A Potential Proposal for Renal Stem Cell Studies

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Abstract: Currently, stem cell medicine has become a practical method on many seriously diseases. The general techniques on stem cell application are to define, isolate and expand stem cells from target tissues so that they can be used to either repair or regenerate damaged organs. Normally, the research practical program on stem cell could be divided into 3 sections: (1) Isolation of stem cells from embryo and/or other resources (such as adipose and somatic tissue). (2) Embryonic stem (ES) cells differentiate into somatic stem cells and/or progenitor cells. (3) Somatic stem and/or progenitor cells differentiated from ES cells are used for body repair and/or regeneration.
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1. Introduction

Embryonic stem cells are different from adult or tissue-specific stem cells. Embryonic stem cells are the stem cell that can be grown in large numbers in the laboratory and retain the ability to grow into any type of cells including renal, nerve, heart muscle, bone and insulin-producing cells. It is difficult for the tissue-specific adult stem cells to grow in a great number, hard to isolate and are difficult to grow outside the body. Adult stem cells, such as skin and bone marrow stem cells, normally grow into a limited number of cell types (Snykers et al. 2008).

The role of embryonic or adult stem cells, in particular bone marrow-derived stem cells, in regenerating the kidney after injury has been the subject of intensive investigation. Bone marrow-derived stem cells have been shown to give rise to small numbers of most renal cell types, including tubular cells, mesangial cells, podocytes, vascular cells and interstitial cells. Injections of bone marrow-derived cells do improve renal function in many animal models of renal disease. Many stages of nephrogenesis can be studied using cultured embryonic kidneys, but there is no efficient technique available to readily knockdown or overexpress transgenes for rapid evaluation of resulting phenotypes. Embryonic stem cells have unlimited developmental potential and can be manipulated at the molecular genetic level by a variety of methods. ES cell technology may achieve the objective of obtaining a versatile cell culture system in which molecular interventions can be used in vitro and consequences of these perturbations on the normal kidney development program in vivo can be studied (Steenhard et al. 2005).

Stem cells and progenitor cells are necessary for repair and regeneration of injured renal tissue. Infiltrating or resident stem cells can contribute to the replacement of lost or damaged tissue. However, the regulation of circulating progenitor cells is not well understood. Many factors influence the stem cell growth in damaged kidney. For example, low levels of erythropoietin induce mobilization and differentiation of endothelial progenitor cells and erythropoietin ameliorates tissue injury. Full regeneration of renal tissue demands the existence of stem cells and an adequate local milieu, a so-called stem cell niche. It is reported that in the regenerating zone of the shark kidney, stem cells exist that can be induced by loss of renal tissue to form new glomeruli. Stem cell may eventually contribute to novel therapies of the kidney disease (Perin et al. 2008).

Recently researchers used a rat model of chronic renal failure in which one kidney is excised so as to increase the load of the remaining kidney, thus causing a chronic deterioration that resembles the clinical situation of renal failure (Alexandre et al. 2008). In Alexandre's project, **t**he rats are divided into 4 groups: Group 1 are sham operated and both kidneys left in place; Group 2 had a kidney removed but are not administered cells; Group 3 are administered $2x10^6$ lineage negative bone marrow cells on day 15 after one of the kidneys is removed; Group 4 are administered $2x10^6$ lineage negative bone marrow cells on days 15, 30, and 45 after one of the kidneys is removed. They found: (1) Expression of inflammatory cytokines is reduced on day 16 in the kidneys of rats receiving stem cells as compared to rats that are nephrectomized but did not receive cells. (2) On day 60 rats receiving stem cells had decreased proteinuria, glomerulosclerosis, anemia, renal infiltration of immune cells and protein expression of monocyte chemoattractant protein-1, as well as decreased interstitial area. (3) Injured rats had higher numbers of proliferating cells in the kidney, whereas

rats receiving stem cells had less. (4) Protein expression of the cyclin-dependent kinase inhibitor p21 and of vascular endothelial growth factor increased after nephrectomy and decreased after stem cell treatment. (5) On day 120, renal function (inulin clearance) is improved in the rats which are administered bone marrow cells compared to controls. This study supports the possibility of using bone marrow cells for various aspects of kidney failure. Other studies have demonstrated that administered stem cells promote kidney repair by secretion of insulin growth factor-1 (Cornelissen et al. 2008).

Bone marrow stromal cells, also known as mesenchymal stem cells or fibroblastic colony-forming units, are multipotent non-hematopoietic stem cells adhering to culture plates (Abdallah and Kassem 2009). Mesenchymal stem cells of the bone marrow have the ability to renew and differentiate themselves into multiple lineages of conjunctive tissues, including bone, cartilage, adipose tissue, tendons, muscle, and bone marrow stroma. Those cells have been first described by Friedenstein et al., who found that mesenchymal stem cells adhere to culture plates, look like in vitro fibroblasts, and build up colonies (Friedenstein et al. 1987).

Bone marrow is the site of hematopoiesis and bone marrow transplant has been successfully used for decades as a means of treating various hematological malignancies in which the recipient hematopoietic compartment is replaced by donor-derived stem cells. Progenitor cells in bone marrow are capable to differentiate into other tissues, such as cardiac tissue. Clinical trials have been conducted demonstrating beneficial effects of bone marrow infusion in cardiac patients. It is believed that injured tissue, whether neural tissue after a stroke, or injured cardiac tissue, has the ability to selectively attract bone marrow stem cells, perhaps to induce regeneration. Bone marrow has therapeutic effect in conditions ranging from liver failure, to peripheral artery disease, and the possibility of using bone marrow stem cells in kidney failure has been relatively understudied (Ma et al. 2009).

Mesenchymal stem cells have been brought to the attention of many researchers, because these cells are of great interest for treating various human diseases. Many studies have isolated mesenchymal stem cells and controlled, in vitro, its differentiation into cartilaginous tissue and bone using specific growth factors, with the objective of using this technology for repairing injured tissues of mesenchymal origin (Xian and Foster 2006; Kurdi and Booz 2007).

A lot of info and contents of this article are collected from libraries and Internet to offer to the readers as the references to design potential projects.

2. General Description of Stem Cell

Stem cells have the remarkable potential to develop into many different cell types in the body during early life and growth. In addition, in many tissues they serve as a sort of internal repair system, dividing essentially without limit to replenish other cells as long as the person or animal is still alive. When a stem cell divides, each new cell has the potential either to remain a stem cell or become another type of cell with a more specialized function, such as a muscle cell, a red blood cell, or a brain cell.

Stem cells are distinguished from other cell types by two important characteristics. First, they are unspecialized cells capable of renewing themselves through cell division, sometimes after long periods of inactivity. Second, under certain physiologic or experimental conditions, they can be induced to become tissue- or organ-specific cells with special functions. In some organs, such as the gut and bone marrow, stem cells regularly divide to repair and replace worn out or damaged tissues. In other organs, however, such as the pancreas and the heart, stem cells only divide under special conditions.

Until recently, scientists primarily worked with two kinds of stem cells from animals and humans: embryonic stem cells and non-embryonic "somatic" or "adult" stem cells. The functions and characteristics of these cells will be explained in this document. Scientists discovered ways to derive embryonic stem cells from early mouse embryos nearly 30 years ago, in 1981. The detailed study of the biology of mouse stem cells led to the discovery, in 1998, of a method to derive stem cells from human embryos and grow the cells in the laboratory. These cells are called human embryonic stem cells. The embryos used in these studies are created for reproductive purposes through in vitro fertilization procedures. When they are no longer needed for that purpose, they are donated for research with the informed consent of the donor. In 2006, researchers made another breakthrough by identifying conditions that would allow some specialized adult cells to be "reprogrammed" genetically to assume a stem cell-like state. This new type of stem cell, called induced pluripotent stem cells (iPSCs), will be discussed in a later section of this document.

Stem cells are important for living organisms for many reasons. In the 3- to 5-day-old embryo, called a blastocyst, the inner cells give rise to the entire body of the organism, including all of the many specialized cell types and organs such as the heart, lung, skin, sperm, eggs and other tissues. In some adult tissues, such as bone marrow, muscle, and brain, discrete populations of adult stem cells generate replacements for cells that are lost through normal wear and tear, injury, or disease.

Given their unique regenerative abilities, stem cells offer new potentials for treating diseases such as diabetes, and heart disease. However, much work remains to be done in the laboratory and the clinic to understand how to use these cells for cell-based therapies to treat disease, which is also referred to as regenerative or reparative medicine.

Laboratory studies of stem cells enable scientists to learn about the cells' essential properties and what makes them different from specialized cell types. Scientists are already using stem cells in the laboratory to screen new drugs and to develop model systems to study normal growth and identify the causes of birth defects.

Research on stem cells continues to advance knowledge about how an organism develops from a single cell and how healthy cells replace damaged cells in adult organisms. Stem cell research is one of the most fascinating areas of contemporary biology, but, as with many expanding fields of scientific inquiry, research on stem cells raises scientific questions as rapidly as it generates new discoveries.

2.1 Embryonic Stem Cells (ES cells)

ES cells are pluripotent cells derived from the inner cell mass of blastocysts, and are in theory able to give rise to all the cell types of the body. ES cells can be directed into forming renal progenitor cells, and eventually differentiated renal cells. Ureteric bud epithelial cells and metanephric mesenchymal cells that comprise the metanephric kidney primordium are capable of producing nephrons and collecting ducts through reciprocal inductive interaction. Once these cells are induced from pluripotent ES cells, they have the potential to become powerful tools in regeneration of kidney tissues. However, there is **a** risk to use stem cells in clinical practice. In vivo, injection of ES cells can give rise to teratomas, which are tumors containing cells of all three lineages (ectoderm, endoderm and mesoderm). ES cell-derived teratomas in vivo, renal primordial structures, can be detected histochemically. Genes involved in metanephrogenesis express the potential of ES cells to produce renal primordial duct structures and provide the insight into the regeneration of kidney tissues (Yamamoto et al. 2006). This same potential is reported when ES cells are injected into embryonic mouse kidneys in vitro, and gave rise to ES cell-derived tubules, in this case without forming teratomas (Steenhard et al. 2005). In vitro, transfection of murine ES cells with renal developmental gene Wnt4, as well as the addition of hepatocyte growth factor and activin-A, both promote the formation of renal tubule-like structures, with expression of tubular marker aquaporin-2. Cultured Wnt4-EBs have an ability to differentiate into renal tubular cells; and second, that Wnt4, HGF, and activin A may promote the differentiation of ES cells to renal tubular cells (Kobayashi et al. 2005). The Wnt4-transfected cells can be transplanted into mouse renal cortex, where they also express aquaporin-2 and formed tubular structures. According to Kim et al reported, murine ES cells primed in vitro with retinoic acid, activin-A and BMP-7 (Kim and Dressler 2005), activin-A alone (Vigneau et al. 2007), or BMP-4, differentiate into cells expressing markers of the intermediate mesoderm, early kidney development and/or renal tubule-specific markers (Bruce et al. 2007). After injection of these primed murine ES cells into embryonic kidney cultures, ES cells are incorporated into developing renal tubules (without cell fusion) or into the nephrogenic zone. The primed cells are enriched for renal progenitor cells by FACS and are injected in vivo into the kidneys of newborn mice, where they are integrated as proximal tubular cells, without teratoma formation (Vigneau et al. 2007). Human ES cells differentiate in vitro into WT1- and renin-expressing cells following treatment with a combination of specific growth factors (Schuldiner et al. 2000). However, research of the role for ES cells in renal regeneration is still in its infancy (Roufosse and Cook 2008).

2.1.1 What stages of early embryonic development are important for generating embryonic stem cells?

Embryonic stem cells, as their name suggests, are derived from embryos. Most embryonic stem cells are derived from embryos that develop from eggs that have been fertilized in vitro—in an in vitro fertilization clinic—and then donated for research purposes with informed consent of the donors. They are not derived from eggs fertilized in a woman's body. The embryos from which human embryonic stem cells are derived are typically four or five days old and are a hollow microscopic ball of cells called the blastocyst. The blastocyst includes three structures: the trophoblast, which is the layer of cells that surrounds the blastocoel, a hollow cavity inside the blastocyst; and the inner cell mass, which is a group of cells at one end of the blastocoel that develop into the embryo proper.

2.1.2 How are embryonic stem cells grown in the laboratory?

Growing cells in the laboratory is known as cell culture. Human embryonic stem cells are isolated by transferring the inner cell mass into a plastic laboratory culture dish that contains a nutrient broth known as culture medium. The cells divide and spread over the surface of the dish. The inner surface of the culture dish is typically coated with mouse embryonic skin cells that have been treated so they will not divide.

This coating layer of cells is called a feeder layer. The mouse cells in the bottom of the culture dish provide the inner cell mass cells a sticky surface to which they can attach. Also, the feeder cells release nutrients into the culture medium. Researchers have devised ways to grow embryonic stem cells without mouse feeder cells. This is a significant scientific advance because of the risk that viruses or other macromolecules in the mouse cells may be transmitted to the human cells.

The process of generating an embryonic stem cell line is somewhat inefficient, so lines are not produced each time an inner cell mass is placed into a culture dish. However, if the plated inner cell mass cells survive, divide and multiply enough to crowd the dish, they are removed gently and plated into several fresh culture dishes. The process of re-plating or subculturing the cells is repeated many times and for many months. Each cycle of subculturing the cells is referred to as a passage. Once the cell line is established, the original cells yield millions of embryonic stem cells. Embryonic stem cells that have proliferated in cell culture for six or more months without differentiating, are pluripotent, and appear genetically normal are referred to as an embryonic stem cell line. At any stage in the process, batches of cells can be frozen and shipped to other laboratories for further culture and experimentation.

2.1.3 What laboratory tests are used to identify embryonic stem cells?

At various points during the process of generating embryonic stem cell lines, scientists test the cells to see whether they exhibit the fundamental properties that make them embryonic stem cells. This process is called characterization.

Scientists who study human embryonic stem cells have not yet agreed on a standard battery of tests that measure the cells' fundamental properties. However, laboratories that grow human embryonic stem cell lines use several kinds of tests, including:

Growing and subculturing the stem cells for many months. This ensures that the cells are capable of long-term growth and self-renewal. Scientists inspect the cultures through a microscope to see that the cells look healthy and remain undifferentiated.

Using specific techniques to determine the presence of transcription factors that are typically produced by undifferentiated cells. Two of the most important transcription factors are Nanog and Oct4. Transcription factors help turn genes on and off at the right time, which is an important part of the processes of cell differentiation and embryonic development. In this case, both Oct 4 and Nanog are associated with maintaining the stem cells in an undifferentiated state, capable of self-renewal.

Using specific techniques to determine the presence of particular cell surface markers that are typically produced by undifferentiated cells.

Examining the chromosomes under a microscope. This is a method to assess whether the chromosomes are damaged or if the number of chromosomes has changed. It does not detect genetic mutations in the cells.

Determining whether the cells can be re-grown, or subcultured, after freezing, thawing, and re-plating.

Testing whether the human embryonic stem cells are pluripotent by 1) allowing the cells to differentiate spontaneously in cell culture; 2) manipulating the cells so they will differentiate to form cells characteristic of the three germ layers; or 3) injecting the cells into a mouse with a suppressed immune system to test for the formation of a benign tumor called a teratoma. Since the mouse's immune system is suppressed, the injected human stem cells are not rejected by the mouse immune system and scientists can observe growth and differentiation of the human stem cells. Teratomas typically contain a mixture of many differentiated or partly differentiated cell types—an indication that the embryonic stem cells are capable of differentiating into multiple cell types.

2.1.4 How are embryonic stem cells stimulated to differentiate?

As long as the embryonic stem cells in culture are grown under appropriate conditions, they can remain undifferentiated (unspecialized). But if cells are allowed to clump together to form embryoid bodies, they begin to differentiate spontaneously. They can form muscle cells, nerve cells, and many other cell types. Although spontaneous differentiation is a good indication that a culture of embryonic stem cells is healthy, it is not an efficient way to produce cultures of specific cell types.

So, to generate cultures of specific types of differentiated cells—heart muscle cells, blood cells, or nerve cells, for example—scientists try to control the differentiation of embryonic stem cells. They change the chemical composition of the culture medium, alter the surface of the culture dish, or modify the cells by inserting specific genes. Through years of experimentation, scientists have established some basic protocols or "recipes" for the directed differentiation of embryonic stem cells into some specific cell types.

If scientists can reliably direct the differentiation of embryonic stem cells into specific cell types, they may be able to use the resulting, differentiated cells to treat certain diseases in the future. Diseases that might be treated by transplanting cells generated from human embryonic stem cells

include Parkinson's disease, diabetes, traumatic spinal cord injury, Duchenne's muscular dystrophy, heart disease, and vision and hearing loss.

2.2 Somatic stem cell (adult stem cell)

An adult stem cell is thought to be an undifferentiated cell, found among differentiated cells in a tissue or organ that can renew itself and can differentiate to yield some or all of the major specialized cell types of the tissue or organ. The primary roles of adult stem cells in a living organism are to maintain and repair the tissue in which they are found. Scientists also use the term somatic stem cell instead of adult stem cell, where somatic refers to cells of the body (not the germ cells, sperm or eggs). Unlike embryonic stem cells, which are defined by their origin (the inner cell mass of the blastocyst), the origin of adult stem cells in some mature tissues is still under investigation.

Research on adult stem cells has generated a great deal of excitement. Scientists have found adult stem cells in many more tissues than they once thought possible. This finding has led researchers and clinicians to ask whether adult stem cells could be used for transplants. In fact, adult hematopoietic, or blood-forming, stem cells from bone marrow have been used in transplants for 40 years. Scientists now have evidence that stem cells exist in the brain and the heart. If the differentiation of adult stem cells can be controlled in the laboratory, these cells may become the basis of transplantation-based therapies.

The history of research on adult stem cells began about 50 years ago. In the 1950s, researchers discovered that the bone marrow contains at least two kinds of stem cells. One population, called hematopoietic stem cells, forms all the types of blood cells in the body. A second population, called bone marrow stromal stem cells (also called mesenchymal stem cells, or skeletal stem cells by some), are discovered a few years later. These non-hematopoietic stem cells make up a small proportion of the stromal cell population in the bone marrow, and can generate bone, cartilage, fat, cells that support the formation of blood, and fibrous connective tissue.

In the 1960s, scientists who are studying rats discovered two regions of the brain that contained dividing cells that ultimately become nerve cells. Despite these reports, most scientists believed that the adult brain could not generate new nerve cells. It is not until the 1990s that scientists agreed that the adult brain does contain stem cells that are able to generate the brain's three major cell types—astrocytes and oligodendrocytes, which are non-neuronal cells, and neurons, or nerve cells.

2.2.1 Where are adult stem cells found, and what do they normally do?

Adult stem cells have been identified in many organs and tissues, including brain, bone marrow, peripheral blood, blood vessels, skeletal muscle, skin, teeth, heart, gut, liver, ovarian epithelium, and testis. They are thought to reside in a specific area of each tissue (called a "stem cell niche"). In many tissues, current evidence suggests that some types of stem cells are pericytes, cells that compose the outermost layer of small blood vessels. Stem cells may remain quiescent (non-dividing) for long periods of time until they are activated by a normal need for more cells to maintain tissues, or by disease or tissue injury.

Typically, there is a very small number of stem cells in each tissue, and once removed from the body, their capacity to divide is limited, making generation of large quantities of stem cells difficult. Scientists in many laboratories are trying to find better ways to grow large quantities of adult stem cells in cell culture and to manipulate them to generate specific cell types so they can be used to treat injury or disease. Some examples of potential treatments include regenerating bone using cells derived from bone marrow stroma, developing insulin-producing cells for type 1 diabetes, and repairing damaged heart muscle following a heart attack with cardiac muscle cells.

2.2.2 What tests are used for identifying adult stem cells?

Scientists often use one or more of the following methods to identify adult stem cells: (1) label the cells in a living tissue with molecular markers and then determine the specialized cell types they generate; (2) remove the cells from a living animal, label them in cell culture, and transplant them back into another animal to determine whether the cells replace (or "repopulate") their tissue of origin.

Importantly, it must be demonstrated that a single adult stem cell can generate a line of genetically identical cells that then gives rise to all the appropriate differentiated cell types of the tissue. To confirm experimentally that a putative adult stem cell is indeed a stem cell, scientists tend to show either that the cell can give rise to these genetically identical cells in culture, and/or that a purified population of these candidate stem cells can repopulate or reform the tissue after transplant into an animal.

2.2.3 What is known about adult stem cell differentiation?

As indicated above, scientists have reported that adult stem cells occur in many tissues and that they enter normal differentiation pathways to form the specialized cell types of the tissue in which they reside.

Normal differentiation pathways of adult stem cells. In a living animal, adult stem cells are available to divide, when needed, and can give rise to mature cell types that have characteristic shapes and specialized structures and functions of a particular tissue. The following are examples of differentiation pathways of adult stem cells (Figure 2) that have been demonstrated in vitro or in vivo.

Hematopoietic stem cells give rise to all the types of blood cells: red blood cells, B lymphocytes, T lymphocytes, natural killer cells, neutrophils, basophils, eosinophils, monocytes, and macrophages.

Mesenchymal stem cells give rise to a variety of cell types: bone cells (osteocytes), cartilage cells (chondrocytes), fat cells (adipocytes), and other kinds of connective tissue cells such as those in tendons.

Neural stem cells in the brain give rise to its three major cell types: nerve cells (neurons) and two categories of non-neuronal cells—astrocytes and oligodendrocytes.

Epithelial stem cells in the lining of the digestive tract occur in deep crypts and give rise to several cell types: absorptive cells, goblet cells, paneth cells, and enteroendocrine cells.

Skin stem cells occur in the basal layer of the epidermis and at the base of hair follicles. The epidermal stem cells give rise to keratinocytes, which migrate to the surface of the skin and form a protective layer. The follicular stem cells can give rise to both the hair follicle and to the epidermis.

Transdifferentiation. A number of experiments have reported that certain adult stem cell types can differentiate into cell types seen in organs or tissues other than those expected from the cells' predicted lineage (i.e., brain stem cells that differentiate into blood cells or blood-forming cells that differentiate into cardiac muscle cells, and so forth). This reported phenomenon is called transdifferentiation.

Although isolated instances of transdifferentiation have been observed in some vertebrate species, whether this phenomenon actually occurs in humans is under debate by the scientific community. Instead of transdifferentiation, the observed instances may involve fusion of a donor cell with a recipient cell. Another possibility is that transplanted stem cells are secreting factors that encourage the recipient's own stem cells to begin the repair process. Even when transdifferentiation has been detected, only a very small percentage of cells undergo the process.

In a variation of transdifferentiation experiments, scientists have recently demonstrated that certain adult cell types can be "reprogrammed" into other cell types in vivo using a well-controlled process of genetic modification (see Section VI for a discussion of the principles of reprogramming). This strategy may offer a way to reprogram available cells into other cell types that have been lost or damaged due to disease. For example, one recent experiment shows how pancreatic beta cells, the insulin-producing cells that are lost or damaged in diabetes, could possibly be created by reprogramming other pancreatic cells. By "re-starting" expression of three critical beta-cell genes in differentiated adult pancreatic exocrine cells, researchers are able to create beta cell-like cells that can secrete insulin. The reprogrammed cells are similar to beta cells in appearance, size, and shape; expressed genes characteristic of beta cells; and are able to partially restore blood sugar regulation in mice whose own beta cells had been chemically destroyed. While not transdifferentiation by definition, this method for reprogramming adult cells may be used as a model for directly reprogramming other adult cell types.

In addition to reprogramming cells to become a specific cell type, it is now possible to reprogram adult somatic cells to become like embryonic stem cells (induced pluripotent stem cells, iPSCs) through the introduction of embryonic genes. Thus, a source of cells can be generated that are specific to the donor, thereby avoiding issues of histocompatibility, if such cells are to be used for tissue regeneration. However, like embryonic stem cells, determination of the methods by which iPSCs can be completely and reproducibly committed to appropriate cell lineages is still under investigation.

2.2.4 What are the key questions about adult stem cells?

Many important questions about adult stem cells remain to be answered. They include:

How many kinds of adult stem cells exist, and in which tissues do they exist?

How do adult stem cells evolve during development and how are they maintained in the adult? Are they "leftover" embryonic stem cells, or do they arise in some other way?

Why do stem cells remain in an undifferentiated state when all the cells around them have differentiated? What are the characteristics of their “niche” that controls their behavior?

Do adult stem cells have the capacity to transdifferentiate, and is it possible to control this process to improve its reliability and efficiency?

If the beneficial effect of adult stem cell transplantation is a trophic effect, what are the mechanisms? Is donor cell-recipient cell contact required, secretion of factors by the donor cell, or both?

What are the factors that control adult stem cell proliferation and differentiation?

What are the factors that stimulate stem cells to relocate to sites of injury or damage, and how can this process be enhanced for better healing?

2.2.5 What are the similarities and differences between embryonic and adult stem cells?

Human embryonic and adult stem cells each have advantages and disadvantages regarding potential use for cell-based regenerative therapies. One major difference between adult and embryonic stem cells is their different abilities in the number and type of differentiated cell types they can become. Embryonic stem cells can become all cell types of the body because they are pluripotent. Adult stem cells are thought to be limited to differentiating into different cell types of their tissue of origin.

Embryonic stem cells can be grown relatively easily in culture. Adult stem cells are rare in mature tissues, so isolating these cells from an adult tissue is challenging, and methods to expand their numbers in cell culture have not yet been worked out. This is an important distinction, as large numbers of cells are needed for stem cell replacement therapies.

Scientists believe that tissues derived from embryonic and adult stem cells may differ in the likelihood of being rejected after transplantation. We don't yet know whether tissues derived from embryonic stem cells would cause transplant rejection, since the first phase 1 clinical trial testing the safety of cells derived from hESCS has only recently been approved by the United States Food and Drug Administration (FDA).

Adult stem cells, and tissues derived from them, are currently believed less likely to initiate rejection after transplantation. This is because a patient's own cells could be expanded in culture, coaxed into assuming a specific cell type (differentiation), and then reintroduced into the patient. The use of adult stem cells and tissues derived from the patient's own adult stem cells would mean that the cells are less likely to be rejected by the immune system. This represents a significant advantage, as immune rejection can be circumvented only by continuous administration of immunosuppressive drugs, and the drugs themselves may cause deleterious side effects.

2.3 Pluripotent stem cells

Induced pluripotent stem cells (iPSCs) are adult cells that have been genetically reprogrammed to an embryonic stem cell–like state by being forced to express genes and factors important for maintaining the defining properties of embryonic stem cells. Although these cells meet the defining criteria for pluripotent stem cells, it is not known if iPSCs and embryonic stem cells differ in clinically significant ways. Mouse iPSCs are first reported in 2006, and human iPSCs are first reported in late 2007. Mouse iPSCs demonstrate important characteristics of pluripotent stem cells, including expressing stem cell markers, forming tumors containing cells from all three germ layers, and being able to contribute to many different tissues when injected into mouse embryos at a very early stage in development. Human iPSCs also express stem cell markers and are capable of generating cells characteristic of all three germ layers.

Although additional research is needed, iPSCs are already useful tools for drug development and modeling of diseases, and scientists hope to use them in transplantation medicine. Viruses are currently used to introduce the reprogramming factors into adult cells, and this process must be carefully controlled and tested before the technique can lead to useful treatments for humans. In animal studies, the virus used to introduce the stem cell factors sometimes causes cancers. Researchers are currently investigating non-viral delivery strategies. In any case, this breakthrough discovery has created a powerful new way to "de-differentiate" cells whose developmental fates had been previously assumed to be determined. In addition, tissues derived from iPSCs will be a nearly identical match to the cell donor and thus probably avoid rejection by the immune system. The iPSC strategy creates pluripotent stem cells that, together with studies of other types of pluripotent stem cells, will help researchers learn how to reprogram cells to repair damaged tissues in the human body.

2.4 Native Renal Stem Cells and Renal Regeneration

In the embryo, most types of renal parenchymal cells are derived from metanephric mesenchymal cells, which are multipotent and are in addition self-renewing, making them attractive candidates as the stem cells of the embryonic kidney.

In animal models, embryonic metanephroi transplanted into the abdominal cavity of adult animals are colonized by host vasculature, undergo nephrogenesis and produce urine, even if the operation is carried out across species barriers, and with a surprising lack of rejection (Little 2006). Human and porcine embryonic kidney progenitor cells have been isolated and, when injected into mice, can lead to the formation of miniature kidneys producing urine (Dekel et al. 2003), or protect against acute renal failure (Lazzeri et al. 2007). However, there are ethical issues to deal with human ES cells.

In adult mammals, a range of methods have been used to identify potential multipotent precursor cells, including label retention in slow cycling cells, identification of a side population, and expression of

stem cell markers such as CD133. This has led to the identification of several candidate renal stem cells, which, depending on the study, are located amongst the tubular cell population (Dekel et al. 2006; Gupta et al. 2006), in the Bowman's capsule, papillary region or cortical interstitium (Bussolati et al. 2005; Sagrinati et al. 2006; Rad et al. 2008). Of note, other studies have not confirmed the presence of a large pool of precursor cells amongst the tubular population and, instead, argue that regeneration occurs through proliferation of differentiated tubular cells (Vogetseder et al. 2008; Witzgall 2008). Some of the candidate renal stem cells have been shown to enhance recovery after tubular injury, possibly by integration in the tubular epithelium (Rad et al. 2008).

2.5 Bone Marrow-Derived Stem Cells and Renal Regeneration

Bone marrow stem cells would be an ideal source of multipotent cells: they are easy to harvest and are in theory an unlimited source of expandable autologous cells. They display an unexpected plasticity which has been the subject of extensive research over the last few years. The plasticity has been observed both for the hematopoietic stem cell, which gives rise to all differentiated blood cell types, as well as for the bone marrow mesenchymal stem cells, which provide stromal support for haematopoietic stem cell in the bone marrow, and also give rise to various mesenchymal tissues, such as bone, cartilage and fat.

There are important discrepancies in the literature addressing the role of bone marrow cells in renal regeneration. These are partly explained by the methods involved in this research.

The technique most commonly used to study bone marrow cell plasticity is bone marrow transplantation. The host bone marrow is replaced by donor bone marrow, and after bone marrow chimerism is established, donor cells are tracked down in the kidney. The donor bone marrow cells are distinguished from host cells by virtue of their chromosome content (male Y chromosome-positive cells in a female host), the expression of a reporter molecule (β-galactosidase, luciferase, enhanced green fluorescent protein), or the performance of a function (re-establishment of a function in a knockout mouse model). The type of host cell that the bone marrow-derived cell has given rise to (tubular, mesangial, etc.) is ascertained most often using immunohistochemistry.

Discrepancies between studies are attributable to several factors: (1) observations in different species (mouse, rat, human); (2) use of different models of renal damage (ischaemia/reperfusion, toxic, immunological); (3) different protocols for bone marrow transplantation (irradiation doses, quantity of cells injected); (4) injection of different subgroups of bone marrow cells (whole bone marrow, haematopoietic stem cell, mesenchymal stem cell); (5) sensitivity and specificity of the detection method for bone marrow cell origin (in situ hybridization for the Y chromosome, detection of reporter molecules, functional assays), and (6) sensitivity and specificity of the detection method of the renal cell type (immunohistochemistry for specific cell types such as tubular cell, mesangial cells, etc.).

Renal failure can be the result of an initial insult directed against the tubular epithelium, the glomerular cells or the vascular compartment. In the search for remedies for these varied renal diseases, studies have therefore addressed potential bone marrow origin for various renal cell types. It is useful to bear in mind these technical variations when analyzing results reported in the literature (Roufosse and Cook 2008).

2.6 Tubular Epithelium

Although initial studies suggested a high contribution of bone marrow to tubular regeneration, the current view is that only a small proportion of tubular cells are bone marrow-derived, and there is disagreement over whether mesenchymal stem cells, haematopoietic stem cells or both are contributing (Humphreys and Bonventre 2008). The current consensus view is that the predominant source of tubular regeneration is through the proliferation of differentiated tubular cells (Lin et al. 2005). A few authors have not found any bone marrow cells engrafted in tubules, and propose that positive observations of bone marrow-derived tubular cells are the result of artifact (Bussolati et al. 2009). There may also be a progenitor slow-cycling cell population contributing to tubular repair. Does this abolish the hope of harnessing the regenerative power of bone marrow-derived cells? The answer is not necessarily.

Firstly, under certain circumstances, bone marrow engraftment in tubules can be dramatically increased. Held et al. made use of a transgenic fumarylacetoacetate (FAH)-/- mouse, in which discontinuation of the rescue drug NTBC leads to acute tubular necrosis (Held et al. 2006). After transplanting bone marrow from wild-type mice into FAH-/- mice, a few bone marrow-derived tubular cells are noted. In a subset of the FAH-/- mice, there is, in addition, loss of heterozygosity (LOH) in the liver for homogentistic acid hydrogenase, which induces a more severe, ongoing form of acute tubular necrosis. In FAH-/- animals with additional hepatic LOH, up to 50% of tubular cells are bone marrow-derived cells. Engraftment of these wild-type bone marrow-derived cells leads to morphological resolution of ATN and to disappearance of the aminoaciduria present in control

mice. In this model, the bone marrow cells have a strong survival advantage over native tubular cells, due to their ability to metabolise toxic products. It is possible that this strong positive selective pressure is necessary for regeneration to occur through wild-type bone marrow cells. Interestingly, most of the bone marrow-derived tubular cells are derived from cell fusion between bone marrow cells and tubular cells. This is supported by a study by Li et al. in which fusion of bone marrow cells to tubular cells account for part of bone marrow-derived tubular cells after ischaemia/reperfusion (I/R) injury, but not all. In this model without selective pressure, the percentage of bone marrow-derived tubular cells is low (1.8%) (Li et al. 2007b).

Secondly, although there is disagreement concerning the underlying mechanism, injection of bone marrow cells, particularly mesenchymal stem cells, has repeatedly been shown to improve renal function in ATN, whether induced by toxins (cisplatin and glycerol) or I/R (Imai and Iwatani 2007). With the role of actual engraftment of bone marrow cells as tubular cells thought to be minimal or absent, mesenchymal stem cells may exert their beneficial effects through their antiapoptotic, mitogenic, immunomodulatory and angiogenic properties, or through the contribution of the bone marrow cells to endothelial cell replacement in the peritubular capillaries. It is important to know the nature of the mediators involved in these properties, and the mechanisms governing the homing of mesenchymal stem cells to the kidney (Imai and Iwatani 2007). Imberti et al. confirmed the importance of paracrine mechanisms using co-culture of mesenchymal stem cells with tubular cells in a Transwell® culture excluding contact between the two cell types, which led to less cisplatin-induced tubular cell death. mesenchymal stem cells have been shown to produce vascular endothelial growth factor, basic fibroblast growth factor, monocyte chemoattractant protein-1, hepatocyte growth factor, and insulin-like growth factor, as well as immunomodulators TGF-β and PGE_2 (Imai and Iwatani 2007; Imberti et al. 2007). In a recent study, administration of conditioned medium from cultured stromal cells provided the same renoprotective effects as injection of mesenchymal stem cells, suggesting that systemic administration of the beneficial mediators may be just as good as mesenchymal stem cell injection, and safer (Imberti et al. 2007). It is a concern that there have been a few observations of adipogenesis associated with fibrosis and osteogenesis after injection of mesenchymal stem cells (Imai and Iwatani 2007).

Mesenchymal stem cell homing to the kidney has been linked to interactions between molecules upregulated in the injured kidney (SDF-1, hyaluronic acid and PDGF) and ligands expressed on mesenchymal stem cells (respectively, CXCR4, CD44 and PDGF-R) (Imai and Iwatani 2007). Similar beneficial effects on renal function may be induced by mobilizing bone marrow cells from the patient's own bone marrow by administration of growth factors (GF) such as granulocyte colony-forming factor, granulocyte/monocyte colony-forming factor, monocyte colony-forming factor, and stem cell factor. Possible explanations for improved renal function include increased numbers of bone marrow-derived tubular cells, a decrease in neutrophilic infiltrate, or increased cell proliferation and decreased apoptosis in kidneys of GF-treated mice (Roufosse and Cook 2008).

In summary, most but not all authors agree that a small proportion of tubular cells (at most a few percent) are bone marrow-derived after renal injury. The role these bone marrow-derived tubular cells play in improved renal function is probably insignificant, with intrinsic renal cells, either stem cells or differentiated, more likely to play the predominant role in regeneration. However, administration of bone marrow cells or mobilization of bone marrow cells using GF may be used to protect against renal injury. This may be due to paracrine/immunomodulatory effects or endothelial regeneration. In addition, there may be a therapeutic role for bone marrow-derived cells engineered to replace a defective gene, due to a local strong positive selective pressure. mesenchymal stem cells have emerged as the most promising candidate for stem cell therapy, and appear safe, such that phase I clinical trials of mesenchymal stem cell injection for the treatment of acute kidney injury are scheduled to begin shortly (Imai and Iwatani 2007).

2.7 Mesangial Cells

Mesangial cells are modified smooth muscle cells in the glomerular tuft, and provide structural support for the complex of glomerular capillaries. They may be injured by immune complex deposition, toxins and in diabetes. Although mesangial cells have regenerative potential, persistent mesangial damage can lead to glomerulosclerosis. In cell culture, bone marrow cells treated with PDGF-BB in the presence of collagen IV convert to cells with many mesangial characteristics (Suzuki et al. 2004). In rodent models of bone marrow transplantation, there is also support for partial bone marrow derivation of mesangial cells, whether glomeruli are injured or not. In models where mesangial damage has been induced, infusion of bone marrow cells may be associated with improved function, which has been attributed to mesangial and endothelial regeneration or, in the case of mesenchymal stem cells, paracrine mechanisms. Conversely, a deleterious mesangial phenotype

responsible for mesangial sclerosis, such as in Os/- or db/db mice, can be induced by transplanting wild-type mice with transgenic mouse bone marrow. Some studies have further illustrated functionality of the bone marrow-derived mesangial cells by harvesting the bone marrow-derived mesangial cells, growing them in culture, and showing angiotensin-II induced contraction in vitro, a typical mesangial function (Kunter et al. 2006).

2.8 Podocytes

Podocytes are epithelial cells with complex interdigitating foot processes which create the slit diaphragm, and contribute to the synthesis of the glomerular basement membrane. Both the slit diaphragm and the glomerular basement membrane are implicated in creating a filtration barrier between blood and urine. Initial studies identified rare bone marrow-derived cells at the periphery of the glomerular tuft, in the location of podocytes. Two recent studies have suggested integration of bone marrow-derived cells as functional podocytes, with production of matrix protein. These studies involved the use of a mouse model of Alport's disease, in which the animals suffer from defective synthesis of the alpha-3 chain of collagen type IV, with glomerular basement membrane abnormalities and progression to glomerulosclerosis and renal failure. Using whole bone marrow transplantation from wild-type animals, both Prodromidi et al. and Sugimoto et al. showed the presence of bone marrow-derived podocytes and mesangial cells, accompanied by re-expression of the defective collagen chains, and improved renal histology and function. Although the bone marrow-derived cells are not numerous, their presence is sufficient to re-establish synthesis of the defective collagen chain. However, the improvement in renal function is substantial raising the possibility that there may be mechanisms involved other than replacement of podocytes. A similar experiment using mesenchymal stem cells only rather than whole bone marrow also led to a reduction in interstitial fibrosis, but without engraftment of bone marrow cells in the kidney, and with no beneficial effect on survival or renal function (Sugimoto et al. 2006).

2.9 Vascular Cells

Endothelial cells are present in the glomerular capillaries, in large vessels and in the abundant network of peritubular capillaries. Endothelial cells are attractive candidates for progeny of bone marrow-derived cells in view of their immediate contact with circulating cells, the existence of known circulating endothelial precursors, and the existence of a known endothelial precursor in the bone marrow: the haemangioblast.

In a rat model of glomerulonephritis, where glomerular endothelial cells are injured, culture-modified bone marrow mononuclear cells injected into the renal artery boosted renal regeneration. This is attributed both to incorporation of bone marrow-derived cells into the endothelial lining and to production of angiogenic factors by the injected cells. Similarly, following acute tubular necrosis, the peritubular capillaries are damaged. The return of blood flow, which depends on endothelial cell integrity, is essential for renal recovery. Duffield et al. contend that bone marrow cells boost renal function after I/R by participating in endothelial cell regeneration. Li et al. observed bone marrow-derived vWF+ and CD31+ endothelial cells in a mouse model of adriamycin-induced nephrosis with subsequent renal fibrosis (Li et al. 2007a).

2.10 Interstitial Cells

The kidney contains a complex population of interstitial cells serving several functions, such as providing a scaffold for renal structure and producing several hormonal substances such as erythropoietin. It may even contain a population of adult native renal stem cells which play a role in renal regeneration. There is also evidence that bone marrow-derived cells could be a source for up to 30% of α-SMA-positive interstitial myofibroblasts, which have been incriminated in the production of extracellular matrix in renal fibrosis. If the bone marrow is indeed a source for such cells, the use of bone marrow cell injections for the treatment of renal failure would run the risk of enhancing fibrosis (Broekema et al. 2007).

2.11 Adipose Stem Cells

Adipose, also known as fat tissue, is the richest and most accessible known source of stem cells. It contains a specialized class of stem cells comprised of multiple cell types that promote healing and repair. Adipose stem cells have been shown to differentiate into multiple cell types including muscle, bone, fat, cartilage and nerve, etc. Beyond differentiation, regenerative cells may provide therapeutic benefit through the release of growth factors and other therapeutic healing mechanisms. The major advantages of adipose tissue as a source of regenerative cells, which distinguish it from alternative cell sources, include: **(1) Yield:** A therapeutic dose of regenerative cells can be isolated in approximately one hour without cell culture. **(2) Safety:** Patients receive their own cells (autologous-use) so there is no risk of immune rejection or transmission. **(3) Versatility:** Stem cells from adipose tissue benefit from multiple mechanisms-of-action.

3. Techniques Used in Stem Cell Research

3.1 Stem cell isolation and cell culture

The technique of magnetic selection using antibody binding will be used for the stem cell separation (e.g., labeled anti-CD34 antibody with magnetic nanoparticles binding to CD34+ cells).

3.1.1 Isolation of multipotent renal progenitor cells (MRPC)

Multipotent renal progenitor cells (MRPC) are isolated from adult mouse kidneys using culture conditions (Jiang et al. 2002).

Mouse kidneys are perfused *in vivo* through aorta with cold saline to flush the blood from the kidney, harvested, minced, and partially digested using collagenase in the presence of soybean trypsin inhibitor. The cell suspension is washed and plated in a medium that consisted of 60% DMEM-LG (Life Technologies-BRL, Grand Island, NY, USA), 40% MCDB-201 (Sigma Chemical Co., St. Louis, MO, USA), 1x insulin-transferrin-selenium (Invitrogen, USA), LA-BSA 1 mg/ml (Sigma, USA), 0.05 uM dexamethasone (Sigma) and 0.1 mM ascorbic acid 2-phosphate (Sigma), 100 U penicillin and 1000 U streptomycin (Life Technologies-BRL, USA) with 2% FCS (Hyclone Laboratories, Logan, UT, USA), 10 ng/ml EGF, 10 ng/ml PDGF-BB, and 10 ng/ml leukemia inhibitory factor (R&D Systems, Minneapolis, MN, USA). The cells are plated on fibronectin coated culture flasks at low density (300 cells/cm^2), to avoid cell–cell contact, and cultured at 37°C in the presence of 5% CO_2. Suppose that the cells could live up to 6 weeks. Single clones of cells are obtained by plating the cells at nontouching density and then using cloning rings to pick individual colonies of cells at the 5- to 10-cell stage.

3.1.2 Embryos treatment

C57BL/6 female mice are injected with pregnant mare serum gonadotropin and human chorionic gonadotropin to collect oocytes. Spermatozoa are collected from the cauda epididymis of mice. In vitro fertilization is performed as described previously (Sugiyama et al., 1992). The fertilized embryos are frozen at the two-cell stage. The embryos developed to blastocyst stage in KSOM medium after thawing. Cell Culture and Chimera Production Brief exposure to acidic Tyrode's solution is performed to remove the zonae pellucidae from the cultured blastocysts. The denuded embryos are placed on a feeder layer of mitomycin C-inactivated confluent embryonic fibroblasts in four-well plates. The embryonic fibroblasts and blastocysts are cultured in Dulbecco's modified Eagle's medium supplemented with 15% KSR (Invitrogen, San Diego, CA), 0.1 mM 2-mercaptoethanol, 103 units/ml leukemia inhibitor factor, LIF (ESGRO), nonessential amino acids, and sodium pyruvate. The growing blastocysts attached to the feeder layer within 48 h. The inner cell mass (ICM) is apparent inside and extended above the flat trophoblast cells spreading from the attached blastocysts. The expanded colonies are dissociated, trypsinized, and seeded onto a new feeder layer 4 days after attachment. This process is repeated several times at intervals of 2 to 4 days; colonies are never allowed to become larger than 400 mm in diameter. The putative ES cells are stocked at passage 7 and 8. We used B6G-2 cells after passage 10 to examine a potential for pluripotency in vitro and in vivo. Host embryos are cultured from the two-cell stage to the morula and blastocyst stages after superovulation and natural mating. The ES-like cells are injected into the cavity of the host blastocyst and the subzonal cavity of the host morula. After injection, the chimeric blastocysts are transferred to the uteri of pseudopregnant recipient mice at 2.5 days postcoitus.

3.1.3 Embryo stem cells isolation and cell line establishment

Renal stem cells are isolated from the blastocysts of mouse embryos using the culture conditions. Natural mating between 20 female superovulated and male mice are done to provide blastocysts. The blastocysts are flushed to form uterus by M2 media 5 days after mating. Mouse embryonic fibroblast in a natural cycle or in a superovulated cycle are prepared to form embryos in a midgestation age according to protocols discribed by Shimizukawa (Shimizukawa et al. 2005).

The blastocysts are transfered to 35 mm dishes on the mouse embryonic fibroblast feeder group or mouse embryonic fibroblast feeder layer group which previously inactivated with mitomycin C (Kyowa, Japan) 10μg/ml for 2 h in CO_2 incubator. The ES media containing DMEM high glucose (Sigma) + 20% FBS (Gibco) + LIF 1000 IU/ml (Sigma) + 2-mercaptoethanol 0.1 mMol (Sigma) + L–Glutamin 2 mMol (Sigma) and Penicillin/Streptomycin 100 mg/100 IU/ml (Sigma) for 3 days. Disaggregation is carried out according to method discribed by Bongso et al. (1994) with some modification. Briefly, the outgrowth ICM are disaggregated mechanically by hand pulled Pasteur pipette in different size in 50 μl DMEM media under mineral oil (Sigma). Then, the disaggregated ICM is transfered to one well of 96-well dish (NUNC) and cultured for 3 days. An alternative procedure for disaggregation of ICM is culturing of blastocysts on 96-well dish and trypsonizing the outgrowth ICM in situ with trypsin/EDTA 0.1% /1 mM (Sigma) in PBS. It is possible to trypsonize the cells in 96-well dishes up to 3 more passages every 3 days until the ES colony morphology appear in the expansion stage. It is essential to monitor

microscopically the formation of ES colonies in this stage daily. The colony positive dishes have to subculture 2 times more in the colony formation stage until the cells became confluent enough for passage in 4-well dish (NUNC). Depending to doubling time the cells must be trypsonized up to 4 further passages every 3 days. Then the confluent cells are passaged into 35 mm dish (NUNC) as the passage number one. The first frozen cells are carried out in passage number two (60 mm dish) using DMSO 10%, FBS 20% and DMEM media. Alkalin phosphatase assessment The ES cells are cultured in 35 mm dish for growing, then the ES colonies are fixed by 4% formalin in PBS buffer and naphtol AS-MX (Sigma) is used according to manufactures instruction for alkalin phosphatase staining.

3.1.4 Cell culture medium

1. **Media for mouse embryonic feeder layer cells:** High-glucose Dulbecco's Modified Eagle Medium (DMEM), 10% FBS, 100 unit/l penicillin, 100 unit/l streptomycin, 1% nonessential amino acids. For 1 liter, mix 890 ml DMEM with 90 ml FBS, 10 ml penicillin and streptomycin solution, 10 ml nonessential amino acids.
2. **Medium for mouse stem cell:** High-glucose DMEM, 10% FBS, 100 unit/l penicillin, 100 unit/l streptomycin, 1% nonessential amino acids, 5 ml nucleoside solution, 0.09 mg/l insulin, 1000 unit/ml LIF. For 1 liter, mix 890 ml DMEM with 90 ml FBS, 10 ml penicillin and streptomycin solution, 10 ml nonessential amino acids, 10 ul insulin solution and 1 ml LIF.
3. **Differentiation medium:** RPMI 1640 supplemented with 10% FBS (heat inactivated), 1 mM L-glutamine, 100 unit/l penicillin, 100 unit/l streptomycin. For 1 liter, mix 890 ml RPMI with 90 ml FBS, 10 ml penicillin and streptomycin solution, 10 ml L-glutomine.
4. **Freezing medium**: 9 ml DMEM and 1 ml DMSO.

3.1.5 Mouse embryo stem cells in culture

Isolated ES cells are added to 5 ml DMEM supplemented by 10% FBS (Fetal Bovine Serum, Gibco, UK), 100 U/ml penicillin (Sigma, USA) and 100 U/ml streptomycin (Sigma, USA) and washed by centrifugation at 1200 rpm for 5 min. The cell pellet is collected and cultured in a 75-cm^2 flask in a DMEM medium supplemented by 10% FBS and antibiotics. The cultures are incubated at 37°C in a 5% CO_2 environment. Four days after primary culture initiation, the culture medium are collected, centrifuged and the resultant cell pellet are replated in a fresh 75-cm^2 flask. These cultures (established from removed medium) are fed twice weekly and upon confluency, the cells are lifted by Tripsin/EDTA (Gibco, UK), counted and passaged at 1:3 ratios (about 1.5×10^6 cell/75-cm^2 flask). Cell passage is performed up to subculture 3 (it should be mentioned that the medium of each passaged culture are contained a few floating cells not attached on culture surface with replating due probably to their non mesenchymal nature). In parallel to the culture established from removed medium, the cultures of marrow, primarily adherent cells, are expanded by three successive passages at 1:3 split ratios. During the cultivation period, time needed by the culture (established either by primarily adherent cells or the cells floating in removed medium) to approach confluence, as an index of cell growth rate, are recorded. At the end, the passaged-3 cells from either group are evaluated in terms of their differentiation potential towards skeletal lineages as bone, cartilage and adipose cells (Saito et al. 2002; Winkler et al. 2008).

1. Mytomycin C treatment of feeder layer cells: When the feeder layer cells reach confluency they are treated with mitomycin C to induce mitotic arrest. The cells are still capable of conditioning the media.
2. Add 5 ml mitomycin C (10 ug/ml) to a 10 ml dish.
3. Incubate the cells for 3 hours.
4. Remove the mitomycin C solution, rinse the dish 5 times with PBS and add fresh medium.
5. Gelatin coating of tissue culture plastic: Coat tissue culture dishes with 1% gelatin solution; Incubate for 4 hours; Wash 3 times with PBS.

3.1.6 Mouse renal stem cells isolation protocol detail

Kidneys of adult C57BL/6 mice (10 to 12 weeks old) are washed extensively with sterile PBS to remove contaminating debris and red blood cells (RBC). Kidneys then are diced and treated with 0.075% collagenase (type D; Sigma-Aldrich, St. Louis, MO, USA) diluted in PBS for 10 min at 37°C with gentle agitation. The collagenase is inactivated with an equal volume of culture medium (DMEM/10% FCS/1% penicillin streptomycin), and the dissolved tissue is minced further and centrifuged for 10 min at low speed. The cellular pellet is resuspended in culture medium and sequentially filtered through 70 and 40 m mesh filters to remove debris and cell segments. Cell suspensions are treated with cold ACK buffer (0.15 M potassium-ammonium chloride buffer) to remove remaining RBC. A comparison of kidney cells, obtained through mincing and filtration, with or without collagenase, yielded similar results.

Enrichment of Sca-1^+ cells is achieved by incubating cells with anti–Sca-1 microbeads (Miltenyi Biotec, Auburn, CA, USA) and purification by at least two cycles of magnetic selection. Sorted populations are reanalyzed by flow cytometry, and the purity of Sca-1^+ cells is confirmed before use. FACS analysis is performed using a modified FACS technique (BD Biosciences, Mountain View, CA, USA). Fluorescence data are collected using three-decade logarithmic amplification, as determined by forward light scatter intensity.

Cells are labeled with Sca-1-PE, Sca-1-APC, Sca-1-Biotin; CD45, B220, Mac-1 (CD11b), NK, TER119, CD11c, CD29, I-AD, Fas (CD95), and H-2b-FITC (BD Pharmingen, San Diego, CA, USA); CD34, CD31, CD25, Gr-1, CXCR4, CD62L, CD49e, CD44, CD90, Flk-1, EpCAM (Pharmingen, USA), and c-Kit-PE (SBA, Birmingham, AL); CD4 and CD8-PerCp (Pharmingen, USA). Biotinylated B7.1 (CD80), B7.2 (CD86; SBA), and 1B2 antibodies are detected with streptavidin-PerCp or streptavidin-APC (Jackson ImmunoResearch Laboratories, West Grove, PA, USA), and nonviable cells are detected with propidium iodide (PI). PE-rat IgG2a, FITC-hamster IgG (Serotec, Oxford, UK), and PerCp- and APC-streptavidin are used as controls. FACS sorting is performed using BD FACSAria, a high-speed sorter (acquisition rates of up to 70,000 events/s) with fixed-alignment cuvette flow cell and up to three aircooled lasers at 488, 633, and 407 nm wavelengths. Cells are sorted in a cold and sterile environment for high and low PE staining (Sca-1). Sca-1^{bright} and Sca-1^{dim} cells are collected into different cold glass FACS tubes, and after cells are centrifuged, they are transferred to culture medium and incubated at 37°C, 7% CO_2 on plastic plates (Dekel et al. 2006).

3.1.7 Maintenance of mouse embryo stem cells (Nichols and Ying 2006)

Mouse embryo stem cells are isolated from the inner cell mass of 5-day old blastocysts, derived from pregnant rats, and isolated mouse ES cells are grown on mitomycin C-treated feeder layer or on gelatin-coated dishes:

1. Culture mouse embryo stem cells at a moderate density and subculture by splitting no more than 1/10.
2. Routinely, subculture mouse embryo stem cells every 3 days. To prevent differentiation, the rat embryo stem cells should be dissociated into single cells after subculturing.
3. Change the media every day.

3.1.8 Tetraploid embryo stem cell aggregates

Two-cell embryos are prepared from C57BL/6 females that are superovulated and mated naturally. The fusion of blastomeres of the two-cell stage is performed using an ET-3 Embryonic Cell Fusion System (Fujihira, Tokyo) in accordance with the manufacturer's instructions to produce tetraploid embryos. The tetraploid embryos are then cultured in KSOM medium until aggregation. The zonae pellucidae from tetraploid embryos are removed with acidic Tyrode's solution. Two tetraploid embryos are aggregated with ES cells at the eight-cell stage (Nagy et al., 1990, 1993) and transferred to the uteri of pseudopregnant recipient mice at 2.5 days postcoitus.

3.1.9 Characterization of stem cells and multipotent renal progenitor cells (Gupta et al. 2006; Lazzeri et al. 2007)

1. **Cell surface marker analysis:** All staining reactions are performed using 10^5 cells in 100 ul of staining buffer. Rat ES cells for stage-specific embryonic antigen-1 (SSEA-1) or freshly isolated rat bone marrow cells are used as positive control. Unstained cells and corresponding isotype antibodies are used as negative control. Primary antibodies are used. Dead cells are excluded and doublets are excluded on the basis of three hierarchical gates (forward/side scatter area, forward scatter height/width, and side scatter height/width). Antibodies of mouse anti-rat CD90-PerCP, CD11b-FITC, CD45-PE, CD106-PE, CD44H-FITC, RT1B-biotin, RT1A-biotin, CD31-biotin (Becton Dickinson, San Diego, CA, USA) and purified anti-mouse SSEA-1 (MAB4301; Chemicon, Temecula, CA, USA) are used.
2. **Telomere length and telomerase enzyme assay:** For measurement of telomere length, DNA is prepared from cells by standard methods of proteinase K digestion followed by salt precipitation and digested overnight with Hinf III and RsaI. Fragments are run on a 0.6% agarose gel and vacuum blotted to positively charged nylon. The blot is probed overnight with a digoxigenin-labeled hexamer (TTAGGG) and then incubated with anti–digoxigenin-alkaline phosphatase-labeled antibody for 30 min. Telomere fragments are detected by chemiluminescence. The TRAP protocol adapted by Roche Applied Science (Indianapolis, IN, USA) is used to assay for telomerase activity.
3. **DNA analysis by FACS:** MRPC are fixed in ice-cold 70% ethanol for 10 min and treated with 1 mg/ml ribonuclease for 5 min at room temperature. Propidium iodide (50 ug/ml) is added to the cell suspension and analyzed

using 488 nm excitation, gating out doublets and clumps, using pulse processing and collecting fluorescence above 620 nm on a FACS Calibur (BD Bioscience, San Jose, CA, USA). Data are analyzed using Modfit LT software (Verity Software House, Topsham, ME, USA).

3.1.10 In vitro differentiation

Differentiation into cells of the neuronal lineage in vitro is performed according to Strubring et al.'s (1995) protocol. The putative ES cells are prepared at 400 cells / 20 ml in DMEM medium containing 20% FCS (Hyclone, Logan, UT), 10-7 all-trans retinoic acid (Sigma), 2 mM glutamine (Invitrogen), nonessential amino acids, and 50 mM 2-mercaptoethanol. The cells are cultured by the hanging drop method for 2 days to form embryo-like aggregates. The embryoid bodies are then collected, washed carefully, and plated into dishes coated with gelatin in the above medium without RA to allow them to attach and differentiate.

For differentiation of MRPC toward a renal cell lineage, cells are grown to confluence on fibronectin-coated four-well chamber slides and incubated with a "nephrogenic cocktail" that contained fibroblast growth factor 2 (FGF2; 50 ng/ml), TGF-beta (4 ng/ml), and leukemia inhibitory factor (20 ng/ml). All differentiation cultures are maintained for 2 weeks except where stated, and medium is renewed every 48 hours. For determination of whether MRPC could differentiate into cells of other germ cell layers, cells are incubated under conditions that promoted differentiation into endothelium (mesoderm), neurons (ectoderm), and hepatocytes (endoderm). Endothelial differentiation is induced by growing MRPC on fibronectin-coated wells (15,000 cells/cm^2) in the presence of 10 ng/ml vascular endothelial growth factor (VEGF). Neuronal differentiation is induced by growing MRPC on fibronectin-coated wells (5000 cells/cm^2) in the presence of 100 ng/ml basic FGF. Hepatocyte differentiation is induced by growing MRPC on Matrigel (20,000 cells/cm^2) in the presence of 10 ng/ml FGF-4 and 20 ng/ml hepatocyte growth factor. Cells are characterized by reverse transcriptase–PCR (RT-PCR) and immunofluorescence as described in the RT-PCR section. For the MRPC that are differentiated into endothelial cells, LDL uptake is examined by incubating the cells with Dil-Ac-LDL (10 ug/ml) at 37°C for 60 min. Undifferentiated MRPC are used as a control (Chen et al. 2008; Wong et al. 2008).

3.1.11 In vivo differentiation

1. **Ischemia reperfusion experiment:** For these experiments, MRPC are transduced using a mouse stem cell virus–enhanced green fluorescence protein (eGFP) retrovirus. These cells expressed eGFP and are referred to as eMRPC. Mice are anesthetized with pentobarbital (50 mg/kg intraperitoneally) and prepared, and using a midline incision, nontraumatic vascular clamps are applied across both renal pedicles for 35 min. Immediately after ischemia, 100 ul (10^6 cells) of an eMRPC cell suspension in PBS is injected directly into the abdominal aorta, above the renal arteries, after application of a vascular clamp to the abdominal aorta below the renal arteries to direct the flow of the injected cells. The kidneys are harvested 10 days later to examine *in vivo* differentiation of the injected cells.
2. **Subcapsular injection experiment:** Mice are anesthetized, the kidneys exposed, and eMRPC (10^6 cells) are injected under the renal capsule. Mice are killed 3 weeks later, and kidneys are harvested for tissue analysis.
3. **Effect of MRPC on renal function after ischemia-reperfusion:** For determination of whether MRPC injection facilitates renal functional recovery, mice undergo 30 min of ischemia induced by bilateral renal artery clamps followed immediately by injection of MRPC. As controls, mice are treated identically except that they receive either the saline vehicle or an MRPC cell suspension (10^6 cells) that have been preincubated for 12 hours with actinomycin D (1 ug/ml) to block transcription in the injected cells. For determination of whether injected MRPC have a deleterious effect on renal function, experiments are performed injecting saline vehicle (n=2) or an MRPC cell suspension (10^6 cells; n=2) after sham operation. Renal function is assessed by serial measurement of serum creatinine and 24-hour creatinine clearance (Hishikawa and Fujita 2008).

3.1.12 Signs of differentiation

Cell surrounding the characteristic colonies, with a flattened morphology and a dark and spiky appearance, are typical for different treated cells. Cells with a clearly visible nucleus and growing within flat colonies are more likely to have undergone differentiation. For AP staining of embryo stem cells, use the following protocol:

1. Rinse cells thoroughly with PBS.
2. Fix the cells in 10 ml ice-cold methanol for 10 min.
3. Rinse with aqua dest and incubate in fresh distilled water for 1 min.

4. Freshly prepare AP substrate.
5. Incubate for 45 min at room temperature, then rinse with aqua dest.
6. Counter stain nuclei with Hemalum for 5 min.
7. Mount the cells with Kaiser's glycerin gelatin and cover with cover slips.

3.1.13 Formation of EBs and spontaneously differentiation

The ES colonies are cultured for 5 days on 24-well dish (Cellstar) in suspension state by adding 1% trypsin to ES media and removing LIF. Then, the EBs are trypsonized with mild 0.5% /0.5mM trypsin/EDTA (Sigma) in PBS and then the media removed and transfer into centrifuge tube for a few minutes. The sedimentary EBs are transferred on the collagen coated 4-well dish and cultured for 20 days to induce the spontaneously differentiation. For detection of hematopoeitic cells, the differentiated cells are fixed by carrnoy's fixative (glacial acetic acid and metanol 1:3) and stained by Wright-Gimsa method.

3.2 Damaged renal repairing and renal regeneration by stem cells

Cultured renal stem cells or MRPC are introduced to the obstructed kidneys of mice. The use of human embryonic ES cells for the treatment of organ dysfunction is associated with legal and ethical issues which society as a whole has yet to decide on. In the meantime, fundamental research aiming to prove that ES cells can be directed into forming renal progenitor cells, and eventually differentiated renal cells, is underway. ES cells are pluripotent cells derived from the inner cell mass of blastocysts, and are in theory able to give rise to all the cell types of the body. ES cell lines have been derived from mice, non-human primates and humans. In vivo injection of ES cells can give rise to teratomas, which are tumors containing cells of all three lineages (ectoderm, endoderm and mesoderm). This tumorigenesis may limit the clinical use of ES cells to treat organ dysfunction. Nevertheless, in murine ES cell-derived teratomas in vivo, renal primordial structures can be detected histochemically, and genes involved in metanephrogenesis are expressed. This same potential is noted when ES cells are injected into embryonic mouse kidneys in vitro, and gave rise to ES cell-derived tubules, in this case without forming teratomas. In vitro, transfection of murine ES cells with renal developmental gene Wnt4, as well as the addition of hepatocyte growth factor and activin-A, both promote the formation of renal tubule-like structures, with expression of tubular marker aquaporin-2. The Wnt4-transfected cells are transplanted into mouse renal cortex, where they also expressed aquaporin-2 and formed tubular structures. Similarly, murine ES cells primed in vitro with retinoic acid, activin-A and BMP-7, activin-A alone, or BMP-4, differentiate into cells expressing markers of the intermediate mesoderm, early kidney development and/or renal tubule-specific markers. After injection of these primed murine ES cells into embryonic kidney cultures, ES cells are incorporated into developing renal tubules, without cell fusion, or into the nephrogenic zone. The primed cells are enriched for renal progenitor cells by FACS and injected in vivo into the kidneys of newborn mice, where they are integrated as proximal tubular cells, without teratoma formation (Wu et al. 2008).

3.3 Analysis of the cultured renal stem cells

3.3.1 RT-PCR

Total RNA is isolated using the TRIzol Reagent (Invitrogen, USA). The RNA is DNase 1 treated, and cDNA is synthesized using the Taqman Reverse Transcription Kit (BioRad, USA). Aliquots of 5 mg of total RNA are used for cDNA synthesis using the SuperScript II first-strand synthesis system with oligo(dT) (Invitrogen). The forward and reverse primers used are listed in Table 1. For *Pax2*, the RT2 PCR primer set is used for rat (LOC293992; Superarray Bioscience Corp., Frederick, MD, USA). The BD rat universal reference total RNA is used as a positive control for this reaction (BD Biosciences, USA). Quantitative real-time PCR is performed on a Bio-Rad RT-PCR equipment. Reaction conditions for amplification are as follows: 40 cycles of a two-step PCR (95°C for 15 seconds and 60°C for 60 seconds) after initial denaturation (95°C for 10 minutes) with 1 ul of a cDNA reaction in 1x SYBR Green PCR Master Mix (BioRab, USA).

cDNAs are amplified with Taq DNA polymerase (Takara, Tokyo, Japan). The PCR reaction consisted of 25–40 cycles. The sequences of the upstream and downstream primer pairs and amplimer lengths (bp) for each gene are as follows:

Pou5f1 (GGCGTTCTCTTTGGAAAGGTGTTC, CTCGAACCACATCCTTCTCTAG, 313 bp),
Pecam1 (TGCGATGGTGTATAACGTCA, GCTTGGCAGCGAAACACTAA, 384 bp),
Utf1 (GCCAACTCATGGGGCTATTG, CGTGGAAGAACTGAATCTGAGC, 204 bp),
Cd9 (CAGTGCTTGCTATTGGACTATG, GCCACAGCAGTCCAACGCCATA, 424 bp),
Zfp42 (CGTGTAACATACACCATCCG, GAAATCCTCTTCCAGAATGG, 123 bp),
Spp1 (GCAGACACTTTCACTCCAATCG, GCCCTTTCCGTTGTTGTCCTG, 243 bp).

3.3.2 Immunohistochemistry

Kidney tissue sections are fixed in 4% paraformaldehyde and permeabilized with Triton X-100. After blocking with 1% BSA/PBS for 1 hour, sections are incubated with primary antibodies diluted in 0.3% BSA/PBS overnight at 4°C. Slides subsequently are washed in PBS and incubated with secondary fluorochrome-conjugated antibodies for 45 minutes. The following antibodies are used in 1:100 dilution: Anti–von Willebrand factor (anft-vWF; F-3220; Sigma, USA), anti-albumin (55442; ICN/Cappel, Costa Mesa, CA, USA), FITC-conjugated anti-pan cytokeratin (F0397; Sigma, USA), anti-neurofilament 200 (N0142; Sigma, USA), Texas red–conjugated anti-GFP (600-109-215; Rockland, Gilbertsville, PA, USA), anti–zona occludens-1 (anti–ZO-1; 61-7300; Zymed, San Francisco, CA, USA), anti–MHC I (12-5321-81; eBioscience, San Diego, CA, USA), anti–MHC II (12-5999-81; eBioscience, USA), TRITC-conjugated anti-PCNA (SC-7907; Santa Cruz Biotechnology, Santa Cruz, CA, USA), anti-THP (CL-1032-A; Cedarlane, Burlington, NC, USA), and anti-vimentin (V4630; Sigma, USA). The following lectins are used in 1:500 dilutions for 45 minutes at room temperature: Rhodamine Peanut Agglutinin (RL-1072; Vector Laboratories, Burlingame, CA, USA) and Rhodamine Phaseolus Vulgaris Erythroagglutinin (RL-1122; Vector Laboratories, USA). For detection of Oct4, 8-um-thick formalin-fixed, paraffin-embedded sections of rat kidney are deparaffinized in xylene for 10 min, followed by hydration through graded ethanol. Endogenous peroxidase is injected for cells. The kidneys are harvested 10 days later to examine *in vivo* differentiation of the injected cells.

3.3.3 Characterization of markers for and regulators of renal progenitors

To define a renal stem cell or drive an ES cell towards a renal fate, it is first critical to define the populations required. Individual projects within Section 1 will involve a series of expression profiling experiments carried out to record the temporal transcriptional program of metanephric development. Each project is aimed at both defining the expression pattern of renal development and identifying secreted proteins and cell surface markers that may be of value to Section 2.

3.3.4 Identification of secreted factors involved in the induction of renal development

Identification of UB tip-specific novel growth factors which induce nephron induction and novel UB tip specific receptors that transduce branching signals from the MM. The former may be useful in experimental induction of stem cells towards a renal fate. The latter may assist in the isolation of UB progenitors. The aim of this project will be to profile ureteric tree versus renal mesenchyme. Profiling will also be performed on tree branch versus tip. These studies will identify growth factors being produced by the tree that may be important in instructing the mesenchyme to form nephrons. Hox7b-GFP transgenic mice will be sued to allow the separation of tree from mesenchyme using FACs and laser microcapture. c-ret antibodies will be used to identify tip from branch of the ureteric tree. Growth factors from mesenchyme that may direct branching will also be identified. Novel factors will be ectopically expressed and their ability to drive mesenchymal differentiation in explants or induce tubule formation from mIMCD3 cells in vitro will be assessed.

3.3.5 Identification of renal progenitor markers to assist in the identification and isolation of renal stem cell populations

In this project, a complete temporal expression analysis of the developing kidney from 10.5 dpc to postnatal will be examined. Upon this temporal framework, spatial information from Project 1 and 3 can be placed. Specific A versus B profiling will also be performed between 10.5 dpc renal mesenchyme and adjacent intermediate mesoderm that will not become kidney. This project particularly seeks to identify transmembrane markers of potential progenitor cell populations in the kidney. As describe previously, the membrane organization of all mammalian genes will be assessed computationally. Genes believed to encode trans-membrane proteins and are found to be expressed in the kidney, based on expression data obtained in projects 1 and 2, will be further analyzed. In situ hybridization will be used to assess the spatial expression pattern of these potential cell surface markers in the kidney. Antibodies will be made to lead markers and these will be used to isolate different cell populations. Finally, the potential of these populations to repair damaged kidneys will be assessed in a variety of explant and engrafting assays.

3.3.6 Expression profiling of renal sub-compartments, including the interstitial cells, tissue macrophages and podocytes, to identify specific markers of the endpoints of renal differentiation

In addition to the temporal expression profiling of kidney development, a series of profiling experiments are to be undertaken to define expression markers of specific cell types and regions of the kidney. Specific cell types are to be generated by primary culture methods (renal interstital cells) and cell sorting of cell specific GFP-tagged cells form the

kidneys of different transgenic mice (renal macrophages, cap condensates, podocytes). This data will provide an expanded set of expression markers for specific cell types and differentiation states for cells that make up the mammalian kidney. It will also provide an excellent recourse for cell specific expression markers that can be used in Project 4.

3.3.7 Examination of the potential for ES cells to be differentiated into the necessary lineages for renal de novo generation or repair

In this project we will attempt to direct murine or human embryonal stem cells towards a renal fate using a variety of inducing conditions. In the case of murine ES cells, this will be an adaptation of the mesodermal induction process used in embryoid body (EB) formation. As tagged murine ES cells can be generated, this will be the most insightful approach. Information from Section 1 will provide i) markers for which progress towards a renal fate can be monitored using wholemount in situ hybridization, ii) growth factors which may assist in the process and iii) cell surface markers which can facilitate the isolation and enrichment of the desired cell types from mixed progenitor populations. We will also use human embryonal cells to more crudely assess this renal potential. Both of these can be used to test novel growth factors isolated in Projects 1 and 2.

3.3.8 Measuring the mesenchymal stem cells dimensions

Since the cell size can influence the time in which the culture become confluence, we measured the mesenchymal stem cells size from both cultures. For this, the length and width (the broadest part of the cells) of the fibroblastic mesenchymal stem cells from unconfluenced culture are measured using the objective micrometer mounted on the phase contrast inverted microscope.

3.3.9 Adipogenesis

Confluenced passaged-3 cells in 6-well culture plates are used to evaluate the adipogenic ability of the isolated cells. The proliferation medium of the cells is replaced by adipogenic DMEM medium containing 100 nM dexamethazone (Sigma, USA) and 50 mg/ml indomethasine (Sigma, USA). The cultures are then incubated for 21 days in 37ºC, 5% CO_2. The medium is changed 3 times a week. Occurrence of adipogenic differentiation is evaluated by Oil red staining as well as RT-PCR analysis.

3.3.10 Oil red staining

The culture is fixed with 4% formalin at room temperature, washed by 70% ethanol and stained by oil red solution in 99% isopropanol for 15 minute. At the end, the stain solution is removed and the cultures are washed with 70% ethanol before they are observed by light microscopy.

3.3.11 Osteogenesis

Confluenced passaged-3 cells in 6-well plates are used to induce bone differentiation. The proliferation medium of the cultures is replaced by osteogenic medium that is consisted of DMEM supplemented with 50 mg/ml ascorbic 2-phosphate (Sigma, USA), 10 nM dexamethazone (Sigma, USA) and 10 mM ßglycerole phosphate (Sigma, USA). The cultures are incubated at 37°C temperature and 5% CO_2 environment for 21 days with medium replacement of three times a week. Occurrence of differentiation is examined by alizarin red staining and RT-PCR analysis.

3.3.12 Alizarin red staining

Alizarin red staining is used to detect wheatear the mineralized matrix is formed in the cultures. For staining, the cultures are first fixed by methanol for 10 minutes, then subjected to alizarin red solution for 2 minutes, washed by distilled water and observed with light microscope.

3.3.13 Chondrogenesis

To induce the cartilage differentiation, micro mass culture system is used. For this purpose, 2.5×10^5 passaged-3 cells are pelleted under 1200 g for 5 minute and cultured in a chondrogenic medium containing DMEM supplemented by 10 ng/ml transforming growth factor-ß (Sigma, USA), 10 ng/ml bone morphogenetic protein-6 (Sigma, USA), 50 mg/ml insulin/ transferin/selenium+ premix (Sigma, USA) and 1.25 mg bovine serum albumin (Sigma, USA) and 1% fetal bovine serum (Gibco, UK). The chondrogenic culture is maintained at 37ºC, 5% CO_2 for 21 days with a medium replacement of three times a week. At the end of this period, the cultures are evaluated for cartilage differentiation by specific straining of toloidin blue and RT-PCR analysis.

3.3.14 Toluidin blue staining

To examine cartilage differentiation, the pellets are subjected to the following: fixing in 10% formalin; dehydrating in an ascending ethanol; clearing in xylene; embedding in paraffin wax and sectioning in 5 µ by microtome. The sections are then stained in toluidin blue for 30 second at room temperature and viewed by light microscope.

3.3.15 RNA extraction and RT-PCR analysis of gene expression

Total RNA is collected from the cells having been induced to differentiate into osteoblastic,

chondrocytic and adipocytic lineages as detailed above, using RNXPlusTM solution (CinnaGen Inc., Tehran, Iran). Before reverse transcription, the RNA samples are digested with DNase I (Fermentas) to remove contaminating genomic DNA. The standard reversetranscription reaction is performed with 5 µg total RNA using Oligo (dT) 18 as a primer and RevertAid TM H Minus First Strand cDNA Synthesis Kit (Fermentas) according to the manufacture's instructions. Subsequent PCR is as follows: 2.5 µl cDNA, 1X PCR buffer (AMS), 200 µM dNTPs, 0.5 µM of each primer pair and 1 unit/25µl reaction Taq DNA polymerase (Fermentas). The primers indicated in Table 1 are utilized to detect differentiations. Amplification conditions are as follows: initial denaturation at 94˚C for 5 minutes, followed by 35 cycles of denaturation at 94˚C for 45 minutes; annealing at 65 (insulin), 57 (GLUT1), 55 (GLUT2), 56 (glucagon), 65 (Oct4) and 60˚C (β-actin) for 45 minutes; extension at 72˚C for 30 minutes; and a final polymerization at 72˚C for 10 minutes. Each PCR is performed in triplicate and under linear conditions. The products are analyzed on 2% agarose gel and visualized by ethidium bromide staining.

3.3.16 Alkaline phosphatase analysis

Activity of the putative ES cells is stained for alkaline phosphatase activity in the cytoplasm using an alkaline phosphatase staining kit (Sigma, St. Louis, MO, USA). Fixation and staining are performed according to the protocol supplied by the manufacturer.

3.4 Analysis of renal repair effects by stem cells

3.4.1 C1earance Studies

The mice are anesthetized with sodium pentobarbital (50 mg/kg i.p.) and placed on a heating pad to maintain body temperature. A tracheostomy is performed. Then the jugular vein and carotid artery are cannulated (with PE-50 catheters) for infusion of inulin/PAH and monitoring of arterial blood pressure/blood sampling, respectively. 10% inulin/20% PAH (in normal saline) infusion is started at the rate of 30 ul/min for measurement of GFR and effective RPF (starting at t=minus 60 min). A small low midline incision (just large enough to slip the bladder through) is made and the bladder is cannulated for urine collection with a PE-240 catheter which has a mushroom-shaped cap. This is secured in the bladder with two 3-0 silk sutures (Chou et al. 2003). Following the surgical preparation, the inulin/PAH are allowed to equilibrate in the rat for 60 minutes before blood and urine samples are obtained. Thereafter (starting at t=0), urine is separately collected from the bladder for three 30 minute periods. Blood samples are taken at t=45 minutes and t=105 minutes. GFR and renal plasma flow are measured with the standard methods of inulin and PAH clearance, respectively. At the end of the clearance experiments, the rats are sacrificed with an intravenous injection of sodium pentobarbital. Urine volume is measured gravimetrically. Blood cells are separated from the plasma by centrifugation. Inulin concentrations in urine and plasma are measured by standard spectrophotometry. GFR is calculated by standard inulin clearance techniques.

3.4.2 Western Blot Analysis of Alpha-smooth Muscle Actin (alpha-SMA)

Accumulation of alpha-SMA, an indicator of tubulointerstitial fibrosis (Bohle A. Strutz F), is measured in the cortex and medulla by Western blotting. Immunoblot analysis of alpha-SMA protein in the cortex and medulla are performed in the sham-operated rats and rats with PUO in 3 groups of rats as described above. After the left kidney is removed through a midline abdominal incision, the cortex and medulla are separated and glass homogenized in lysis buffer on ice for total protein extraction. The homogenates are centrifuged at 12,000 r.p.m. for 20 min at 4°C. The supernatants are stored at -80°C in aliquots until analysis. The total protein concentrations of the samples are determined using BCA Protein Assay (Pierce, Rockford, IL) with bovine serum albumin as a standard. Protein extracts containing 100 µg of total protein are used. Western blot analysis is performed according to the procedures previously reported from our laboratory (Chou et al. 2003). Mouse monoclonal anti-alpha-SMA (Sigma Chemical, Ann Arbor, MI) and rabbit anti-mouse IgG conjugated to horseradish peroxidase (Amersham, Arlington Heights, IL) are used as the primary and secondary antibody at a dilution of 1:1000. The alpha-SMA immunoblot signals are normalized to the corresponding beta-actin band signals (Miyajima et al. 2000). A monoclonal mouse antibody for the structural protein β-actin (Sigma Chemical, St. Louis, MO) is used as a loading control. Membranes are stripped prior to β -actin analysis with buffer containing 0.2% sodium dodecyl sulphate and 50 mM glycine, adjusted to pH 2.6 with HCl, at room temperature for 2 min. After washing three times for 5 minutes each in 0.1% TBS, steps 3 to 9 above are repeated for β -actin. The immunoblot films are scanned and analyzed using imaging densitometry software (Bio-Rad, Hercules, CA). The data for alpha-SMA immunoblot signals are normalized to the corresponding ß-actin band signals.

3.4.3 Histological Studies:

The kidney specimens are embedded in paraffin after overnight fixation in 10% neutral buffered formalin. Sections (5- m thick) are stained by H&E method and trichrome method with Gomori trichrome kit (Richard-Allen Scientific, Kalamazoo, MI) to demonstrate collagen deposition. Tubular and interstitial changes in each group are graded on a scale from 0-4 under a micrometric ocular grid in accordance with the methods previously described (Remuzzi et al. 1999).

3.4.4 Radiological studies:

Sham-operated rats and rats with PUO are anesthetized with pentobarbital sodium (50 mg/kg i.p.) and a tail vein is cannulated with a 24-gauge catheter. Ioversol (Optiray 300, Mallinckrodt Inc, St. Louis, MO) is injected intravenously at 2 ml/kg BW and x-ray images of the rats are captured at 5 minutes by a portable x-ray machine (General Electric). A nuclear renal scan is also performed.

3.4.5 Blood biochemistry.

Body/organ weight, serum lipids, serum glucose and urine glucose are measured.

3.4.6 Kidney lipid contents.

Determine cholesterol/triglycerol content from kidney tissue (n=4-5 from each group).

3.4.7 Protein expression in kidney.

Use ½ kidney. Western blot for HMGCR, PPAR, SREBP-1, SREBP-2, TNF-α, TGF-β1, TGF-β2, HMG-CoA, PAI-1, nephrin, podocin, ABCA1, α-actin, VEGF, COX-2, and HIF expressions are performed.

3.4.8 Kidney RNA for RT-PCR analysis.

Use the other ½ kidney. Total RNA is ideally extracted with TRIzol and kept in 80% ethanol until PCR. Gene expression (mRNA) is determined for SREBP-1, SREBP-2, TGF-1, TGF-2, HMGCR, ABC-1, ABCA-1, PAI-1, nephrin and podocin (n=4-5 from each group).

3.4.9 Histology study.

¼ of the kidney is used. TRI and HE staining for fibrosis. Microphage infiltration/MCP-1 expression (n=3-4 from each group).

3.4.10 Blood and urine chemistries:

Serum glucose, urine glucose, total cholesterol, and triglycerides are determined by kits (Wako Chemicals USA, Inc., Richmond, VA, USA).

3.4.11 Serum creatinine and BUN:

Serum creatinine and BUN are determined using Autoanalyzer (Beckman Instruments Inc., Fullerton, California, USA). Urine albumin concentration is determined by competitive ELISA via the Albuwell M kit (Exocell, Philadelphia, PA, USA). Urine creatinine concentration is determined by Jaffe's reaction of alkaline picrate with creatinine via the Creatinine Companion kit (Exocell, Philadelphia, PA, USA, catalog number 1012).

3.4.12 RNA isolation and quantitative real-time PCR:

Total RNA is isolated from the cortex of kidney by using TRIzol (Invitrogen, Carlsbad, CA, USA). The cDNA is synthesized by using reverse transcript reagents (Bio-Rad iScript cDNA synthesis kit) after DNase treatment (Invitrogen, Carlsbad, CA, USA). The mRNA level is quantified by using Bio-Rad iCyCler Real Time PCR system. 36B4 is used as internal control and the amount of RNA is calculated by the comparative CT method. All the data are calculated from duplicate reactions. The primer sequences used are indicated in Table 1.

3.4.13 Homogenate, nuclei and membrane isolation:

Kidneys are homogenized at 4°C in homogenization buffer (20 mM Tris-Cl, pH 7.4, 75 mM NaCl, 2 mM EGTA, 2 mM EDTA, 1 mM Na_3VO_4, 1 mM dithiothreitol), supplemented with a protease inhibitor cocktail consisting 10 mM AEBSF, 0.08 mM Aprotinin, 2 mM Leupeptin, 4 mM Bestatin, 1.5 mM pepstatin A, 1.4 mM E-64 (Sigma-Aldrich, St. Louis, MO, USA). Nuclear extracts are prepared according to the method of Morooka et al [18] with minor modifications as we have previously described (Sun et al. 2002; Jiang et al. 2005a; Jiang et al. 2005b).

3.4.14 Protein electrophoresis and Western blotting of nuclear extracts and cortical homogenates:

Equal amount of protein samples are subjected to SDSPAGE (10% wt/vol) and they are then transferred to nitrocellulose membranes. After blockage with 5% fat-free milk powder with 1% Triton X-100 in Tris-buffered saline (20 mM Tris-Cl, 150 mM NaCl, pH 7.4), blots are incubated with antibodies against SREBP-1 (Santa Cruz, 1:1000), SREBP-2 (Santa Cruz, 1:1000), PPAR-β (ABR: 1:1000), TGF-1 (Santa Cruz, 1:1,000), TGF-2, plasminogen activator inhibitor-1 (PAI-1, Santa Cruz, 1:1,000), VEGF (Santa Cruz, 1:1,000), TGFb-1 (Santa Cruz, 1:1,000), type IV collagen (Santa Cruz, 1:1,000), or fibronectin (Sigma, 1:2,000). Corresponding secondary antibodies are visualized using enhanced chemiluminescence (Pierce, Bradford, IL, USA). The signals are quantified with a Phosphor Imager with chemiluminescence detector and the accompanying

densitometry software (Bio-Rad, Richmond, CA, USA).

3.4.15 Lipid extraction and measurement of lipid composition

Lipids from the renal cortex are extracted by the method of Bligh and Dyer [19]. **A) To determine triglyceride and total cholesterol content:** Totals lipids are extracted from the renal cortex and triglyceride and cholesterol content is measured as we have previously described (Sun et al. 2002; Jiang et al. 2005a; Jiang et al. 2005b). **B) To determine the glycosphingolipid composition:** an aliquot of the lipid extract is evaporated to dryness and subjected to alkaline methanolysis. The lipids are chromatographed on high performance thin layer chromatography plates (HPTLC, E. Merck 5641). Glucosylceramide and ganglioside GM3 are separated with a solvent system consisting of chloroform: methanol: water (65:25:4) on plates which are pretreated with 2.5% borax in methanol: water (1:1). The lipid bands are visualized by impregnating the plates with a modified charring reagent (100 g of $CuSO_45H_2O$ in conc. H_3PO_4: water: methanol (100:750:400). The charred TLC plates are scanned with a video densitometer. Comparing the density of each spot with the density of the corresponding standard curve is used to quantify the glucosylceramide and ganglioside GM3 bands [20-21].

3.4.16 Perfusion fixation of kidneys

Rats are anesthetized and perfused through the abdominal aorta as previously described (Sun et al. 2002; Jiang et al. 2005a; Jiang et al. 2005b)[20-21].

3.4.17 Periodic acid Schiff (PAS) staining

Paraffin sections are stained for PAS. The stained kidney sections are imaged with an Olympus microscope and semi quantitatively scored in a blinded manner by the renal pathologist (Sun et al. 2002; Jiang et al. 2005a; Jiang et al. 2005b).

3.4.18 Immunofluorescence microscopy

Staining for type IV collagen and fibronectin are performed in frozen kidney sections as previously described (Sun et al. 2002; Jiang et al. 2005a; Jiang et al. 2005b)[20-21]. For adipophilin imaging, paraffin-embedded sections are used and adipophilin is detected by incubating with antibodies to adipophilin (1:500) (Roche Biochemicals, Indianapolis, IN, USA), and then with Alexa-488- (Molecular Probes Inc., Eugene, OR, USA) labeled secondary antibody. Lipid droplets and nuclei are stained with Nile red and 4', 6-diamidino-2-phenylindol [22-23].

3.4.19 Electron Microscopy

Tissue is fixed in 3% paraformaldehyde in a 6:4 mixture of cacodylate buffer (pH 7.4; adjusted to 300 mosmol with sucrose) and 10% hydroxyethyl starch. The tissue is then post fixed in 1% buffered osmium tetraoxide. The sample is dehydrated in a graded series of ethanol, and embedded in an epoxy resin. Tissue is surveyed with a series of one micrometer sections for a representative sample. The selected specimens are thin sectioned, viewed and photographed with a Phillips electron microscope 201 (Phillips Electron Optics, Inc., Mahwah, NJ, USA). The sections are read by the renal pathologist in a blinded fashion for determination of basement membrane thickness and podocyte morphology (Jiang et al. 2005b)[23].

3.4.20 Synapse

The therapeutic efficacy of HMG-CoA reductase inhibitors in various renal diseases has been shown extensively in both experimental settings and clinical renal patient. However, the precise molecular mechanism underlying statin-mediated renal protective effect remains unclear. Pharmacologically, statin is a class of drugs inhibiting HMG-CoA reductase, a direct target gene of transcription factor sterol response element binding protein-2 (SREBP-2), subsequently suppressing de novo cholesterol biosynthesis and lowering serum cholesterol level. It is proposed that statin- mediated renal protective effect in diabetic animal models is direct suppression of renal inflammation process and possibly independent of its systemic cholesterol lowering effect, although the hypothesis hasn't been experimentally validated. Further, renal in situ cholesterol/lipid lowering effect mediated by statins treatment hasn't been examined yet. Previously, we and others have shown that renal lipid metabolism may play important roles in renal inflammation, glomerulosclerosis and tubulointerstitial injury in diabetic nephropathy. Furthermore, the facts that lipids serve as primary inflammation mediators participating in multiple disease processes have been very well recognized. Thus, we surmise that the disturbance of renal lipid metabolism may be involved in STZ associated renal injury, and the normalization of lipid metabolism abnormality contributes to statins-mediated renal protection. Based on the above mentioned rationales, we attempt to examine:

1. If renal SREBP-1, 2 expression/activation is modified in STZ rats. SREBP-2 is the principal transcription factor directly controlling the expression of HMG-CoA reductase gene expression. It is possible that SREBP-2 activity is altered and modified by statin treatment.

2. If HMG-CoA reductase expression is altered with or without the modulation of SREBP-2. Alternatively, HMG-CoA reductase could be modified post-transcriptionally.
3. If renal cholesterol or triglycerol content is altered in STZ rat kidney and normalized by statin treatment.
4. If certain other important lipid metabolism pathways altered, such as lipid transport, lipid oxidation pathways, in addition to *de novo* biosynthesis namely SREBP-2/HMG-CoA Reductase pathway in STZ rat and corrected by statin.
5. The statin may regulate certain key fibrosis associated factors such as VEGF, TGFb.

3.4.21 Parameters need to be analyzed

1. *Blood biochemistry*. Body/organ weight, serum lipids, BUN/Cr, e-GFR, cytokines (Interleukin 1b, TNFa, check one of them if possible, since these cytokines are elevated in patient with chronic kidney disease and suppressed by statin according to recent literature).
2. *Kidney lipid contents*. Determine cholesterol/triglycerol content from kidney tissue. (n=4-5 from each group)
3. *Protein expression in kidney*. **Use 1/2 kidney.** Western blot for HMG-CoA reductase. Save the rest for future use, n=3-4 from each group. VEGF or TGF level can be re-blotted with same filter.
4. *Nuclear extract for SREBP-2 protein*. **Use ½ kidney.** Including both nuclear and cytosol lysate in western blot and compare the abundance of nuclear form and cytosol form SREBP-2. Antibody can be obtained from Santa Cruz. (n=3-4 from each group).
5. *Kidney RNA for RT-PCR analysis*. **Use ½ kidney.** Ideally extract and keep RNA in 80% ETOH. Determine gene expression for SREBP-2, SREBP-1, HMG-CoA reductase, ABCA-1, IL-1, TNFa, podocyte markers nephrin, and podocin. (n=4-5 from each group)
6. *Histology study*. **Use 1/3 kidney.** PAS staining for fibrosis. Microphage infiltration/MCP-1 expression (n=3-4 from each group). May include some other markers later, depends on the result.

3.4.22 Data Analysis

The data are expressed as the mean±SD. The statistical significance of the results between samples obtained from four groups is determined by one-way analysis of variance with Student-Newman-Keuls analysis for multiple comparisons. Significance is accepted at the $p<0.05$ level.

4. Vertebrate Animals

Three hundred C57BL/6 mice (Charles River Laboratories, Inc., Boston, MA, USA) will be used in this project. Mice are housed according to NIH guidelines and the study is conducted according to Brookdale Hospital's Animal Care and Use Committee approved protocol. Animal housing, maintenance, operating and post-operative facilities are available in the Animal Lab of Brookdale Hospital's.

5. Statistical Analysis

With Microsoft Office Excel and Jandel Scientific program SigmaStat (Sigma Chemical Co., St. Louis, Missouri) will be used for data statistical analysis of transfected gene expression data. $P<0.05$ is considered statistically significant difference. Measured data are reported as mean±SD. The student t-test is used for comparison.

6. Discussion

6.1 What are the potential uses of human stem cells and the obstacles that must be overcome before these potential uses will be realized?

There are many ways in which human stem cells can be used in research and the clinic. Studies of human embryonic stem cells will yield information about the complex events that occur during human development. A primary goal of this work is to identify how undifferentiated stem cells become the differentiated cells that form the tissues and organs. Scientists know that turning genes on and off is central to this process. Some of the most serious medical conditions, such as cancer and birth defects, are due to abnormal cell division and differentiation. A more complete understanding of the genetic and molecular controls of these processes may yield information about how such diseases arise and suggest new strategies for therapy. Predictably controlling cell proliferation and differentiation requires additional basic research on the molecular and genetic signals that regulate cell division and specialization. While recent developments with iPS cells suggest some of the specific factors that may be involved, techniques must be devised to introduce these factors safely into the cells and control the processes that are induced by these factors.

Human stem cells could also be used to test new drugs. For example, new medications could be tested for safety on differentiated cells generated from human pluripotent cell lines. Other kinds of cell lines are already used in this way. Cancer cell lines, for example, are used to screen potential anti-tumor drugs.

The availability of pluripotent stem cells would allow drug testing in a wider range of cell types. However, to screen drugs effectively, the conditions must be identical when comparing different drugs. Therefore, scientists will have to be able to precisely control the differentiation of stem cells into the specific cell type on which drugs will be tested. Current knowledge of the signals controlling differentiation falls short of being able to mimic these conditions precisely to generate pure populations of differentiated cells for each drug being tested.

Perhaps the most important potential application of human stem cells is the generation of cells and tissues that could be used for cell-based therapies. Today, donated organs and tissues are often used to replace ailing or destroyed tissue, but the need for transplantable tissues and organs far outweighs the available supply. Stem cells, directed to differentiate into specific cell types, offer the possibility of a renewable source of replacement cells and tissues to treat diseases including Alzheimer's diseases, spinal cord injury, stroke, burns, heart disease, diabetes, osteoarthritis, and rheumatoid arthritis.

For example, it may become possible to generate healthy heart muscle cells in the laboratory and then transplant those cells into patients with chronic heart disease. Preliminary research in mice and other animals indicates that bone marrow stromal cells, transplanted into a damaged heart, can have beneficial effects. Whether these cells can generate heart muscle cells or stimulate the growth of new blood vessels that repopulate the heart tissue, or help via some other mechanism is actively under investigation. For example, injected cells may accomplish repair by secreting growth factors, rather than actually incorporating into the heart. Promising results from animal studies have served as the basis for a small number of exploratory studies in humans (for discussion, see call-out box, "Can Stem Cells Mend a Broken Heart?"). Other recent studies in cell culture systems indicate that it may be possible to direct the differentiation of embryonic stem cells or adult bone marrow cells into heart muscle cells.

There is crucial disagreement on the issue of functionality of these cells. Do the bone marrow-derived cells actively participate in extracellular matrix synthesis? Roufosse et al. in a mouse model of unilateral ureteric obstruction, detected bone marrow-derived α-SMA-positive cells. Using two reporter molecules under the control of the promoter and enhancer elements of the collagen I α2 chain gene, we did not however observe any functional bone marrow-derived fibroblasts or myofibroblasts producing collagen I. On the other hand, Iwano et al. in a mouse model of unilateral ureteric obstruction, and Broekema et al. in a rat model of unilateral I/R injury, demonstrated double immunostaining positivity of α-SMA-positive interstitial cells with pro-collagen I protein (Broekema et al. 2007).

In this project, with the mouse model, we aim to find the practical conditions to induce ES cells differentiating into renal stem cells and to find the ways using the renal stem cells to repair and regenerate obstructed kidney. For these, we will explore the techniques to induce ES cells to adopt a renal fate using co-culture with cell lines, metanephroi and novel growth factors. Meantime, we will characterize the expression profile of different renal subcompartments so as to identify the secreted proteins involved in renal differentiation and to isolate the specific cell surface markers identifying renal stem cells.

The theoretical background justifying the pursuit of the potential of bone marrow cells to participate in renal regeneration has been laid. Stem cells, both embryonic and from the adult bone marrow, in the right conditions, can express renal markers in vitro and give rise to renal cells in vivo.

In addition, injection of stem cells into the kidney or the bloodstream can lead to an improvement of renal function, although this does not always seem to be mediated by transdifferentiation into renal cells. Current views favor a predominant role for the delivery of a cocktail of angiogenic and immunomodulatory mediators as the main means by which bone marrow cells enhance epithelial and endothelial cell survival. As far as engraftment of bone marrow cells as renal parenchymal cells is concerned, proving functionality of the engrafted bone marrow-derived cells is crucial in order to assign to them a role in improved renal function, rather than relying on morphological observations alone.

The kidney is a complex organ with over 30 different cell types, and present technology does not envisage constructing a whole kidney from stem cells. However, within existing kidneys where the basic scaffolding is intact, stem cells may contribute to a variety of specialized cell types, either promoting more efficient repair or correcting genetic defects. These would include: (1) acute tubular necrosis (ATN) caused by toxins or ischaemia/reperfusion (associated with kidney transplantation); (2) mesangial damage, often associated with immune complex deposition and diabetes; (3) defective podocyte function (Alport's disease); (4) vascular endothelial damage (e.g. in glomerulonephritis) (Alison et al. 2007; Alison 2009).

Whether stem cell injections will ever be used for the treatment of renal failure is at this stage still unknown. There is certainly some hope to be found in the numerous animal models that have been developed and analyzed over the last few years.

To reach the goal, we propose the following basic research objectives: (1) Use expression profiling to further dissect the processes of commitment to a metanephric fate during normal development. (2) Identify novel renal progenitor cell markers and growth factors to assist in the identification, isolation and/or reactivation of renal stem cells. (3) Examine the potential for ES cells to be differentiated into the lineages necessary for renal regeneration or endogenous repair.

6.2 Can Stem Cells Mend a Broken Heart?: Stem Cells for the Future Treatment of Heart Disease

Cardiovascular disease (CVD), which includes hypertension, coronary heart disease, stroke, and congestive heart failure, has ranked as the number one cause of death in the United States every year since 1900 except 1918, when the nation struggled with an influenza epidemic. Nearly 2600 Americans die of CVD each day, roughly one person every 34 seconds. Given the aging of the population and the relatively dramatic recent increases in the prevalence of cardiovascular risk factors such as obesity and type 2 diabetes, CVD will be a significant health concern well into the 21st century.

Cardiovascular disease can deprive heart tissue of oxygen, thereby killing cardiac muscle cells (cardiomyocytes). This loss triggers a cascade of detrimental events, including formation of scar tissue, an overload of blood flow and pressure capacity, the overstretching of viable cardiac cells attempting to sustain cardiac output, leading to heart failure, and eventual death. Restoring damaged heart muscle tissue, through repair or regeneration, is therefore a potentially new strategy to treat heart failure.

The use of embryonic and adult-derived stem cells for cardiac repair is an active area of research. A number of stem cell types, including embryonic stem (ES) cells, cardiac stem cells that naturally reside within the heart, myoblasts (muscle stem cells), adult bone marrow-derived cells including mesenchymal cells (bone marrow-derived cells that give rise to tissues such as muscle, bone, tendons, ligaments, and adipose tissue), endothelial progenitor cells (cells that give rise to the endothelium, the interior lining of blood vessels), and umbilical cord blood cells, have been investigated as possible sources for regenerating damaged heart tissue. All have been explored in mouse or rat models, and some have been tested in larger animal models, such as pigs.

A few small studies have also been carried out in humans, usually in patients who are undergoing open-heart surgery. Several of these have demonstrated that stem cells that are injected into the circulation or directly into the injured heart tissue appear to improve cardiac function and/or induce the formation of new capillaries. The mechanism for this repair remains controversial, and the stem cells likely regenerate heart tissue through several pathways. However, the stem cell populations that have been tested in these experiments vary widely, as do the conditions of their purification and application. Although much more research is needed to assess the safety and improve the efficacy of this approach, these preliminary clinical experiments show how stem cells may one day be used to repair damaged heart tissue, thereby reducing the burden of cardiovascular disease.

In people who suffer from type 1 diabetes, the cells of the pancreas that normally produce insulin are destroyed by the patient's own immune system. New studies indicate that it may be possible to direct the differentiation of human embryonic stem cells in cell culture to form insulin-producing cells that eventually could be used in transplantation therapy for persons with diabetes.

To realize the promise of novel cell-based therapies for such pervasive and debilitating diseases, scientists must be able to manipulate stem cells so that they possess the necessary characteristics for successful differentiation, transplantation, and engraftment. The following is a list of steps in successful cell-based treatments that scientists will have to learn to control to bring such treatments to the clinic. To be useful for transplant purposes, stem cells must be reproducibly made to:

Proliferate extensively and generate sufficient quantities of tissue.

Differentiate into the desired cell type(s).

Survive in the recipient after transplant.

Integrate into the surrounding tissue after transplant.

Function appropriately for the duration of the recipient's life.

Avoid harming the recipient in any way.

Also, to avoid the problem of immune rejection, scientists are experimenting with different research strategies to generate tissues that will not be rejected.

To summarize, stem cells offer exciting promise for future therapies, but significant technical hurdles remain that will only be overcome through years of intensive research.

6.3 Where can I get more information?

For a more detailed discussion of stem cells, see the NIH's Stem Cell Reports. Check the Frequently Asked Questions page for quick answers to specific queries. The navigation table at right can connect you to the information you need.

The following websites, which are not part of the NIH Stem Cell Information site, also contain

information about stem cells. The NIH is not responsible for the content of these sites.
http://www.isscr.org/public
Stem cell information for the public from the International Society for Stem Cell Research (ISSCR).
http://www.nlm.nih.gov/medlineplus/stemcells.html
Medline Plus is a consumer health database that includes news, health resources, clinical trials, and more
http://www.explorestemcells.co.uk
A United Kingdom-based resource for the general public that discusses the use of stem cells in medical treatments and therapies.
http://www.stemcellresearchnews.com
A commercial, online newsletter that features stories about stem cells of all types.

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