UC DAVIS OFFICE OF RESEARCH

Stem Cell Quick Guide: Stem Cell Basics

What is a Stem Cell?

Stem cells are the starting point from which the rest of the body grows.

The adult human body is made up of hundreds of millions of different types of cells specialized for different tasks. Nerve cells for the brain and nervous system; muscle cells; red blood cells to carry oxygen; white blood cells to fight infection; gut cells to absorb nutrients; cells to make hormones, cells to break down toxins; cells to store fat; cells to make hair; cells to line blood vessels.

All of these highly specialized cells have to grow from unspecialized stem cells. Stem cells produce new cells by dividing. In the right conditions, these new cells can then continue to divide and differentiate into specialized cells. Stem cells can also divide to produce new stem cells to replace themselves.

Stem cells have three properties that set them apart from other cells:

- They are self-replicating. Most body cells can go through a limited number of divisions and then die. Stem cells can continue to divide indefinitely.
- They are undifferentiated. This means that they do not have any of the specialized features associated with most of the cells in the body -- such as muscle, nerves, fat.
- They can divide and develop into cells of other types, to a greater or lesser degree.

Embryonic Stem Cells

When a sperm and egg fuse, they form a single fertile cell. This cell begins a series of divisions into two, four, eight cells and so on to form an embryo. By about five or six days after fertilization, the embryo is called a blastocyst -- a ball of cells with a clump of stem cells inside. At this stage, human embryonic stem cells can be extracted from the blastocyst and grown in a laboratory culture.

The first embryonic stem cells to form are totipotent. Each can form any of the cells needed to produce viable offspring, including the placenta.

A few days later, as the embryo develops, the stem cells are pluripotent. They can form any of the cells found in an adult, but not additional tissues such as the placenta. After seven to eight weeks of development, when major organs have developed, the embryo becomes a fetus. Pluripotent stem cells are also found in the developing fetus.

Adult Stem Cells

Some stem cells can be found in the tissues of fully grown adults. These adult stem cells are multipotent. They can develop only into a limited range of differentiated cell types, usually within a particular tissue or organ.

Hematopoietic (blood-forming) stem cells

These are perhaps the best-studied type of stem cell. Through a series of cell divisions and developmental changes, these stem cells give rise to red blood cells that carry oxygen; platelets that form blood clots; cells that make antibodies; cells that attack and engulf bacteria; and the T-cells that regulate immune responses. Hematopoietic stem cells are found mostly in the bone marrow. Blood in the placenta and umbilical cord also contains large numbers of hematopoeitic stem cells that can be collected when a baby is born.

Hematopoietic stem cells are already being used to treat leukemia and related diseases. Leukemias are cancers of blood cells. Drugs and high doses of radiation therapy can be used to kill the cancerous cells, but this also kills the stem cells in the bone marrow, leaving patients vulnerable to anemia, hemorrhage and infections.

To reduce these effects, stem cells can be transplanted to replace the cells killed by therapy. These stem cells are separated from the blood or bone marrow of a donor with a closely matched tissue type. There is a risk of an immune reaction in which the transferred cells attack the patient's tissues (graft-versus-host disease), or the patient's remaining immune system rejects the transplant.

In a new approach, stem cells can be taken from the patient before radiation treatment, stored or expanded in number, and transfused back into the patient after treatment.

Stem cells from umbilical cord blood can also be used in these transplants. These stem cells appear to be less likely to cause graft-versus-host disease than stem cells from adult bone marrow of an unrelated donor.

Mesenchymal stem cells

Another type of stem cell, they are found in adult bone marrow. They can develop into cells that make up or build connective tissues such as bone, cartilage and fat.

Neural stem cells

These are found in some small areas of the brain. They can develop into new nerve cells (neurons) or the cells that support them (glia).

Growing stem cells in the laboratory

Stem cells of different types can now be isolated and grown in the laboratory as cell lines. Human embryonic stem cells were first grown in the laboratory by researchers at the University of Wisconsin, Madison in 1998.

Human embryonic stem cells are typically extracted from unused blastocysts developed for in vitro fertilization (IVF) or similar procedures. IVF procedures usually involve fertilizing more eggs than will eventually be implanted in the patient.

In some cases, especially with older-established cell lines, embryonic stem cell cultures are grown on top of "feeder layers" of other cells, such as mouse cells. This is a common trick in cell culture when scientists are trying to cultivate a cell type that is difficult to grow.

The problem with using feeder cell layers from other animals to grow human cells is that there is a slight possibility that some unknown virus could transfer from the animal cells to the human cells. If the cell lines are used for research, that is not a great concern, but if the stem cells are to be used for clinical purposes and transferred back into patients, then there is a possibility, however small, that such a virus could establish in humans.

More recently, researchers have developed techniques for isolating and growing stem cells without using feeder layers of animal cells or other animal products that might cause contamination.

Importance of Stem Cells

Research

Understanding how a single cell can develop and grow into a complete human being -- or a mouse, a cow, a fruit fly or a tree -- is one of the most fascinating and challenging problems in biology. At the same time, many diseases are rooted in the development process including cancers and birth defects.

Much remains to be discovered about how an embryonic stem cell can differentiate into different kinds of specialized cells. This process involves chemical changes to the DNA in which certain genes are permanently turned on or off. This "imprinting" process seems to be important in understanding how cancers can develop.

Stem cells appear to differentiate in one direction, from undifferentiated embryonic stem cells to functional, fully differentiated specialized cells. However, there is some uncertainty about the extent to which cells can move back up this path to a less differentiated state, how great a range of final cell types an adult stem cell can differentiate into, and even if differentiated cells can be reversed and turned into other kinds of cells.

Researchers also want to know how to control the differentiation of stem cells so that they can be grown into specific tissues or organs, and the best ways to grow and maintain these cells in the lab.

Just by studying embryonic stem cells and how they develop, scientists hope to gain insight into how these processes work and find ways to prevent or treat diseases such as cancer and birth defects.

Gene transfer

Some genetic diseases, such as cystic fibrosis or muscular dystrophy, are caused by a small number of genetic changes. "Gene therapy," in which corrected genes are introduced into the patient, has been put forward as a way to treat these diseases, but it has proven difficult to get the "repaired" genes into the right location.

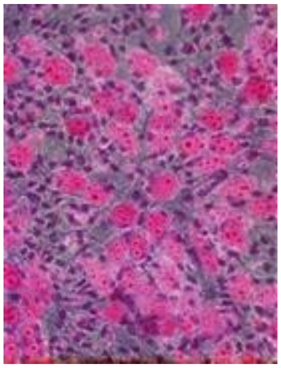
Using stem cells, it might be possible to take stem cells from the patient, transfer the correct version of the gene into them, and return them to the patient. The stem cells would then form new tissue to repair the damaged tissue.

Somatic Nuclear Transfer ("Therapeutic Cloning")

If cells from one person are transferred into another, they may be recognized by the immune system as foreign and rejected. An approach to solving this problem is to take a fertilized egg, remove its DNA, replace it with the complete nucleus of a cell from the patient, and grow it to the blastocyst stage -- five to six days -- to produce embryonic stem cells. Those stem cells would be near-identical in their DNA makeup to the original patient. In 2004, South Korean scientists reported that they had achieved this feat.

Therapeutic cloning is not the same as "reproductive cloning," where the aim is to produce viable cloned offspring. In reproductive cloning, the embryo is implanted into a recipient female and allowed to grow to term instead of being used as a source of stem cells. Reproductive cloning has been achieved in animals including mice, sheep, cattle and cats, but not in humans.

Regenerative medicine



Stem cell research could lead to a new area of "regenerative medicine:" replacing tissues or body parts damaged by injury of disease with new ones derived from stem cells.

"Replacement" medicine is now routine. Transplants of organs such as the heart, liver, kidneys or lungs are well-known, but there are not enough donor organs available to treat all patients in need. Organ transplants also pose serious problems of immune rejection. Tissues from animals have been used to treat humans, pig skin products used for skin grafts in burns victims. Many more people carry artificial and mechanical devices such as artificial joints, pacemakers, stents and cochlear implants.

Using stem cells, it might be possible not just to replace a damaged or worn out organ or tissue, but to grow a new one, inside or outside the body. This could lead to new treatments for chronic diseases and conditions such as heart disease, diabetes, Parkinson's disease, burns, spinal cord injuries and arthritis.

Blood stem cells are already in use to treat patients whose blood-forming and immune systems have been destroyed, for example by treatment for leukemia. The stem cells are infused into the patient and regrow the blood-forming and immune system from stem cells.

Trials of stem cells

Human embryonic stem cells have not yet been used in human patients. Some small-scale trials are under way to begin testing adult stem cells as treatments for specific conditions, including cancer, heart and bone disease.

External Information Sources

- National Institutes of Health
  http://stemcells.nih.gov/info/basics/
- Glossary of Stem Cell-Related Terms - International Society for Stem Cell Research
  http://www.isscr.org/glossary