days, 2 weeks, 16 to 20 days, or more, from the time of administration. In certain embodiments, the time period is even longer. The dose is determined by the efficacy of the particular pharmaceutical composition and the condition of the animal (e.g., human), as well as the body weight of the animal (e.g., human) to be treated.

**[0077]** Many assays for determining an administered dose are known in the art. In some embodiments, an assay which comprises comparing the extent to which HSCs are localized to an injured kidney upon administration of a given dose of such HSCs to a mammal among a set of mammals of which is each given a different dose of the HSCs is used to determine a starting dose to be administered to a mammal. The extent to which HSCs are localized to an injured kidney upon administration of a certain dose can be assayed by methods known in the art, including, for instance, the methods described herein.

**[0078]** Additionally or alternatively, an assay which comprises comparing the extent to which a particular dose of HSCs cause attenuation of kidney peritubular capillary loss, regeneration of tubular epithelial cells, prevention of long-term fibrosis, reduction of mortality, or improvement of kidney function after a kidney injury can be used to determine a

starting dose to be administered to a mammal. Such assays are described herein under EXAMPLES.

**[0079]** The dose of the pharmaceutical composition also will be determined by the existence, nature and extent of any adverse side effects that might accompany the administration of a particular pharmaceutical composition. Typically, the attending physician will decide the dosage of the pharmaceutical composition with which to treat each individual patient, taking into consideration a variety of factors, such as age, body weight, general health, diet, sex, therapeutic agent(s) of the pharmaceutical composition to be administered, route of administration, and the severity of the condition being treated. By way of example and not intending to limit the invention, the dose of the pharmaceutical composition can be such that at least about  $0.5 \times 10^6$  (e.g., at least about  $1 \times 10^6$ ,  $1.5 \times 10^6$ ,  $2 \times 10^6$ ,  $2.5 \times 10^6$ ,  $3.0 \times 10^6$ ,  $5.0 \times 10^6$ ,  $10^7$ ,  $10^8$ ) HSCs are administered to the patient.

**[0080]** *Timing of Administration*

**[0081]** In methods provided, the HSCs are administered to the patient at a time in reference to the time of injury to the kidney. In certain embodiments of the invention, administration of the HSCs is delayed; that is, the HSCs are not administered immediately after the kidney injury (e.g., not before about 30 minutes, not before about 1 hour, not before about 2 hours, not before about 3 hours, not before about 4 hours, not before about 5 hours, not before about 6 hours, not before about 7 hours, not before about 8 hours, not before about 9 hours, not before about 10 hours, not before about 11 hours, or not before about 12 hours post-injury).

**[0082]** In some aspects of the invention, the HSCs are administered to the patient at the beginning of the repair phase of the kidney injury. The term “repair phase of the kidney injury” as used herein refers to the time after injury at which a renal regenerative response is observed, as represented by, e.g., repopulation of the existing nephron after cells have been destroyed, lining of the tubules with basophilic, flattened squamous cells, restoration of normal morphology of tubule cells, epithelial cell dedifferentiation, movement, proliferation, or redifferentiation, restoration of functional integrity of nephron, restoration of renal function. The repair phase of the kidney is well documented in mammals. See, for example, Reimschuessel, *ILAR J* 42: 285-291 (2001). In some embodiments, the HSCs are administered at least about 12 hours (e.g., at least about 14 hours, at least about 16 hours, at least about 18 hours, at least about 20 hours, at least about 21 hours, at least about 22 hours, at least about 23 hours, at least about 24 hours, at least about 25 hours, at least about 26 hours, at least about 28 hours, at least about 30 hours, at least about 32 hours, at least about

32 hours, at least about 34 hours, at least about 36 hours, at least about 38 hours, at least about 40 hours, at least about 42 hours, at least about 44 hours, at least about 46 hours, at least about 48 hours, at least about 50 hours, at least about 52 hours, at least about 54 hours, at least about 56 hours, at least about 58 hours, at least about 60 hours, at least about 62 hours, at least about 64 hours, at least about 66 hours, at least about 68 hours, at least about 70 hours, at least about 72 hours) post-injury.

**[0083]** In further embodiments, the HSCs are administered to the patient at a timepoint as described above and before about 14 days (e.g., before about 13 days, before about 12 days, before about 11 days, before about 10 days, before about 9 days, before about 8 days, before about 7 days, before about 6 days, before about 5 days, before about 4 days, before about 3 days) post injury. In some embodiments, the HSCs are administered to the patient at about 24 hours post-injury, or some time thereafter, but before about 14 days post-injury.

**[0084]** In some aspects, the HSCs are administered after X post-injury and before Y post-injury, wherein X is selected from a group consisting of about 20 h, 21 h, 22 h, 23 h, 24 h, 25 h, 26 h, 27 h, 28 h, 29 h, 30 h, 31 h, 32 h, 33 h, 34 h, 35 h, 36 h, 40 h, 48 h, 52 h, 58 h, 64 h, 72 h, 3.5 d, 4 d, 5 d, 6 d, 1 week, 8 d, 9 d, 10 d, wherein Y is selected from a group consisting of 16 d, 15 d, 14 d, 13 d, 12 d, 11 d, 10 d, 9 d, 8 d, 1 week, and wherein X is less than Y. In some aspects of the invention, the HSCs are administered about 20, 21, 22, 23, 24 hours post-injury.

**[0085]** In some embodiments of the invention, the HSCs are administered to the patient more than once. The HSCs may be administered once daily, twice daily, 3X, 4X daily, once weekly, once every 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, or 14 days, or once monthly. In some embodiments, the HSCs are administered after about 24 hours (e.g., at 24 hours) post-injury and administered again after about 48 hours (e.g., at 48 hours) post-injury.

**[0086]** *Controlled Release Formulations*

**[0087]** The pharmaceutical composition are in certain aspects modified into a depot form, such that the manner in which the pharmaceutical composition is released into the body to which it is administered is controlled with respect to time and location within the body (see, for example, U.S. Patent No. 4,450,150). Depot forms are in various aspects, an implantable composition comprising the therapeutic or active agent(s) and a porous or non-porous material, such as a polymer, wherein the HSCs is encapsulated by or diffused throughout the material and/or degradation of the non-porous material. The depot is then implanted into the

desired location within the body and the HSCs are released from the implant at a predetermined rate.

**[0088]** Accordingly, the pharmaceutical composition in certain aspects is modified to have any type of in vivo release profile. In some aspects of the invention, the pharmaceutical composition is an immediate release, controlled release, sustained release, extended release, delayed release, or bi-phasic release formulation.

**[0089]** *Conjugates*

**[0090]** In some embodiments of the invention, the HSCs are attached or linked to a second moiety, such as, for example, a therapeutic agent or a diagnostic agent. The HSCs of these embodiments act as a targeting agent, since the HSCs are able to specifically localize to injured kidney tissue. Accordingly, the invention provides in one aspect a composition comprising HSCs attached to a therapeutic agent or a diagnostic agent. Suitable therapeutic agents and diagnostic agents for purposes herein are known in the art and include, but are not limited to, any of those mentioned herein.

**[0091]** *Combinations*

**[0092]** The pharmaceutical compositions described herein, including the conjugates, are administered by itself in some embodiments. In other embodiments, the pharmaceutical compositions, including the conjugates, are administered in combination with other therapeutic or diagnostic agents. In some embodiments, the pharmaceutical composition is administered with another therapeutic agent known to treat a renal disease or renal medical condition, including, for example, a cytokine or growth factor, an anti-inflammatory agent, a TLR2 inhibitor, a ATF3 gene or gene product, and a mineralocorticoid receptor blocker (e.g., spironolactone), a lysophosphatidic acid, 2-methylaminochroman (e.g., U83836E), a 21-aminosteroid (e.g., lazoroid (U74389F)), trimetazidine, angiotensin converting enzyme (ACE) inhibitors or angiotensin receptor blockers (ARB), and suramin.

**[0093]** In some embodiments, the HSCs are administered with other additional therapeutic agents, including, but not limited to, antithrombogenic agents, anti-apoptotic agents, anti-inflammatory agents, immunosuppressants (e.g., cyclosporine, rapamycin), antioxidants, or other agents ordinarily used in the art to treat kidney damage or disease such as eprodisate and triptolide, an HMG-CoA reductase inhibitor (e.g., simvastatin, pravastatin, lovastatin, fluvastatin, cerivastatin, and atorvastatin), cell lysates, soluble cell fractions, membrane-enriched cell fractions, cell culture media (e.g., conditioned media), or extracellular matrix trophic factors (e.g., hepatocyte growth factor (HGF), bone morphogenic protein-7 (BMP-7),

transforming growth factor beta (TGF- $\beta$ ), matrix metalloproteinase-2 (MMP-2), and basic fibroblast growth factor (bFGF).

**[0094]** *Patient types*

**[0095]** With regard to the inventive methods described herein, the patient is any host. In some embodiments, the host is a mammal. As used herein, the term "mammal" refers to any vertebrate animal of the mammalia class, including, but not limited to, any of the monotreme, marsupial, and placental taxa. In some embodiments, the mammal is one of the mammals of the order Rodentia, such as mice and hamsters, and mammals of the order Logomorpha, such as rabbits. In certain embodiments, the mammals are from the order Carnivora, including Felines (cats) and Canines (dogs). In certain embodiments, the mammals are from the order Artiodactyla, including Bovines (cows) and Swines (pigs) or of the order Perissodactyla, including Equines (horses). In some instances, the mammals are of the order Primates, Ceboidea, or Simiiformes (monkeys) or of the order Anthropoidea (humans and apes). In particular embodiments, the mammal is a human.

**[0096]** The following examples are given merely to illustrate the present invention and not in any way to limit its scope.

## EXAMPLES

### EXAMPLE 1

**[0097]** The following materials and methods were used in Examples 2-7.

**[0098]** *Animals*

**[0099]** Male immune deficient non-obese diabetic (NOD/SCID) mice (NOD.CB17-*Prkdc<sup>scid</sup>*/J) (Jackson Laboratories, Bar Harbor, ME) were used at the age of 8-10 weeks. Note these mice are not diabetic, but lack functional T and B cells. All mice were maintained in filter top cages and received sterilized food and acidified water. All experimental protocols were approved by the Harvard Center for Animal Research and Comparative Medicine.

**[00100]** *Human Peripheral Blood CD34+ Cell Purification And Tracking*

**[00101]** Human peripheral blood CD34+ stem cells were selected from granulocyte colony stimulating factor (G-CSF) mobilized apheresis products obtained from normal healthy adult

donors (catalog# mPB026, AllCells, Berkeley, CA). Briefly, G-CSF (10 $\mu$ g/kg/day) was administered to donors for 5 consecutive days to mobilize CD34+ cells from the bone marrow into peripheral circulation. Donors underwent apheresis on days 5 and 6 to collect mobilized peripheral blood mononuclear cells. CD34+ cells were highly enriched from the apheresis product using ISOLEX 300i Magnetic Cell Positive Selection System (version 2.5, Baxter Healthcare, Deerfield, IL, USA) according to the protocol provided with the instrument's User Manual. Purified cells were characterized by flow cytometry (see below). Enriched, selected cells were maintained in RPMI with 0.5% human serum albumin at 25 °C and used within 48h. To test viability, aliquots of 2 x 10<sup>5</sup> cells were labeled with 7-AAD (20  $\mu$ g/ml, 20min, 4 °C in 100  $\mu$ l PBS), washed with FACS buffer (PBS/5%BSA), then analyzed by Flow cytometry. In some experiments, in order to track HSCs following systemic administration, human CD34+ cells were labeled with the green fluorescent tracer 5-chloromethylfluorescein diacetate (CMFDA, Invitrogen) using 1 $\mu$ g/10<sup>7</sup> cells for 30 minutes at 25 °C in 10 ml of RPMI. Excess CMFDA was quenched after centrifugation (250xg 5min) by resuspending in 10ml 5%BSA (ultrapure) (Sigma) in RPMI (Invitrogen). After further centrifugation cells were resuspended in 1%BSA/RPMI (12.5 x 10<sup>6</sup>/ml). CMFDA labeling did not yield any changes in viability detected using 7-AAD (not shown).

**[00102]** *Animal Model*

**[00103]** Ischemia-reperfusion injury of the kidney was modified from methods previously described [1]. In brief, on day 0, kidneys of anesthetized male mice (8-10 weeks) were exposed through surgical incisions to the flanks, and at core temperature of 36.8-37.3 °C a surgical clamp was placed across the renal artery and vein of either one or both kidneys. The kidneys were confirmed to become dusky, then replaced in the retroperitoneum for 27 minutes (unilateral model) or 25 minutes (bilateral model). Clamps were removed and reperfusion to kidneys was confirmed visually, and wounds closed. To test the effect of human HSCs, these mice with unilateral IRI kidney injury were divided into two groups. In the treatment group (n = 6-10/group), on days 1 and 2 after kidney injury, 200  $\mu$ l of cell suspension containing 2.5 x 10<sup>6</sup> human CD34+ cells labeled with CMFDA was infused intravenously through the tail vein. In the control group, mice were only given vehicle. Mice were sacrificed on days 3, 5, 7, 14 and 28 IRI of the kidney.

**[00104]** *Renal Function*

**[00105]** To evaluate renal function, mice with bilateral IRI kidney injury (d0) were randomly divided into two groups. The treatment group (n = 10), received 2.5 x 10<sup>6</sup> human

HSCs by intravenously tail vein infusion on days 1 and 2. The control group (n = 16) received vehicle only. Plasma creatinine was analyzed from blood samples were taken from the tail vein on days 1, 2, 5, 7, 14 and 28 after injury using Methods previously described [1].

**[00106]** *Tissue Preparation, Immunostaining, Imaging And Quantification Of Injury And Repair*

**[00107]** Mice were perfused with ice cold PBS then organs fixed in periodate-lysine paraformaldehyde (PLP) solution for 2h followed by 18% sucrose 16h, then preserved in optimal cutting temperature (OCT) medium (an embedding medium used for frozen tissue to ensure Optimal Cutting Temperature and to embed tissue before sectioning on a cryostat) (-80 °C) [2], or tissue for light microscopy was fixed in 10% neutral-buffered formalin for 12h, transferred to 70% ethanol, then processed for paraffin sections (3mm) and sections and stained with periodic acid-Schiff (PAS) or picrosirius red stain 2. Immunofluorescence labeling was performed on 5mm cryosections. To detect infused human cells in kidneys, spleen and heart, either antibodies against human leukocyte antigens with no cross-reactivity to mouse antigens were used or fluorescence of CMFDA was used (up to d7). The following antibodies were used employing methods described elsewhere [1, 2]: anti-human leukocyte antigen class I (HLA)-ABC (FITC, 1:200, eBioscience), anti-human CD45 (FITC, 1:200, eBioscience), rat-anti-human CD45 (1:200, Abcam), anti-human CD68 (FITC, 1:200, eBioscience), anti-human CD3 (FITC, 1:200, eBioscience), anti-human CD31 (FITC, 1:200, eBioscience), rabbit anti-human vWF (1:200, Abcam), anti-human CD146 (FITC, 1:100, Abcam), biotin-anti-human CD 13 3 (1:100, Miltenyi), rabbit-anti-human-CD 13 3 (1:100, CellSignaling), goat-anti-human KDR (1:100, R&D Systems), and rabbit-anti-human KDR (1:100, NeoMarkers), followed by rabbit-anti FITC (1:200, Invitrogen), anti-rat Cy3 or anti-rabbit Cy3 or anti-goat Cy3 (1:400, Jackson Immunosresearch) or anti-avidin Cy3 (1:3000, Jackson Immunosresearch). To label mouse vasculature rat-anti-mouse CD31 (1:200, eBioscience), which does not cross-react with human antigen was applied, followed by anti-rat Cy3 (1:400, Jackson Immunosresearch). Sections were post- fixed with 1% paraformaldehyde (PFA), then mounted in Vectashield with DAPI. Peritubular capillary loss and tubule injury were determined by assessing anti-CD31-Cy3 labeled kidney sections or PAS stained paraffin sections respectively using a blinded scoring method as reported previously [3]. In brief, images were captured by digital imaging (X200) sequentially over the entire sagittal section incorporating cortex and outer medulla (10-20 images). Each image was divided into 252 squares by a grid. To calculate peritubular capillary loss, each square without a peritubular capillary resulted in a positive score; the final score presented as a



percentage positive score. To assess the tubular injury, each square the presence of tubule injury (tubule flattening, necrosis, apoptosis or presence of casts) resulted in a positive score. The final score is the percentage of squares with positive score per image, which was averaged for all images from the individual kidney. Epifluorescent images were taken with a Nikon TE2000 microscope, CoolSnap camera (Roper Scientific, Germany) and processed using IP lab software (BD Biosciences, San Jose, CA). Confocal images were generated using a Nikon C1 D-Eclipse confocal microscope. Projection images were generated from 10 Z- stack images that were acquired at 0.1 mm steps. To allow comparison between sections, all confocal settings including were kept constant between sections.

**[00108]** *Flow Cytometric Analysis And Sorting*

**[00109]** Isolex-enriched CD34 cells were analyzed using the following human antibody combinations: anti-CD31-FITC (1:100, BD), anti-CD146-PE (1:100, BD), anti-KDR- FITC (1:100, R&D Systems), anti-CD45-FITC (1:100, BD), anti-CD140b-Alexa Fluor 488 (1:100, BD), anti-CD29-PE (1:100, BD), anti-CD105-FITC (1:100, R&D Systems), anti-CD34-PE (1:100, BD), anti-CD99-FITC (1:100, BD), anti-CD144-PE (1:100, R&D Systems), anti-CD38-FITC (1:100, BD), anti-CD14-FITC (1:100, BD), anti-CD64-PE (1:100, BD), anti-CD61-PerCP (1:100, BD) anti-CD133-APC (1:100, Miltenyi), antiCXCR4-APC (1:100, BD), anti-CD90-APC (1:100, BD), anti-CD 117-APC (1:100, BD), anti-VEGFR1-APC (1:100, R&D Systems), using methods previously described [1]. Full characterization of HSCs will be documented elsewhere (D.M. & A.C. unpublished). Single cells were prepared from kidney, spleen and bone marrow as previously described [2]. In brief, single cells ( $1 \times 10^5$ ) from kidney, spleen and bone marrow were resuspended in FACS buffer and incubated with antibodies against human CD45 (FITC, 1:200, eBioscience) and mouse CD11b (PE, 1:200, eBioscience) for 30 minutes. After washing with FACS wash buffer, and resuspending in 200  $\mu$ l FACS buffer, cells were analyzed using BD FACSCalibur flow cytometer. The human HSCs labeled with CMFDA on day 2 after injection were sorted directly by FACS sorting using FACSaria [2]. Sorted CMFDA+ cells from kidney were immediately lysed and RNA purified using RNA Easy (Qiagen) system, for real time PCR.

**[00110]** *Real Time PCR*

**[00111]** Total RNA was generated from tissue and cells using a kit (RNA Easy Qiagen), according to the manufacturer's instructions. Purity determined by A260 to A280. cDNA was synthesized from 1  $\mu$ g of total RNA using iScript and primers comprising random hexamers and poly dT [2]. Real-time PCR of human and mouse samples was performed

using an ABI7900HT sequence detection system (PerkinElmer Life Sciences, Boston, Applied BioSystems, Foster City, CA) in the presence of SYBR -Green (SYBR Green PCR kit; Qiagen) using methods previously described [4]. Primer/probe sets specific for human GAPDH, HPRT1, Angiopoietin 1 (ANGPT1), Fibroblast growth factor 2 (FGF2), Hepatocyte Growth Factor (HGF), Insulin-like growth factor 1(IGF1), interleukin-8 (IL8), Platelet-derived growth factor b (PDGFb), transforming growth factor b 1 (TGFb 1), Vascular endothelial growth factor (VEGF), TIE1, were from Sabiosciences. Equal amounts of cDNA were used for RT-PCR reaction and mixed with ready to use reaction mix (Sabiosciences). All of the reactions were performed in triplicate. Optimization of the real-time PCR was performed according to the manufacturer's instructions. For standard curve determination, a pool of all the samples, serially diluted in four log<sub>2</sub> steps and run in parallel to the samples, were used. The total volume of each reaction was 20  $\mu$ l, containing 300 nM forward and 300 nM reverse primer and 125ng of cDNA. Appropriate negative controls were run for each reaction.

**[00112]** *Statistical Analysis*

**[0100]** All values are given as mean  $\pm$  standard deviation (SD). Mantel-Cox Log-rank test was used to analyze survival. Comparisons between two groups were carried by unpaired t-test (two tailed). Paired t test was used to compare directly the left (IRI) and right (control) kidney of an animal or diseased mouse compared with sham operated mouse. *P* values less than 0.05 were considered significant in all statistical tests.

EXAMPLE 2

**[0101]** *Characterization Of Isolex-Purified G-Csf-Mobilized Hematopoietic Stem Cells*

**[0102]** CD34+ enriched leukocytes from hematopoietic stem cell-mobilized human donors were analyzed for viability and purity. More than 99% of HSCs were viable by 7-AAD exclusion (not shown). More than 96% of leukocytes were CD45+, CD34+ indicating they were hematopoietic stem cells (HSCs) (see Table 1). A minority expressed CD34 but not CD45. Further characterization of the enriched leukocytes was performed using the cell surface markers CD14, CD34, CD146, CD133, CD31, VEGFR2 for confirmation of multi-lineage potential and identification of putative endothelial progenitors (see Table 2) [19]. The characterization indicates that in addition to HSCs, mobilized human peripheral blood CD34+ cells contain small numbers of circulating endothelial progenitor cells (CEPs) and rare circulating endothelial cells (CECs).

TABLE 1

<b>Human CD34+ enriched mobilized peripheral blood stem cells (n = 6/group).</b>			
<b>Markers</b>	<b>CD34+</b>	<b>CD34+CD45-</b>	<b>CD34-CD45+</b>
<b>Average</b>	96.44	0.08	2.96
<b>SD</b>	0.84	0.13	0.89

TABLE 2

<b>CEC and CEP phenotypes in human CD34+ enriched mobilized peripheral blood stem cells (n = 6/group)</b>					
	<b>CEPs</b>				<b>CECs</b>
<b>Markers</b>	<b>CD34+ CD14+</b>	<b>CD34+KDR+ CD133+</b>	<b>CD34+KDR+ CD146- CD31-</b>	<b>CD34+CD133+ CD45+CD146+</b>	<b>CD34+CD133- CD146+CD31+</b>
<b>Average</b>	0.05	0.30	0.05	0.07	0.05
<b>SD</b>	0.04	0.22	0.07	0.11	0.06

## EXAMPLE 3

**[0103]** *Human Hematopoietic Stem Cells Are Recruited To Kidney During Repair Following Ischemia Reperfusion Injury*

**[0104]** To study the effect of human HSCs on kidney repair we initially determined whether they could be recruited to the injury kidney. In preliminary studies I.V. infusion of  $2.5 \times 10^6$  HSCs labeled with CMFDA prior to injury did not result in significant recruitment 24h after injection (data not shown). Next we infused CMFDA-labeled HSCs on day 1 and 2 after kidney IRI, and looked in the kidney 3, 5, 7 days following injury (Figure 1A, B) where many recruited HSCs could be detected in the kidney parenchyma. Many were localized within peritubular capillaries (PTC), but some were detected outside of the confines of the capillaries in a perivascular location (Figure 1C). We also noticed that following unilateral IRI there was a small but significant recruitment of HSCs to the uninjured kidney (Figure

1B). However we could not detect any HSCs in the heart (not shown) indicating that this was specific recruitment of HSCs to the uninjured and injured kidney. Due to concern that CMFDA might become diluted with time we infused unlabeled HSCs into mice on d1 and d2 following injury. These unlabeled cells were detected by antibodies against HLA class I (Figure 1 C, D). HLA-I positive cells were readily detected in the kidneys at all time points but notably there was persistence of HLA-I+ cells in the kidney 14 and 28 after IRI (Figure 1D). As expected, HSCs were also identified in spleen and bone marrow (Figure 1E-H), and there was persistence of HSCs in the marrow, with evidence on d7 following IRI that HSCs in the bone marrow had induced the myeloid marker CD11b (Figure 1G) suggesting that HSCs had engrafted the mouse bone marrow and that the mice were now chimeric.

#### EXAMPLE 4

**[0105]** *Systemic Human Hematopoietic Stem Cell Therapy Reduces Mortality And Improves Kidney Function Following Ischemia Reperfusion Injury*

**[0106]** To determine whether HSC recruitment to the injured kidney had any functional consequence during repair, we subjected mice to bilateral IRI (day 0), followed by intravenous infusion of human HSCs on d1 and d2. Plasma creatinine was assessed in sham surgery mice (d0, plasma creatinine value is  $0.05 \pm 0.06$ ) and on d1, d2, and d7 following IRI. Bilateral kidney IRI resulted in significant increase in serum creatinine at 24 hours and peaked at 48h (Figure 2A). Although plasma creatinine levels at 24 hours (time of first injection) were no different in treatment and vehicle groups, there was a marked and significant decrease in plasma creatinine at 48h in mice that had received HSCs (Figure 2A), while the vehicle group of mice had persistently highly elevated plasma creatinine levels at this time. By d7, in mice that had survived, both vehicle and treatment groups showed similar levels of plasma creatinine. This is not surprising since the IRI model is a recovery model. In the vehicle group, however, only 50% of mice survived to day 7 (Figure 2B), whereas 90% of mice that received human HSCs survived to day 7 (Figure 2B). The surviving numbers in the two groups can be seen in Figure 2B. These striking findings indicate that human HSCs both promote kidney repair/regeneration and enhance survival.

#### EXAMPLE 5

**[0107]** *Human Hematopoietic Stem Cell Therapy Attenuates Kidney Peritubular Capillary Loss, Promotes Tubular Epithelial Regeneration And Prevents Long-Term Fibrosis Following Ischemia Reperfusion Injury*

**[0108]** To study the mechanism by which HSCs promote kidney repair we analyzed kidney sections for loss of peritubular capillaries (PTCs) and persistence of tubule injury (Figure 3). Analysis of mCD31-labeled PTCs by morphometry revealed that HSC treatment prevented PTC loss (Figure 3A-C) during repair. However notably the PTC loss after 14 and 28 days was not different indicating that there are endogenous factors that promote regeneration of PTCs, but that HSC therapy attenuates early loss of vasculature. Similarly, HSC therapy attenuated persistence of tubule injury during the repair phase of this model of IRI (Figure 3 D-F), suggesting that HSCs are either directly or indirectly promoting tubule regeneration. We have previously demonstrated that kidney IRI can lead to persistent interstitial fibrosis, a harbinger of chronic kidney disease and strongly associated with progressive long-term loss of kidney function [14, 20-22]. To test whether systemic infusion of HSCs during repair of the injured kidney affected long-term consequences of injury we quantified interstitial fibrosis (Figure 3G-I). In vehicle treated mice, interstitial fibrosis progressively accumulated in the four weeks following injury but in those mice that had received HSCs interstitial fibrosis was attenuated by d28.

#### EXAMPLE 6

**[0109]** *Human Hematopoietic Stem Cells Acquire Early Lymphoid And Myeloid Differentiation And Endothelial Progenitor Cell Markers In The Kidney Following Ischemia Reperfusion Injury*

**[0110]** HSCs are the source of myeloid, erythroid, megakaryocyte and lymphoid lineage cells. We noted that while many HSCs were recruited to kidneys on d3 after injury the number of retained cells fell progressively through d7, but thereafter increased again up to d28 after injury (Figure 1). We labeled kidneys for human lymphoid and myeloid commitment markers (Figure 4). As early as d3 after injury many of the recruited HSCs had acquired CD68 or CD3 and this induction was similar in both uninjured and injured kidney (Figure 4). While none of the HSCs recruited to kidney through d7 acquired monocytic nuclear morphology, these data suggest that there is early local commitment toward myeloid and lymphoid lineages within the kidney. The number of human cells in the kidney increases late after injury. We observed occasional human cells with characteristic nuclei of neutrophils in d14 and d28 post IRI kidneys (not shown). These findings together with findings of BM chimerism suggest that the late increase in human cells in the kidney either reflects bone marrow chimerism or reflects local differentiation of mature cell types in the kidney.

**[0111]** To investigate further the local differentiation of HSCs in the kidney, sections labeled with markers VEGFR2 (KDR), CD146 and CD133, and cell surface expression was compared with stem cells prior to infusion (Table 3). While few mobilized enriched HSCs expressed KDR or CD146, the majority expressed CD133. However in the kidney d3 post IRI there was a phenotypic switch since nearly all recruited HSCs expressed CD146, but none expressed CD133. The expression of KDR was similar in mobilized, enriched HSCs compared with those recruited to kidney. Since CD146 has been associated with CEP functions, our findings suggest that the kidney promotes HSC differentiation toward CEP type function.

TABLE 3

<b>Percentage of HSCs expressing cell surface markers before IV injection and following recruitment to kidney at d3 and d5 post IRI (n = 5/group)</b>			
Markers	CD34+ KDR+	CD34+CD146+	CD34+CD133+
hCD34+before IV	0.32±0.15	0.12±0.16	73.9±5.97
D3 after IRI	1.0±1.7	97.9±3.63	0
D5 after IRI	0	47.6±4.1	0

## EXAMPLE 7

**[0112]** *Human Hematopoietic Stem Cells Contribute To Vascular Repair Primarily By Paracrine Mechanisms*

**[0113]** To study further the role of HSCs to support neovascularization, we initially determined whether HSCs had differentiated into endothelial cells. Using the human-specific antibodies against CD31 and human vWF, two markers of endothelial cells, we identified human CD31+ cells in injured kidneys at day 7, 14 and 28, but not at earlier timepoints (Figure 5A, B, C). Therefore CD31 expression did not coincide with maximal repair. Occasional CD31+ HSCs lacked CD45 expression and were found in the PTC wall with morphology consistent with endothelial cells (Figure 5A). However the vast majority of CD31+ human cells also co-expressed CD45 (Figure 5B) or were located in the interstitium with leukocyte morphology, consistent with CD31 expression by lymphocytes and monocytes, and indicating that human CD31 is not a specific marker of endothelium. Parallel

studies using anti human-vWF antibodies (that did not cross react with mouse vWF) also identified very rare vWF+ human cells which lacked CD45 expression (Figure 5D), adding weight to the observation that occasional human cells do become functioning endothelial cells. Since these investigations provided evidence for only a minor contribution of human CD34+ cells to direct capillary regeneration, but there was marked induction of the CEP marker CD146 in all HSCs (Table 1), we tested whether HSCs were functioning by paracrine mechanisms. This was particularly tractable given the intra and perivascular locale of HSCs in the kidney following injury. To study this further we purified CMFDA-labeled HSCs that had been recruited to the kidney on d4 post IRI and analyzed their human specific transcriptional profile by RT-PCR comparing it to the transcriptional profile of homogeneous HSCs prior to systemic injection into mice. HSCs generated high levels of transcripts for pro-angiogenic cytokines including ANG-1, FGF-2, and VEGF-A, and in addition generated high levels of HGF recognized for its role in epithelial regeneration (Figure 6). Strikingly, those HSCs that were recruited to the kidney exhibited highly similar transcriptional activity for the pro-angiogenic cytokines, further supporting a paracrine role in angiogenesis.

#### EXAMPLE 8

##### **[0114]** *Discussion of the Data Presented Herein*

**[0115]** Acute kidney injury in humans continues to confer high mortality and has limited therapeutic options, therefore identifying potential regenerative approaches, as new therapeutic strategies are highly desirable. In addition emerging evidence indicates that acute kidney injury in humans is a harbinger of chronic kidney disease characterized by inflammation, vasculopathy, epithelial atrophy, fibrosis and progressive loss of function leading to organ failure [2, 14, 22, 23]. New strategies that attenuate kidney injury or enhance repair and regeneration will not only have short-term impact but conceivably will alter the long term course for kidney function. The long-term consequences for such therapies will impact not only kidney disease but also cardiovascular diseases since chronic kidney disease is an independent risk factor for cardiovascular diseases [4]. Recently, adult human peripheral blood CD34+ cells as well as HSCs have been reported to promote vasculogenesis and osteogenesis following stroke and bone injury [16, 24]. Furthermore, CD34+ cells are capable of expansion and mobilization into the peripheral circulation in the presence of exogenously applied G-CSF [25-27], making HSCs readily available, and strengthening the rationale of clinical cellular therapy.

**[0116]** In the present study, we demonstrated that human HSCs administered systemically 24h following kidney injury were selectively recruited to injured kidneys and localized prominently in and around vasculature. This recruitment was associated with enhanced repair of the microvasculature, tubule epithelial cells, enhanced functional recovery and increased survival and additionally, prevented long-term fibrosis. HSCs induced early lymphoid and myeloid commitment markers in the kidney, acquired CEP markers but retained synthesis of high levels of pro-angiogenic transcripts following recruitment to the kidney. Although the purified HSCs contained small numbers of circulating endothelial progenitors and occasional circulating endothelial cells prior to recruitment to the kidney and kidney-recruited HSCs induced CD146 consistent with CEP differentiation, we identified very few human endothelial cells in the mouse capillary walls. Taken together these data indicate that HSC-mediated renal repair is by paracrine mechanisms rather than replacement of vasculature (Figure 7).

**[0117]** Human HSCs were selectively recruited into injured kidney in the model of unilateral kidney IRI, indicating that injured kidney can selectively recruit HSCs that are in the peripheral circulation. Selective recruitment of human HSCs to post IRI kidney indicates local release of chemokines, including stromal derived factor-1 (SDF-1) and its receptor CXCR4, may be important and the transcription factor hypoxia inducible factor-1 (HIF-1) may play a role in regulating local chemokine induction [28, 29]. It was notable that systemic administration of HSCs at the onset of injury (d0) led to poor recruitment of HSCs, but that delayed administration of HSC at the beginning of the repair phase was highly effective in triggering recruitment. This recruitment pattern is similar to monocyte influx to the kidney, and unlike neutrophil recruitment, which suggests that additional monokines may play a role in HSC recruitment. Our prior studies in mice provided no evidence for endogenous HSC mobilization from the bone marrow or recruitment to the kidney, simply in response to IRI, indicating that there is an inadequate endogenous signal for recruitment of HSCs from their normal niche in the bone marrow [30]. Since injection of HSCs into the peripheral circulation results in effective recruitment to the kidney, HSC therapy overcomes a normal block in release from the bone marrow niche. Small numbers of human HSCs were also recruited to the uninjured kidney in the unilateral model of IRI. No HSCs were recruited to heart or gut in the same mice, or to kidneys of healthy mice (not shown). In response to unilateral IRI, the uninjured kidney undergoes compensatory changes which included hypertrophy and hyperplasia. It is possible therefore that HSC recruitment to the uninjured kidney either promotes angiogenesis or plays a protective role in the absence of injury.



**[0118]** HSCs were detected in the kidney through d14 and d28 after IRI, using antibodies against HLA-class-I antigens. There was a bimodal distribution of HSC retention in the kidney with time, with the nadir occurring at about seven days. We noted that the mice developed bone marrow chimerism, and that at d14 and d28 (but not earlier) some of the human cells in the kidney were neutrophils. It is likely therefore that for the first 7d-10d during repair of the kidney the HSCs remained as stem cells, early committed cells or CEPs, and slowly disappeared from the kidney as repair progressed, to be subsequently replaced with mature leukocytes which were recruited from bone marrow rather than deriving from the original systemic circulation HSCs. The late increase in human leukocytes in the kidney together with late expression of CD31 and appearance of human neutrophils are consistent with leukocyte recruitment from the chimeric bone marrow. However, our data strikingly point to HSC infusion on d1 and d2 of disease resulting in long-term impact on fibrosis. It is unclear from these current studies whether a reduction in long-term fibrosis reflects improved early vascular repair or whether it reflects a persistent population of reparative human HSCs in the kidney at late time-points.

**[0119]** Ischemic injury in the kidneys is characterized by epithelial injury. Less well described is the loss of peritubular capillaries (PTCs). But, data derived from several severe acute kidney injury models (ischemia, toxin, transient angiotensin II) demonstrate capillary loss that typically precedes the development of prominent fibrosis [14, 15, 31], and neoangiogenesis may be a central process in preservation of vascular structure and restoration of organ function [12, 13, 32, 33]. We also show in these studies that following IRI there is marked loss of PTCs with only relatively mild renal injury and that although there is significant regeneration of these PTCs during repair, there is persistent loss of vasculature one month after injury, indicating that the kidney has an inherent defect in revascularization after injury [14], unlike other organs such as skin. Our studies show unequivocally that HSCs attenuate that loss of PTCs in the kidney during the repair, and this is associated with both rapid functional recovery of the kidney and enhanced survival of mice. In our unilateral IRI model, HSC-mediated regeneration of PTCs did not attenuate the long-term persistent PTC loss at 28 weeks, but nevertheless impacted on recovery and survival seen in the bilateral IRI model, pointing to early vascular repair as a central process in renal repair. Despite the efficacy HSC-mediated vascular repair being restricted to early timepoints after injury, there is nevertheless prevention of fibrosis progression in the kidney at one month after injury. Further studies will be required to understand whether this long-term effect of early HSC infusion is due to enhanced pericyte-endothelial cell interactions which may be a

central interaction in the development of interstitial fibrosis [34]. In preliminary studies late administration of HSCs to mice 14 days post IRI kidney resulted in poor recruitment and little evidence of enhanced vascular repair (not shown), indicating that there is a restricted period post injury during which HSCs can be efficacious.

**[0120]** Although the kidney IRI model is characterized by severe injury and repair of the tubule epithelial cells, particularly the S3 segment of the proximal tubule cells, it is likely that without PTC regeneration those injured tubules will not regenerate successfully due to persistent ischemia [14, 35]. Our studies also showed that HSCs promoted epithelial regeneration, as assessed by tubule injury score and functional recovery. HSCs generated high levels of transcripts for pro-angiogenic factors, and their locale in the kidney (intravascular and perivascular) suggests a primary role in vascular repair, which secondarily promotes epithelial repair. However high level transcripts for HGF which is known to have pro-reparative effects directly on epithelia and also the epithelial reparative cytokine WNT7b (not shown) (Lin et al. manuscript in submission) suggests that HSCs might have direct paracrine role on epithelial repair, independently of PTC repair.

**[0121]** It is also interesting that HSCs rapidly induced CD3+ and CD68+ expression in the repairing kidney. Increasing evidence points to reparative roles for both T cells and monocyte derived cells in the kidney following injury [36, 37]. Therefore it is also possible that HSCs are locally differentiating into reparative T cells and reparative macrophages. Further studies will be required with determine the differences between kidney recruited HSCs and mature T cells and monocytes from the peripheral blood [36, 37].

**[0122]** The role of circulating endothelial cells (CECs) and CEPs in endothelial regeneration by directly forming mature endothelial cells has been the subject of considerable study [18, 38]. In fact we have previously reported in mouse bone marrow chimeras that a minority of endothelial cells derive from the chimeric bone marrow following kidney IRI and repair [30]. In some studies, the use of the promoter Tie2 to detect leukocytes that have become endothelial cells has rendered post hoc interpretation problematic since Tie2 labels both leukocytes and endothelial cells [39]. Therefore the claims that CEPs become endothelial cells may be over stated. In these current studies we consistently found that almost all the recruited human HSCs retained the common leukocyte marker CD45, which is consistent with other published data [11]. We used the endothelial marker CD31 to identify human endothelial cells, but CD31 also labels B cells and monocyte/macrophages [40], and proved to be non-specific for endothelial cells in these studies. However, occasional cells were identified within the capillary wall with endothelial morphology, expression of CD31,

vonWillebrand Factor (vWF) and absence of CD45 [41], consistent with human endothelial cells. In our initial characterization of purified HSCs there was a minor population of purified CECs (<0.05%) [38, 42], and a small population of CEPs. In the post IRI kidney, the majority of human HSCs acquired CEP markers. It is possible therefore that these occasional human endothelial cells derive from cell fusion of CEPs with endothelial cells, incorporation of rare CECs, or transdifferentiation of CEPs. Certainly, appearance of human endothelial cells was not a significant mechanism of kidney PTC regeneration. Rather, our studies indicate that HSCs and the HSCs recruited to the repairing kidney that have CEP markers are capable of secretion of angiogenic factors including VEGF-A, HGF, ANG-1, IL-8, IGF-1 and FGF-2 as has been reported in other studies [18, 24, 43]. All of these cytokines are recognized as potent angiogenic factors and can promote kidney repair by increased angiogenesis [44-46]. Combined with the intravascular and perivascular locale of HSCs in the kidney we propose that the major mechanism of both survival and kidney repair by HSCs is PTC regeneration by paracrine mechanisms [24].

**[0123]** In conclusion, we demonstrate here that systematically administered peripheral blood mobilized human HSCs reduce mortality and promote rapid renal repair and regeneration of the kidney by paracrine mechanisms directed at peritubular capillaries. These findings support human HSCs as a promising therapeutic strategy for treatment of acute kidney diseases, and in the prevention of chronic kidney diseases.

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**[0124]** All description herein relating to compositions or methods of treatment also should be construed to define “uses” of the invention. For example, the invention includes use of a source of salicylic acid for the treatment of conditions identified herein or achieving a therapeutic goal identified herein (e.g., lowering blood glucose in a human in need thereof). Likewise, the invention also includes use of a source of salicylic acid for manufacture of a medicament for such treatments/purposes.

**[0125]** The foregoing summary is not intended to define every aspect of the invention, and additional aspects are described in other sections, such as the Detailed Description. The entire document is intended to be related as a unified disclosure, and it should be understood that all combinations of features described herein are contemplated, even if the combination of features are not found together in the same sentence, or paragraph, or section of this document.

**[0126]** In addition to the foregoing, the invention includes, as an additional aspect, all embodiments of the invention narrower in scope in any way than the variations specifically mentioned above. With respect to aspects of the invention described as a genus, all individual species are individually considered separate aspects of the invention. With respect to aspects described as a range, all subranges and individual values are specifically contemplated.

**[0127]** Although the applicant(s) invented the full scope of the claims appended hereto, the claims appended hereto are not intended to encompass within their scope the prior art work of others. Therefore, in the event that statutory prior art within the scope of a claim is brought to the attention of the applicants by a Patent Office or other entity or individual, the applicant(s) reserve the right to exercise amendment rights under applicable patent laws to redefine the subject matter of such a claim to specifically exclude such statutory prior art or obvious variations of statutory prior art from the scope of such a claim. Variations of the invention defined by such amended claims also are intended as aspects of the invention. Additional features and variations of the invention will be apparent to those skilled in the art from the entirety of this application, and all such features are intended as aspects of the invention.

**WHAT IS CLAIMED:**

1. A method of treating a kidney injury in a patient, comprising administering to the patient an amount of hematopoietic stem cells (HSCs) at least about 20 hours post injury and before about 14 days post injury, wherein the amount is effective to treat the kidney injury in the patient.
2. A method of preventing a renal disease or renal medical condition in a patient comprising a kidney injury, comprising administering to the patient an amount of hematopoietic stem cells (HSCs) at least about 20 hours post injury and before about 14 days post injury, wherein the amount is effective to prevent the renal disease or renal medical condition in the patient.
3. The method of claim 2, wherein the renal disease or renal medical condition is selected from a group consisting of: acute renal failure, chronic kidney disease, and interstitial fibrosis.
4. A method of increasing survival of a patient comprising a kidney injury, comprising administering to the patient an amount of hematopoietic stem cells (HSCs) at least about 20 hours post injury and before about 14 days post injury, wherein the amount is effective to increase survival of the patient.
5. The method of any of claims 1 to 4, wherein the kidney injury causes peritubular capillary loss in a kidney of the patient.
6. The method of any of claims 1 to 5, wherein the acute kidney injury is caused by one or more of: ischemia, a toxin, use of an angiotensin-converting enzyme inhibitor (ACEI) or angiotensin II receptor blocker, a blood transfusion reaction, an injury or trauma to muscle, surgery, shock, and hypotension in the patient.
7. The method of any of claims 1 to 6, wherein the kidney injury is renal ischemia reperfusion injury.
8. The method of any of claims 1 to 7, wherein the HSCs are administered at least about 20 hours post injury and before about 7 days post injury.

9. The method of claim 8, wherein the HSCs are administered at least 22 hours post injury and before about 4 days post injury.

10. The method of claim 9, wherein the HSCs are administered at approximately 24 hours post injury.

11. The method of any of the preceding claims, further comprising a second administration of HSCs.

12. The method of claim 11, wherein the second administration of HSCs is administered at least about 12 hours after the first administration.

13. The method of claim 12, wherein the second administration of HSCs is administered at least about 24 hours after the first administration.

14. The method of any of the preceding claims, wherein the HSCs are part of a cell population of which at least 30% of the cells are CD34<sup>+</sup>HSCs.

15. The method of claim 14, wherein at least 50% of the cells are CD34<sup>+</sup> HSCs.

16. The method of claim 15, wherein at least 75% of the cells are CD34<sup>+</sup> HSCs.

17. The method of claim 16, wherein more than 75% of the cells are CD34<sup>+</sup> HSCs.

18. The method of any of the preceding claims, wherein the HSCs are mobilized bone marrow cells isolated from peripheral blood of a donor.

19. The method of claim 18, wherein the donor is the patient and the HSCs are autologous to the patient.

20. The method of any of claims 1 to 19, wherein at least  $2.5 \times 10^6$  HSCs are administered to the patient.

21. The method of any of the foregoing claims, wherein the HSCs are administered parenterally.

22. A pharmaceutical composition comprising a population of HSCs and a pharmaceutical carrier.
23. The pharmaceutical composition of claim 22, formulated for parenteral administration.
24. The pharmaceutical composition of claim 22 or 23, wherein the HSCs are conjugated to a therapeutic agent for renal ischemia reperfusion injury.
25. The pharmaceutical composition of any of claims 22 to 24, further comprising a therapeutic agent for treating a renal disease or renal medical condition.
26. The pharmaceutical composition of claim 25, wherein the therapeutic agent is selected from the group consisting of: a TLR2 inhibitor, a ATF3 gene or gene product, and a mineralocorticoid receptor blocker, a lysophosphatidic acid, 2-methylaminochroman, a 21-aminosteroid, trimetazidine, and suramin.

Figure 1

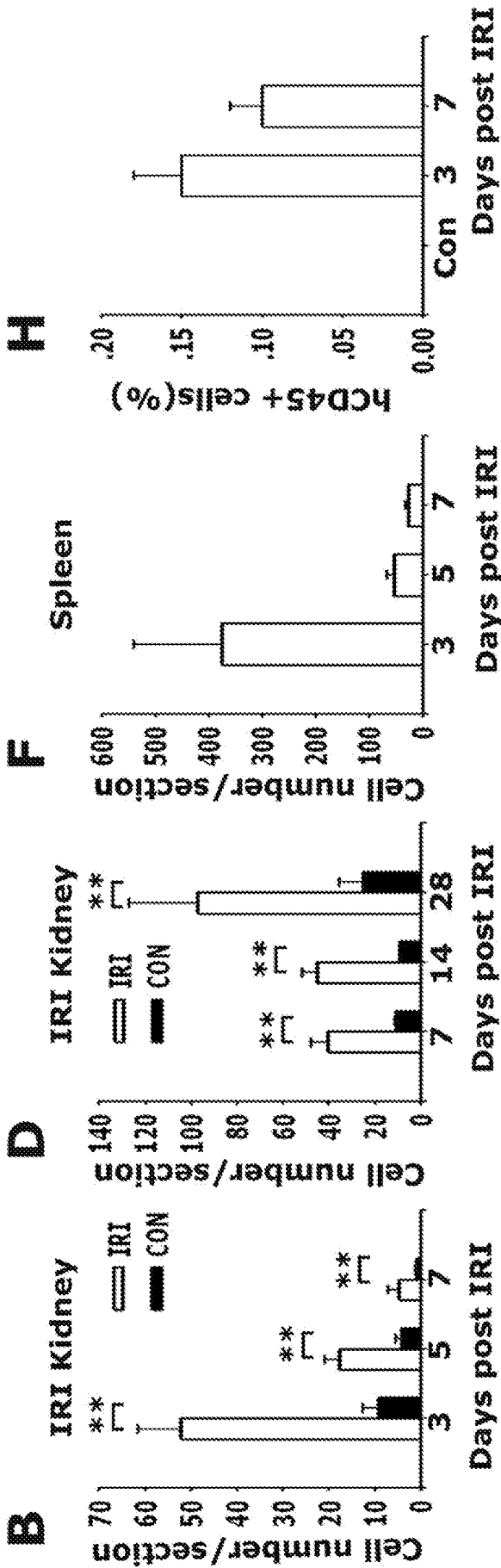
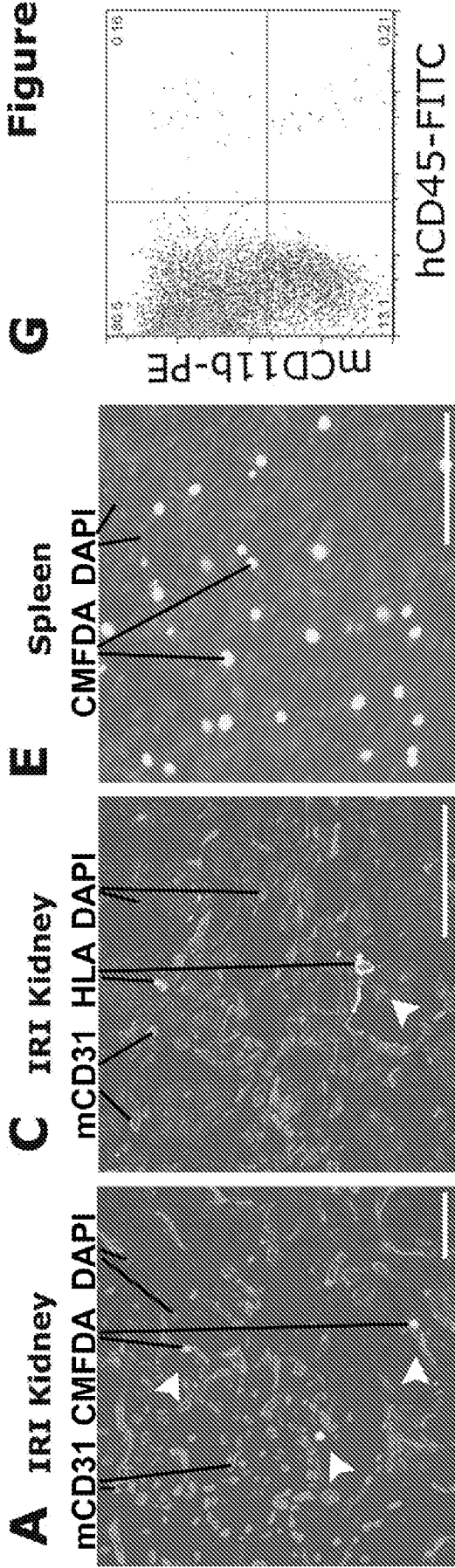
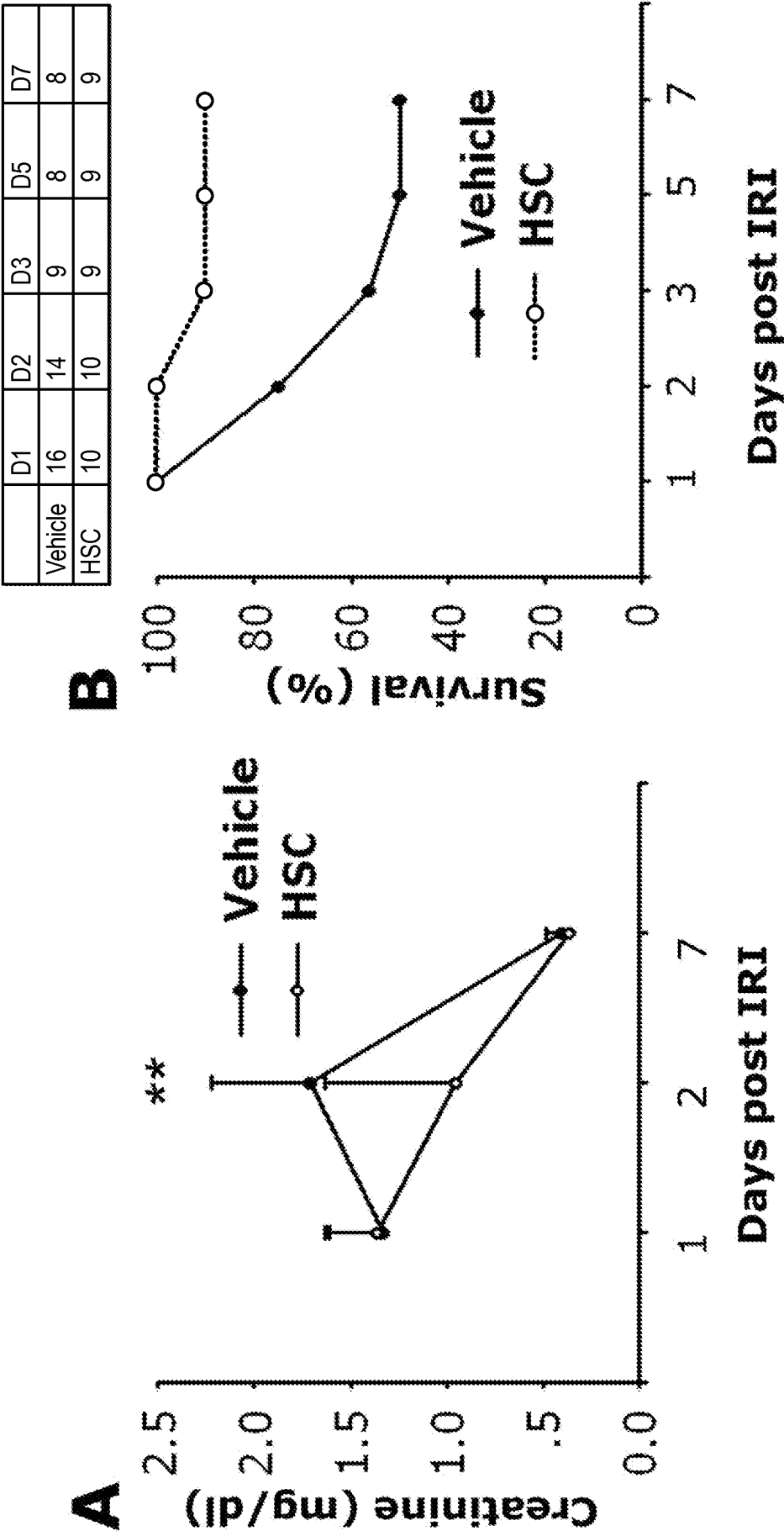


Figure 2



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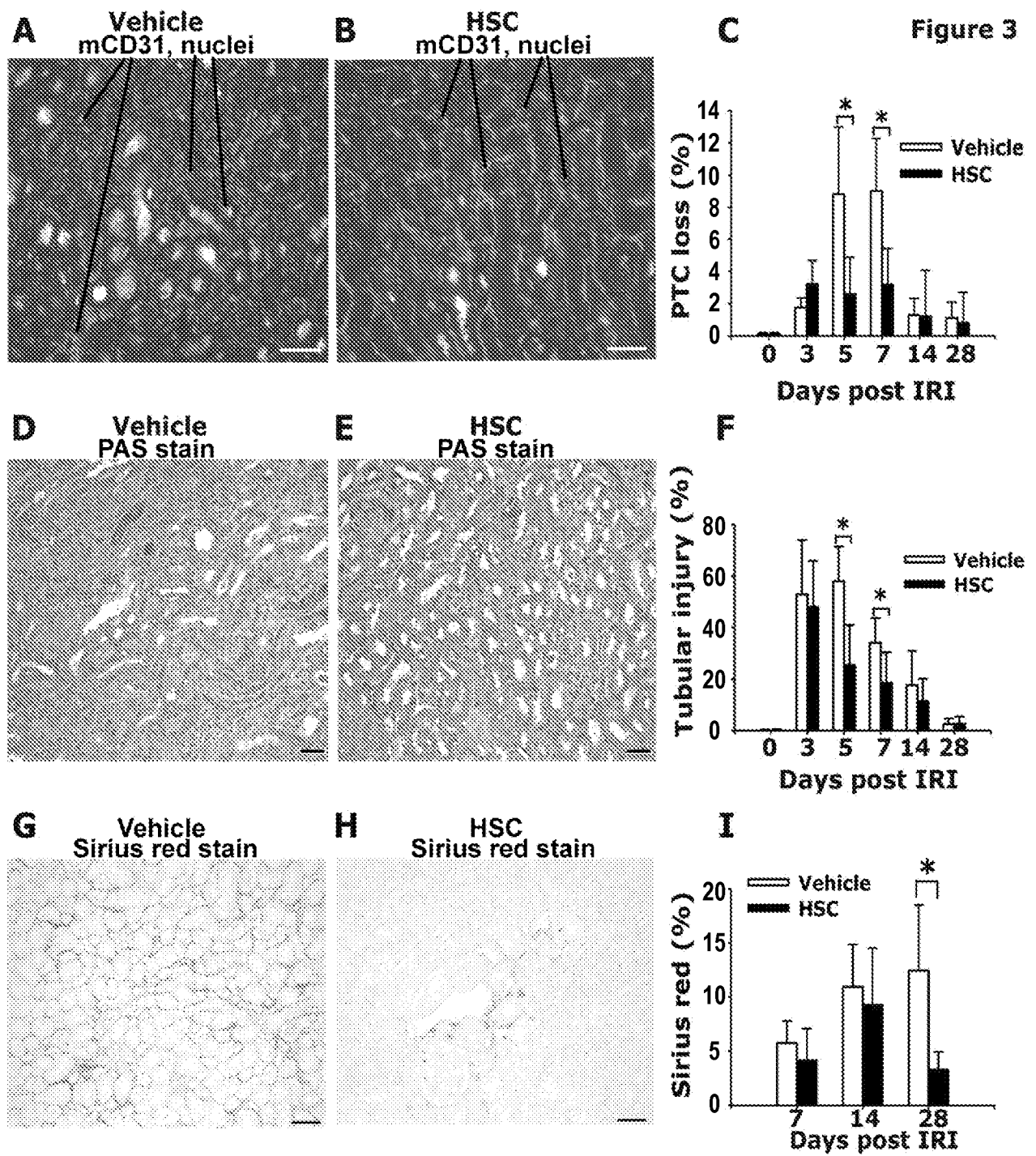


Figure 4

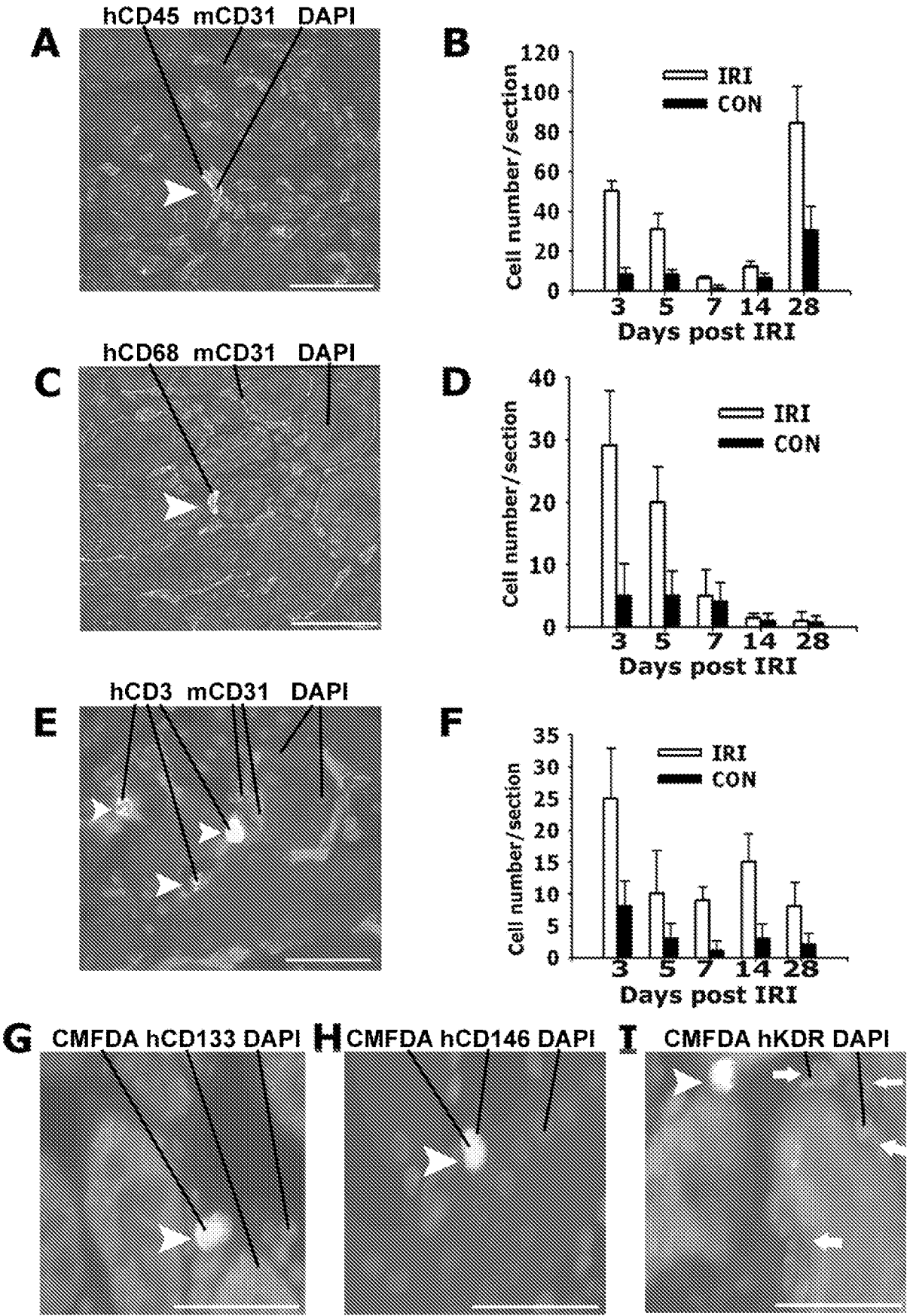
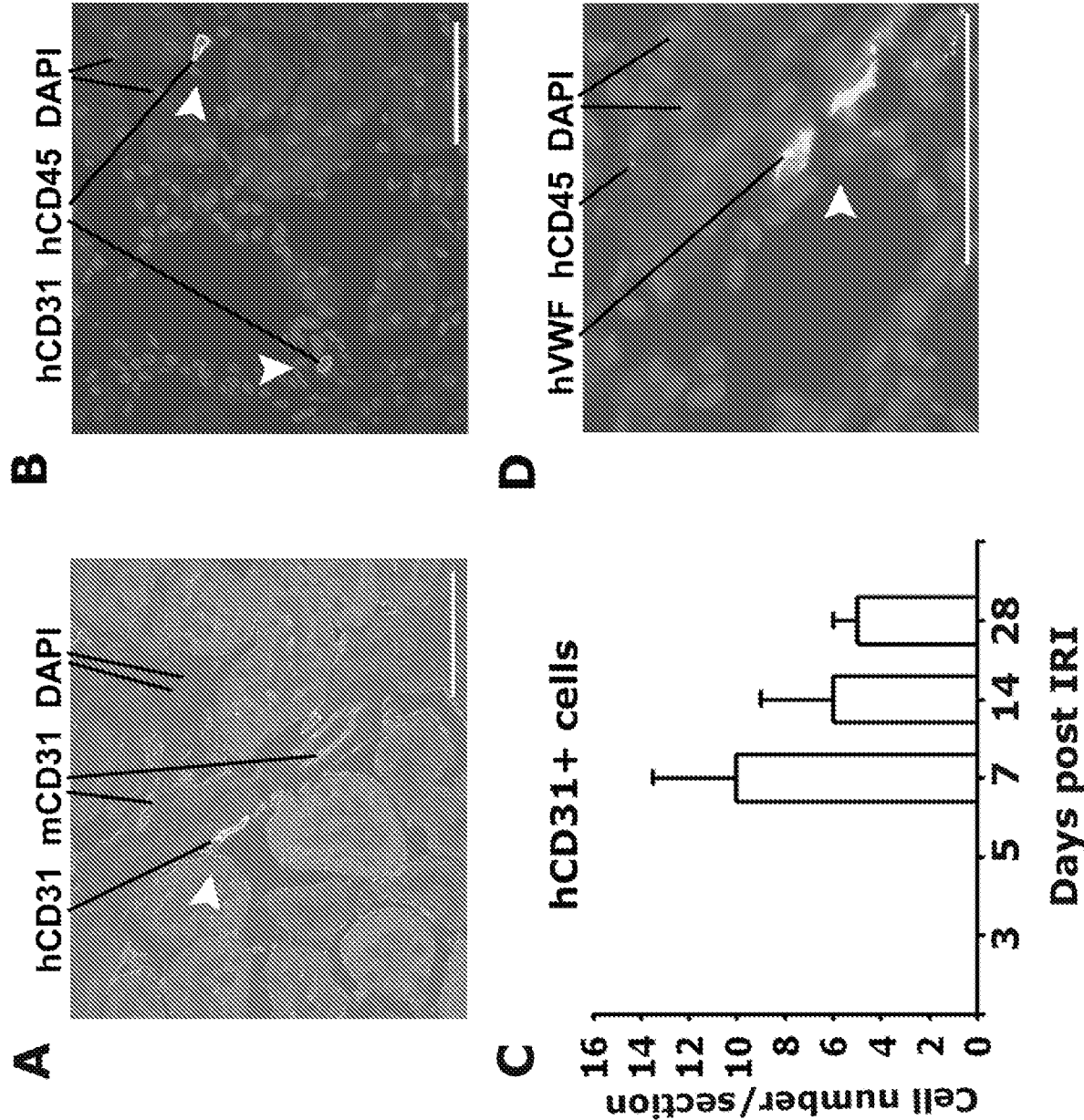


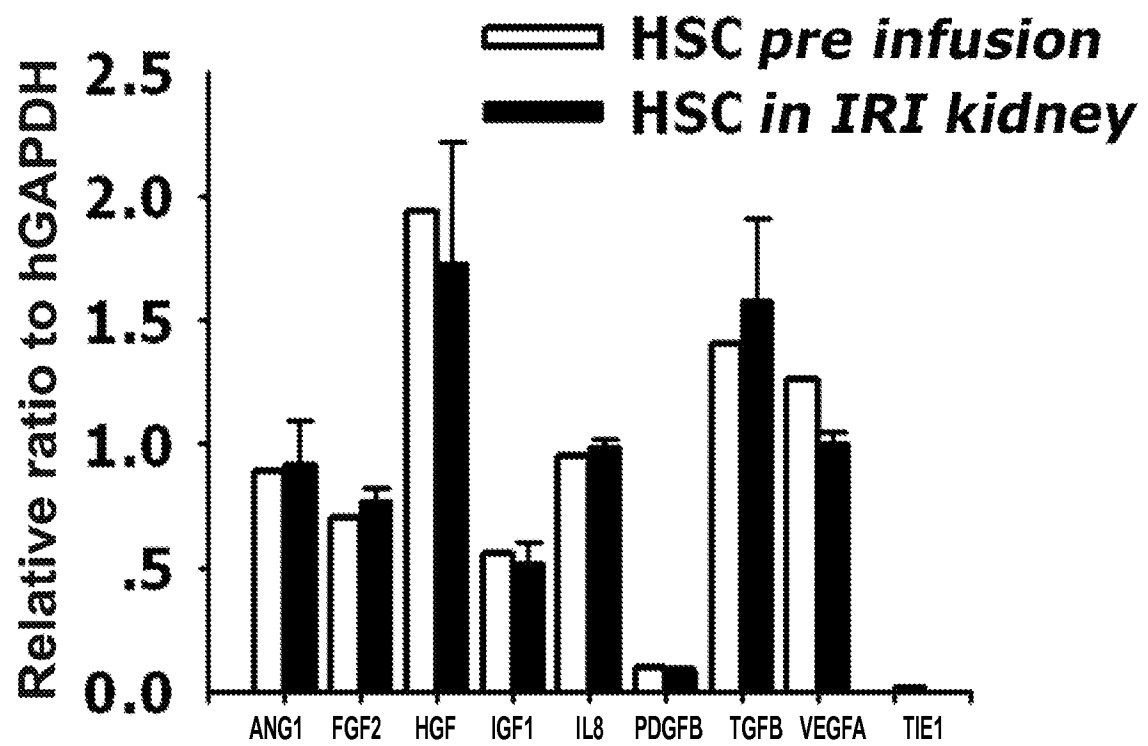


Figure 5



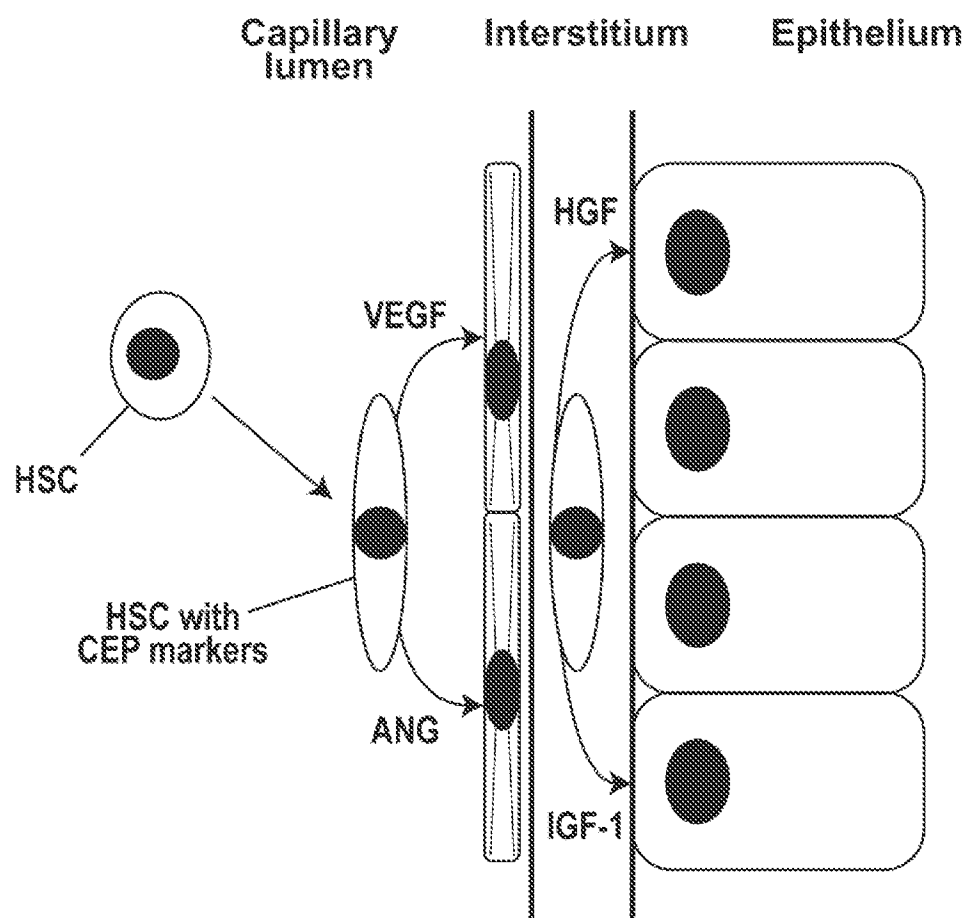
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Figure 6



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Figure 7



# INTERNATIONAL SEARCH REPORT

International application No

PCT/US2010/050812

## A. CLASSIFICATION OF SUBJECT MATTER

INV. A61K35/14 A61K35/28

ADD. A61P13/12

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

A61K A61P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, EMBASE, BIOSIS

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2004/090112 A2 (US OF AMERICA DEPT OF VETERAN [US]; UNIV UTAH RES FOUND [US]; WESTENFE) 21 October 2004 (2004-10-21)	1-11, 18-25
Y	example 1 page 27 - page 28 claims 1, 6, 11, 14, 15, 28, 29 page 6, paragraph 14 page 8, paragraphs 23, 24 page 11, paragraph 34 - page 13, paragraph 36 page 15, paragraph 47 the whole document	1-26
X	US 2007/178071 A1 (WESTENFELDER CHRISTOF [US]) 2 August 2007 (2007-08-02)	1-11, 18-25
Y	the whole document page 5, paragraph 47 page 9, paragraph 72	1-26
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☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

20 January 2011

Date of mailing of the international search report

26/01/2011

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## INTERNATIONAL SEARCH REPORT

International application No

PCT/US2010/050812

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	the whole document * abstract page 1189, left-hand column, last paragraph – right-hand column, paragraph 1 page 1196, right-hand column, last paragraph – page 1197, right-hand column, last paragraph	1-26
X	PARIKH G C ET AL: "Autologous Hematopoietic Stem Cell Transplantation May Reverse Renal Failure in Patients with Multiple Myeloma", BIOLOGY OF BLOOD AND MARROW TRANSPLANTATION, KLUGE CARDEN JENNINGS PUBLISHING, CHARLOTTESVILLE, VA, US, vol. 15, no. 7, 1 July 2009 (2009-07-01), pages 812-816, XP026192842, ISSN: 1083-8791, DOI: DOI:10.1016/J.BBMT.2009.03.021 [retrieved on 2009-06-16]	1-6,8,9, 18,19, 21-25
Y	* abstract the whole document page 813, left-hand column, last paragraph page 815, left-hand column, paragraph 1 DISCUSSION; page 815	1-26
X	MORIGI MARINA ET AL: "The regenerative potential of stem cells in acute renal failure", CELL TRANSPLANTATION, ELSEVIER SCIENCE, US, vol. 15, no. Suppl. 1, 1 January 2006 (2006-01-01), pages S111-S117, XP009143012, ISSN: 0963-6897	22-25
Y	page S113, left-hand column, last paragraph – right-hand column, paragraph 2	1-26
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International application No

PCT/US2010/050812

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Y,P	the whole document page 2212, right-hand column, paragraph 2 page 2217, right-hand column, last paragraph	1-26
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