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What Are Stem Cells?

(Released December 2004)

by [Preeti Gokal Kochar](#)

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Stem cell research has been hailed for the potential to revolutionize the future of medicine with the ability to regenerate damaged and diseased organs. On the other hand, stem cell research has been highly controversial due to the ethical issues concerned with the culture and use of stem cells derived from human embryos. This article presents an overview of what stem cells are, what roles they play in normal processes such as development and cancer, and how stem cells could have the potential to treat incurable diseases. Ethical issues are not the subject of this review.¹

In addition to offering unprecedented hope in treating many debilitating diseases, stem cells have advanced our understanding of basic biological processes. This review looks at two major aspects of stem cells:

I. Three processes in which stem cells play a central role in an organism, development, repair of damaged tissue, and cancer resulting from stem cell division going awry.

II. Research and clinical applications of cultured stem cells: this includes the types of stem cells used, their characteristics, and the uses of stem cells in studying biological processes, drug development and stem cell therapy; heart disease, diabetes and Parkinson's disease are used as examples.

What are stem cells?

[Stem cells](#) are unspecialized cells that have two defining properties: the ability to [differentiate](#) into other cells and the ability to [self-regenerate](#).

The ability to differentiate is the potential to develop into other cell types. A [totipotent](#) stem cell (e.g. fertilized egg) can develop into all cell types including the embryonic membranes. A [pleuripotent](#) stem cell can develop into cells from all three germinal layers (e.g cells from the inner cell mass). Other cells can be oligopotent, bipotent or unipotent depending on their ability to develop into few, two or one other cell type(s).²

Self-regeneration is the ability of stem cells to divide and produce more stem cells. During early development, the cell division is symmetrical i.e. each cell divides to give rise to daughter cells each with the same potential. Later in development, the cell divides asymmetrically with one of the daughter cells produced also a stem cell and the other a more differentiated cell.

Differentiation Potential	Number of cell types	Example of stem cell	Cell types resulting from differentiation	Source
Totipotent	All	Zygote (fertilized egg), blastomere	All cell types	[m1]
Pleuripotent	All except cells of the embryonic membranes	Cultured human ES cells	Cells from all three germ layers	[m2]

News

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Multipotential	Many	Hematopoietic cells	skeletal muscle,cardiac muscle, liver cells, all blood cells	[m3]
Oligopotential	Few	Myeloid precursor	5 types of blood cells (Monocytes, macrophages, eosinophils, neutrophils, erythrocytes)	[m4]
Quadripotential	4	Mesenchymal progenitor cell	Cartilage cells, fat cells, stromal cells, bone-forming cells	[m5]
Tripotential	3	Glial-restricted precursor	2 types of astrocytes, oligodendrocytes	[m6]
Bipotential	2	Bipotential precursor from murine fetal liver	B cells, macrophages	[m7]
Unipotential	1	Mast cell precursor	Mast cells	[m8]
Nullipotential	None	Terminally differentiated cell e.g. Red blood cell	No cell division	

Table 1: Differential potential ranges from totipotent stem cells to nullipotent cells. Compiled from information in sources shown

I. Stem cells are central to three processes in an organism: development, repair of adult tissue and cancer.

A. Stem cells in mammalian development

The zygote is the ultimate stem cell. It is totipotent with the ability to produce all the cell types of the species including the trophoblast and the embryonic membranes. Development begins when the zygote undergoes several successive cell divisions, each resulting in a doubling of the cell number and a reduction in the cell size. At the 32- to 64-cell stage each cell is called a [blastomere](#).² The blastomeres stick together to form a tight ball of cells called a [morula](#). Each of these cells retains totipotent. The next stage is the [blastocyst](#) which consists of a hollow ball of cells; [trophoblast](#) cells along the periphery develop into the embryonic membranes and placenta while the inner cell mass develops into the fetus. Beyond the blastocyst stage, development is characterized by [cell migration](#) in addition to cell division. The gastrula is composed of three [germ layers](#): the ectoderm, mesoderm and endoderm. The outer layer or [ectoderm](#) gives rise to the future nervous system and the epidermis (skin and associated organs such as hair and nails). The middle layer or [mesoderm](#) gives rise to the connective tissue, muscles, bones and blood, and the [endoderm](#) (inner layer) forms the gastrointestinal tract of the future mammal.

Early in embryogenesis, some cells migrate to the primitive gonad or genital ridge. These are the precursors to the gonad of the organism and are called [germinal cells](#). These cells are not derived from any of the three germ layers but appear to be set aside earlier.

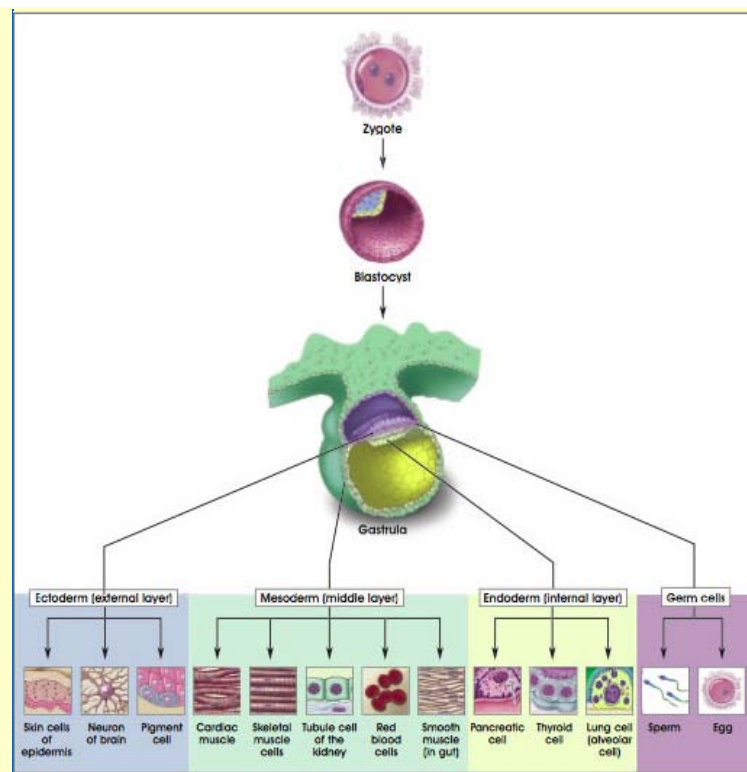
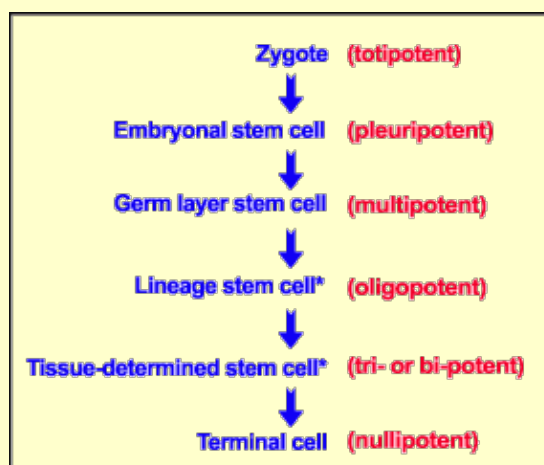


Figure 1: Differentiation of Human Tissues
Source: <http://stemcells.nih.gov/info/scireport/chapter1.asp>

Stem cells in late development

As development proceeds, there is a loss of potential and a gain of specialization, a process called [determination](#). The cells of the germ layers are more specialized than the fertilized egg or the blastomere. The germ layer stem cells give rise to [progenitor cells](#) (also known as progenitors or [precursor cells](#)). For example, a cell in the endoderm gives rise to a primitive gut cell (progenitor) which can further divide to produce a liver cell (a terminally differentiated cell).



Hierarchy of stem cells during differentiation.²at each stage, differential potential decreases and specialization increases.
(* These are also called transit-amplifying cells)

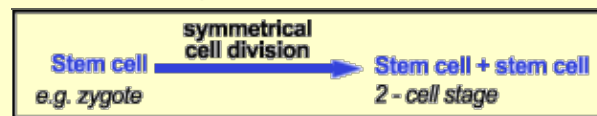
Role of Progenitor Cells in Development

While there is consensus in the literature that a progenitor is a partially specialized type of stem cell, there are differences in how progenitor cell division is described. For instance, according to one source,³ when a stem cell divides at least one of the daughter cells it produces is also a stem cell; when a progenitor cell undergoes cell division it produces two specialized cells. A different source,² however, explains that a progenitor cell undergoes asymmetrical cell division, while a stem cell undergoes symmetrical cell division.

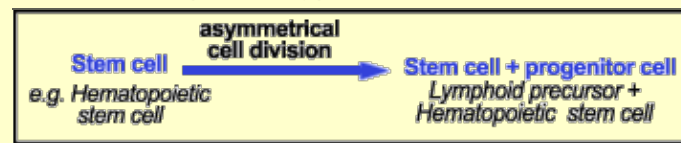
The apparent inconsistency of these two versions illustrates the diversity and complexity of progenitor cells and their role in differentiation. This diversity is reflected in the nomenclature as well; progenitor cells are also called Transit-amplifying cells, Precursor cells, Progenitors, [Lineage stem cells](#), and [Tissue-determined stem cells](#).

The table below shows these complex stages:

Early in development:



Late in development: type 1



Late in development: type 2

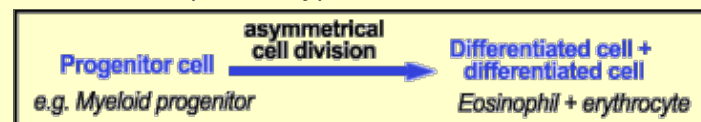


Table 2: Summarized from information in references 6 and 7.

The number of stem cells present in an adult is far fewer than the number seen in early development because most of the stem cells have differentiated and multiplied. This makes it extremely difficult to isolate stem cells from an adult organism, which is why scientists hope to use embryonic stem cells for therapy because embryonic stem cells are much easier to obtain.

B. The role of adult stem cells in tissue repair

During development, stem cells divide and produce more specialized cells. Stem cells are also present in the adult in far lesser numbers. The role of adult stem cells (also called somatic stem cells) is believed to be replacement of damaged and injured tissue. Observed in continually-replenished cells such as blood cells and skin cells, stem cells have recently been found in other tissue, such as neural tissue.

Organ regeneration has long been believed to be through organ-specific and tissue-specific stem cells. Hematopoietic stem cells were believed to replenish blood cells, stem cells of the gut to replace cells of the gut and so on. Recently, using cell lineage tracking, stem cells from one organ have been discovered that divide to form cells of another organ. Hematopoietic stem cells can give rise to liver, brain and kidney cells. This [plasticity](#) of adult stem cells has been observed not only under experimental conditions, but also in people who have received bone marrow transplants.⁴

Tissue regeneration is achieved by two mechanisms: (1) Circulating stem cells divide and differentiate under appropriate signaling by [cytokines](#) and growth factors, e.g. blood cells; and (2) Differentiated cells which are capable of division can also self-repair, e.g. hepatocytes, endothelial cells, smooth muscle cells, keratinocytes and fibroblasts. These fully differentiated cells are limited to local repair. For more extensive repair, stem cells are maintained in the quiescent state, and can then be activated and mobilized to the required site.⁵

For wound healing in the skin, epidermal stem cells and bone-marrow progenitor cells both contribute.⁶ Thus it is likely that organ-specific progenitors and hematopoietic stem cells are involved in repair, even for other organ repair.

Fundamental remaining questions regarding adult stem cells include: Does one common type of stem cell migrate to different organs and repair tissue or are there multiple types of stem cells? Does every organ have stem cells (some of which have not yet been discovered)? Are the stem cells programmed to divide a finite number of times or do they have unlimited cell proliferation capacity?

C. Role of stem cells in cancer

Ontogeny (development of an organism) and oncology (cancer development) share many common features. From the 1870s the connection between development and cancer has been reported for various types of cancers. Existence of "cancer stem cells" with aberrant cell division has also been reported more recently. The connection between cancer and development is clearly evident in [teratocarcinomas](#).

As early as 1862, Virchow discovered that the germ cell tumor teratocarcinoma is made up of embryonic cells. In 1970, Stevens derived embryonal carcinoma cells from teratocarcinomas. A

teratocarcinoma is a spontaneous tumor of germ cells that resembles development gone awry. This tumor may contain several types of epithelia: areas of bone, cartilage, muscle, fat, hair, yolk sac, and placenta. These specialized tissues are often adjacent to an area of rapidly dividing unspecialized cells. The teratocarcinomas are able to differentiate into normal mature cells when transplanted into another animal. This alternation between developmental and tumor cells status demonstrates how closely development and cancer are related.

McCulloch explored the connection between normal development of blood cells and leukemia.⁷ According to him, normal hematopoietic development requires the interaction of [stem cell factor](#) with its receptor, c-kit. A hierarchy of stem and progenitor cells differentiates and produces different sublineages of cells resulting from response to varied growth factors. Malignancies of the hematopoietic system originate from two sources: those with an increased growth in an early stem cell produce acute leukemia, while those that arise from a decreased response to death or differentiation in a stem cell produce chronic leukemia.

The present-day challenge is to decode the common molecular mechanism and genes involved in self-renewal for cancer cells and stem cells.⁸

II. Stem cells used in research and clinical applications

Rao and colleagues postulate that all stem cells, regardless of their origin, share common properties.⁹ These researchers have reviewed the literature for candidate "stemness" genes. They conclude that there are a set of candidate genes that are present in all stem cells and can serve as universal markers for stem cells. These code for proteins are involved in self-renewal and differentiation. In addition they predict some differences in gene expression between different populations of stem cells.

A. Types and characteristics of stem cells for culture:

Embryonic stem (ES) cells are obtained from the inner cell mass and cultured as illustrated:

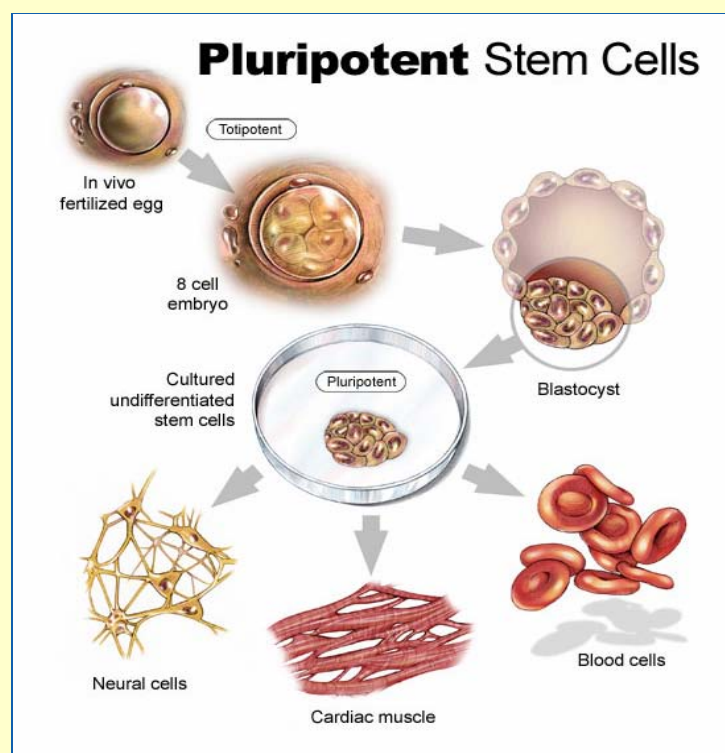


Figure 2: Embryonic stem cell culture

Source: <http://www.stemcellresearchfoundation.org/WhatsNew/Pluripotent.htm>

ES cells from mouse embryos have been cultured since the 1980s by various groups of researchers working independently.¹⁰ These pioneers established murine embryonic stem cells lines that could differentiate into several different cell types.¹¹ ES cell lines have been established from other mammals (hamsters, rats, pigs, and cows). Thompson and colleagues at the University of Wisconsin reported isolation of primate ES cells in 1995 and human ES cells in 1998.¹²

ES cells are the best characterized of all the cultured stem cells. Properties of ES cells:¹³

- (i) ES cells are pluripotent, i.e. they have the ability to differentiate into cells derived from all three germ layers, but not the embryonic membranes.
- (ii) ES cells are immortal i.e. cells proliferate in culture and have been maintained in culture for

several hundred doublings. The advantage of maintaining stem cells in culture is that they are a source of a large number of cells in the undifferentiated state. So far other adult stem cells have not been maintained indefinitely.

(iii) ES cells maintain a normal [karyotype](#) (there are no major structural changes in the chromosomes)

(iv) ES cells display Oct-4 protein and other unique markers on the cell surface.

Generally, ES cells are maintained in culture on [feeder cells](#) (mouse fibroblast cells) There have been recent reports of ES cultured on feeder cell-free medium.¹⁴

ES cells can be induced to differentiate in vitro by culturing in suspension to form three-dimensional cell aggregates called [embryoid bodies](#) (EBs).¹⁵ The cells spontaneously differentiate into various cell types, e.g. neurons, cardiomyocytes, and pancreatic beta cells. The addition of growth factors to the culture directs differentiation to specific cell types. However, it is still challenging to isolate pure differentiated cell types.

Following injection of ES cells into immunodeficient mice, teratomas develop with derivatives of all three germ layers. This is a major disadvantage of using ES cells for cell therapy since any contaminating undifferentiated cells could give rise to cancer.

Embryonic germ cells Gearhart and colleagues originally derived stem cells from primordial germ cells.¹⁶ Cells cultured from the genital ridge of the human embryo have been isolated and cultured. These cells have a lesser capacity of proliferation than ES cells but have an advantage in that they are not tumorigenic, unlike ES cells.¹⁷

Embryonal carcinoma cells Embryonal carcinoma cell lines were first developed in 1967 by Ephrussi and colleagues from mouse teratomas, followed in 1975 by Fogh and Tempe from a human testicular teratocarcinoma. These cells are malignant relatives of ES and EG cells, which were used in many of the techniques to cultivate them. EC cells can differentiate under the right conditions and have a potential to be used for research and perhaps clinical applications.¹⁸ Once they differentiate they would not be expected to cause cancer, but these cells have not been studied as well as ES cells and are of limited use at present.

Adult or somatic stem cells The existence of hematopoietic stem cells was discovered in the 1960s, followed by the discovery of [stromal cells](#) (also called mesenchymal cells). Only in the 1990s did scientists confirm the reports of neural stem cells in mammalian brains. Since then stem cells have been found in the epidermis, liver and several other tissues.¹⁹

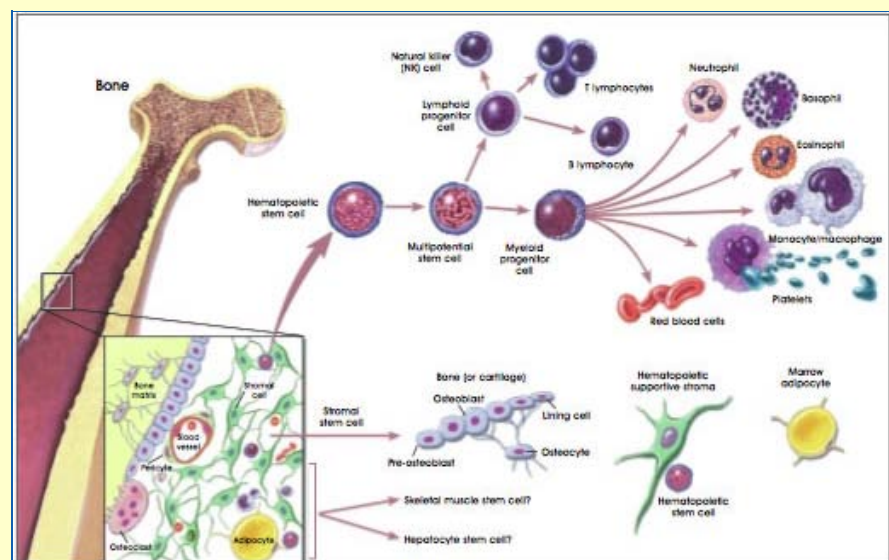


Figure 4: Hematopoietic and Stromal stem cell differentiation

Source: <http://stemcells.nih.gov/info/scireport/chapter5.asp>

Adult stem cells offer hope for cell therapy to treat diseases in the future because ethical issues do not impede their use. In addition, if the patient's own cells are used, immunological compatibility is not an issue. However, ES cells have been found to be superior for both differentiation potential and ability to divide in culture.

Two concepts are useful to describe characteristics of adult stem cells:

[Plasticity](#) is a newly recognized ability of stem cells to expand their potential beyond the tissue from which they are derived. For example, Dental pulp stem cells develop into tissue of the teeth but can also develop into neural tissue.²⁰

[Transdifferentiation](#) is the direct conversion of one cell type to another,²¹ e.g.

transdifferentiation of pancreatic cells into hepatic cells and vice versa has been reported in both animals and humans as has the transdifferentiation of blood cells into brain cells and vice versa.²²

Cell fusion: ES cells can fuse in vitro with neuronal cells and with hematopoietic stem cells.¹⁷ This has started a new debate in adult stem cell plasticity, namely that some cells may have fused and the nucleus was reprogrammed instead of transdifferentiating.

Cord blood stem cells Cord blood, from the umbilical cord, was believed to be an alternate source of hematopoietic stem cells; however, it is impossible to obtain sufficient numbers of stem cells from most cord blood collections to engraft an adult of average weight. Development continues on techniques to increase the number of these cells ex vivo. Cord blood contains both hematopoietic and non-hematopoietic stem cells.²³

B. Research and Clinical Applications of Cultured Stem Cells

What are the uses of Cultured Stem cells? The most prominent is cell therapy for treating conditions such as spinal cord injuries and for curing disease. Stem cells are used to investigate questions to further basic and clinical research. Here are the major applications to date:

1. Functional Genomic studies

In 1986, Gossler et al. reported using mouse ES cells to produce transgenic animals.²⁴ Soon after, two landmark papers in the field of mouse genetics demonstrated the ability to manipulate a specific gene of ES cells.²⁵ Combining these techniques, a specific gene can be introduced into ES cells to produce transgenic mice. This gene can be transmitted to their offspring through the germline. Today these techniques enable the study of the function of mammalian genes and proteins in the mouse (through introducing human histocompatibility genes into mice).²⁶

2. Study of biological processes

Studies of biological processes, namely development of the organism and progress of cancer, are facilitated by the ability to trace stem cell fate. The spleen colony assay developed by Till and McCulloch is an example study of the development of blood cells. In this method single cells were injected into heavily irradiated mice so that all the hematopoietic cells in these mice originated from the original colony. Studies of this nature helped decipher the clonal origin of cancer,

3. Drug discovery and development

The combination of isolation and purification of mouse ES cells and genetic engineering techniques has led to the use of murine ES cells in drug discovery. With the sequencing of the human genome many potential targets of new drugs have been identified. Studies using human ES may follow those of murine ES cells.²⁷ Interest in using stem cells as models for toxicology has also grown recently.²⁸

4. Cell-based therapy

Cultured ES cells spontaneously form embryoid bodies containing different cell types from all three germ layers. The desired cells are isolated and cultured and the differentiated cells are then used for therapy. ES cells have been induced to differentiate into neurons, cardiomyocytes and endoderm cells.

The identification of hematopoietic stem cells in mice by Till and McCulloch in 1961 heralded the use of stem cell therapy.²⁹ By 1999, 50 diseases had been treated by bone marrow and stem cell therapy with varying degrees of success,³⁰ among them leukemia, breast cancer, inflammatory bowel disease and osteogenesis imperfecta (a bone disease) in humans. ES and adult stem cells now offer hope for reversing the symptoms of many diseases and conditions including cancer, neurodegenerative diseases, spinal cord injuries, and heart disease.

The following stem cell characteristics make them good candidates for cell-based therapies:³¹

- i. Potential to be harvested from patients
- ii. High capacity of cell proliferation in culture to obtain large number of cells from a limited source
- iii. Ease of manipulation to replace existing non functional genes via gene transfer methods
- iv. Ability to migrate to host's target tissues, e.g. the brain
- v. Ability to integrate into host tissue and interact with surrounding tissue

Following is a summary of three diseases in which stem cell-based therapy has been used.

a) Heart disease

Cardiovascular disease is a leading cause of death worldwide killing 17 million people each year,³² especially due to heart attack and stroke. In the United States, heart disease is the number one cause of death. The high rate of mortality associated with heart diseases is the inability to repair damaged tissue³³ due to the full differentiation of heart tissue. Interruption of blood supply to the tissue

causes infarction of the myocardium and death of myocardiocytes.

A recent report used a swine model of atrioventricular block and transplanted human ES cell-derived cardiomyocytes into the pig's heart to work as a pacemaker.³⁴ The ES cells survived, functioned and integrated well with the host cells. The researchers used embryoid bodies to select spontaneously beating areas of culture (cultured myocytes will actually beat in synchrony just like a heartbeat). This study bodes well for future myocardial regeneration using human ES cells.

Adult stem cells have also been used in cell therapy for the heart.³⁵ Skeletal muscle myoblast transfers showed contraction but did not differentiate into cardiomyocytes and did not integrate with the host myocardium. Ideally, both contraction and integration with host myocardium should have occurred in order for the therapy to be effective. Endothelial progenitor cells transplants halted the degenerative process but did not initiate regeneration. Early clinical studies may soon follow.

Another approach is cardiac [tissue engineering](#).³⁶ Cohen and Leor grew embryonal heart cells in vitro with an alginate scaffold (alginate is an algal polysaccharide) to provide 3D-support and organization for the cells. They transplanted the cells with the scaffold into the scar tissue of the rats with myocardial infarction and observed extensively. The vascularization shows that there was acceptance of the engineered tissue. This unique method of treating heart disease is promising and may be explored in other animal models in the future.

b) Diabetes

Elevated glucose levels in the blood are responsible for diabetes. Diabetes affects 16 million Americans (5.9 percent of the population) and is the seventh leading cause of death.³⁷ Worldwide it afflicts 120 million people and the World Health Organization estimates that the number will reach 300 million by 2025.³⁸ Type I diabetes, or juvenile onset diabetes, is an autoimmune disease that causes destruction of the insulin-producing beta cells in the pancreas. Insulin injections are given to diabetics but they cause surges in blood glucose levels followed by a drop in the glucose levels and lack fine tuning. Pancreas transplantation has been performed in diabetics as more recently has pancreatic islet cell transplantation. The latter has the advantages that it does not require whole organ transplantation. However, the need for [immunosuppression](#) to prevent rejection of allogeneic islet transplants and a serious shortage of organ donors are lingering problems.²⁵ The Edmonton protocol, developed by Shapiro and colleagues, is promising. This procedure transplants a large amount of islet cells and uses a glucocorticoid-free type of immunosuppression regimen. In early clinical testing it reversed diabetes in all of the patients tested.

c) Stem cell therapy for diabetes

Cells need to be able to self-regenerate and differentiate. Also it has been observed that the presence of all the islet cell types is preferable to only beta cells since the former are better able to respond to changing levels of glucose in the blood. Growth must be balanced with ability to produce insulin. The insulin producing cells tend not to divide and those which divide actively do not produce insulin.

Adult stem cells from the pancreas have been elusive so far. However, a recent report of a clone from mouse pancreas that can generate both pancreatic and neural cell lines is exciting, as is a second report that adult small hepatocytes (liver cells) can be induced to produce insulin.³⁹ Both reports offer hope for using adult stem cells as a treatment and cure for diabetes.

d) Parkinson's Disease

Parkinson's disease is the second most common neurodegenerative disease following Alzheimer's. Approximately 1.5 million people in the United States suffer from Parkinson's disease,⁴⁰ which is caused when 80% or more of dopamine producing-neurons in the substantia nigra of the brain die. Normally, dopamine is secreted from the substantia nigra and transmitted to another part of the midbrain. This allows body movements to be smooth and coordinated.

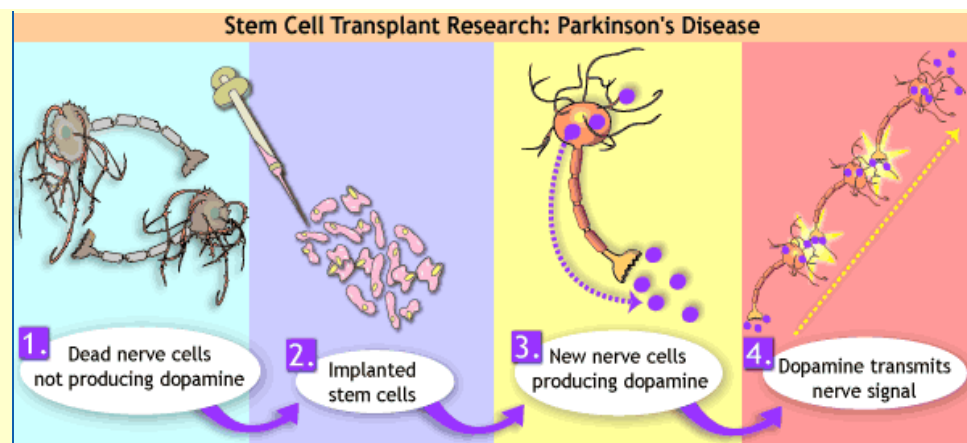


Figure 4: Stem Cell Transplant Research, Parkinson's Disease
<http://gslc.genetics.utah.edu/units/stemcells/scsuccess/1define.cfm>

Patients with Parkinson's disease are treated with the drug levodopa (or L-dopa), which is converted to dopamine in the body. Initially effective, the treatment's success is reduced over time and side effects increase, leaving the patient helpless.⁴¹

It has been recognized that dopamine-producing cells are required to reverse Parkinson's disease. Since the 1970s, many types of dopamine-producing cells have been used for transplantation. These include adrenal glands from the patient, human fetal tissue and fetal tissue from pigs.⁴² Limited success has been achieved with these cells. Rat and monkey models of Parkinson's were used to test fetal mesencephalic cells.⁴¹ Success with animal models led to clinical trials.

Fetal tissue transplantation has been performed in 350 patients, including trials using pig fetal tissue. So far, the success of reversing Parkinson's disease using fetal tissue has been limited at best. However, in the most successful cases, patients have been able to lead an independent life without L-dopa treatment.⁴³ The limitations include (i) lack of sufficient tissue for the number of patients in need, (ii) variation in results between patients ranging from no benefit to reversal of symptoms, and (iii) Occurrence of uncontrolled flailing movements (called dyskinesias).

The many criteria for the cells used in therapy include the ability to produce dopamine, to divide and survive in the brain and to integrate into the host brain. For these reasons, differentiated embryonic stem cells offer more promise. Mouse ES cells have been used in rat models of Parkinson's disease and recently human ES cells have been reported to differentiate into dopamine-producing neurons in culture.⁴⁴

Another consideration is the immune problem. It was believed that the brain is an immunologically privileged site tolerating transplanted cells from a different individual (meaning that the immune system will not attack tissue transplanted into this location). However, a recent report challenges this view.⁴⁵ For this reason autologous cells may offer a safer alternative. Neural stem cells and hematopoietic stem cells are both likely candidates.³¹ Also, dental pulp cells in both rats and humans produce neurotrophic factors and are a candidate for autologous transplantation in Parkinson's.²⁰

5) Therapeutic cloning

Somatic cell nuclear transfer was used to clone Dolly, the sheep.⁴² Since then, seven animal species have been cloned using this technique.⁴⁴ A modified version for use in humans is as follows: The patient's DNA is injected into an enucleated unfertilized egg and used to generate ES cells which are then cultured and allowed to differentiate, followed by transplantation into the patient. This technique is called therapeutic cloning. The use of such cells may bypass the ethical objections and immunological issues of using ES cells and is the future of stem-cell clinical application.

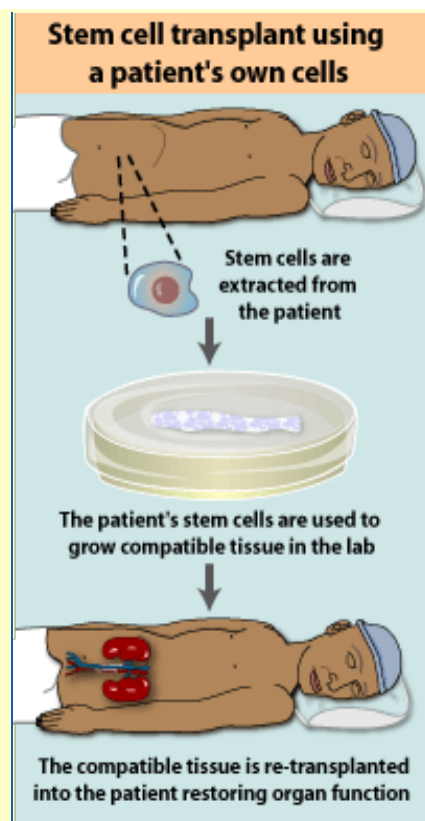


Figure 5: Stem Cell Transplant Using a Patient's Own Cells
<http://gslc.genetics.utah.edu/units/stemcells/scfuture/>

Conclusion

This review has summarized the role of stem cells in basic biological processes in vivo, namely in development, tissue repair and cancer in Part I. Part II focused on cultured stem cells and their uses, describing the different sources of stem cells, their properties and their research uses and clinical applications.

Remarkable progress has been achieved in studying stem cells. The most exciting use of cultured stem cells is the promise for curing many devastating diseases like Parkinson's and diabetes. However, more basic research remains before stem-cell based therapy is widely used.

Of the stem cells discussed, ES cells have the most capacity to differentiate into a variety of cells and their proliferation capacity is also unsurpassed by any other cell type. There are three major problems with ES cells; ethical issues, immunological rejection problems and the potential of developing teratomas.

In the future, ideally, somatic stem cells from the patient will be extracted and manipulated and then reintroduced into the same patient to cure debilitating diseases. This would preclude the use of embryonic stem cells for cell therapy, eliminate the ethical objections against stem cell research, and also resolve immunological rejection problems. However, at present the cell proliferation and differentiation potential of embryonic stem cells remains far more likely to produce a cure than do the somatic cells.

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1. For ethical issues and stem cell research refer to <http://stemcells.nih.gov/info/ethics.asp>; <http://athome.harvard.edu/programs/psc/index.html>; <http://www.aaas.org/spp/sfrr/projects/stem/main.htm> Ethical Issues Associated with Pluripotent Stem Cells. Human Embryonic Stem Cells (2003) ed. by Chiu A.Y., Rao, M.S, 3-25.
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