SBI3U-C

Biotechnology

Introduction

The demand for insulin in the treatment of diabetes is soaring. According to the biotechnology industry, the number of people with diabetes is increasing dramatically due to an aging population combined with obesity and a sedentary lifestyle. Traditional methods of obtaining insulin from livestock are expensive and can't keep up with the demand.

A Canadian company, SemBioSys, has an innovative solution to this insulin shortage. They claim they have genetically engineered a safflower plant to produce insulin. This insulin can be mass-produced, isolated, and injected into diabetic patients at a fraction of the cost of other sources of insulin. This is just one example of how new methods in biotechnology, especially the transfer of genes between organisms, are changing medicine and agriculture. As you will see later in this lesson, biotechnology is also raising challenging ethical and moral issues.

In this lesson, you will learn about some techniques in modern biotechnology and how they differ from traditional approaches used for thousands of years. You will learn how modern biotechnology is being applied in agriculture and medicine, including some reproductive technologies that increase the genetic diversity of species by inserting new genes. You will also explore some of the potential drawbacks of these revolutionary techniques.

Planning Your Study

You may find this time grid helpful in planning when and how you will work through this lesson.

Suggested Timing for This Lesson (hours)	
Techniques in Modern Biotechnology	1½
Applications of Biotechnology in Food Production	¾
Applications of Biotechnology in Human Biology	1
Key Questions	1¼

What You Will Learn

After completing this lesson, you will be able to

- analyze, on the basis of research, some of the social and ethical implications of research in genetics and genomics such as genetic screening, gene therapy, and in vitro fertilization
- evaluate, on the basis of research, the importance of some recent contributions to knowledge, techniques, and technologies related to genetic processes such as research into the cystic fibrosis gene and the use of safflowers to produce insulin for human use
- describe some reproductive technologies such as cloning, artificial insemination, in vitro fertilization, and recombinant DNA, and explain how their use can increase the genetic diversity of a species (for example, farm animals or crops)

Techniques in Modern Biotechnology

Have you eaten some yogurt or cheese, or maybe some canola oil today? These foods are produced by biotechnology, a field of biology that encompasses various techniques using living organisms to make products or provide services.

Early examples of biotechnology include artificial breeding in agriculture to create breeds of domesticated animals and plants with the desired characteristics. Plants, for example, may have been selectively bred by pollinating them by hand and covering the plants so no other plants could fertilize them. Biotechnology was also used in food production. Yogurt and cheese were made with bacteria and fungi, while bread and beer were made with yeast, using techniques that have not changed much in thousands of years.

In the following sections, you will learn about the different techniques of modern biotechnology and their uses in society.

Genetic Engineering

Genetic engineering is a technique used by molecular biologists to artificially combine genes in a cell. The DNA from the cell of one organism is combined with the DNA of another organism to produce a new combination called a transgenic organism. Cutting open DNA to isolate a specific gene and attaching it to another strand of DNA is called gene splicing. When DNA comes from more than one source and is combined this way, it is referred to as recombinant DNA.

As you know, cells are extremely small, so how do scientists form recombinant DNA? You will now examine some of the tools that molecular biologists use in genetic engineering.

Restriction Endonucleases (Restriction Enzymes)

Restriction endonucleases are enzymes that behave like molecular scissors, with the ability to cut DNA at a specific point within the base pair sequence (this is known as cleaving). These enzymes are isolated and extracted from bacteria. These molecular scissors let biologists cut out sections of DNA or open up strands of DNA to insert new genes.

Each type of restriction enzyme is able to recognize a characteristic sequence of DNA that is known as its recognition site. Most recognition sites have a length of 4 to 8 DNA bases arranged in a specific sequence. For example, the restriction enzyme *Eco*RI, that comes from the bacteria *E. coli*, binds to the following DNA base sequence:

GAATTC

…and makes a cut between the G and the A nucleotides.

You can see how the *Eco*RI restriction enzyme endonuclease is used to cut the following piece of DNA into two pieces (the recognition site is highlighted in bold):

A T T A G A G A T **G A A T T C** A G A T T C A G A T A G C A T

↓

A T T A G A G A T G A A T T C A G A T T C A G A T A G C A T

Gel Electrophoresis

Once a piece of DNA has been cut out from its source, the desired fragment must be separated from the unwanted fragments so it can be used elsewhere. Gel electrophoresis is a process that separates DNA fragments based on their size. The smaller the DNA fragment is, the faster it will travel through the gelatinous "gel". The gel acts like a sieve, sorting the DNA fragments into a sequence from largest to smallest. Individual fragments can then be removed for further use.

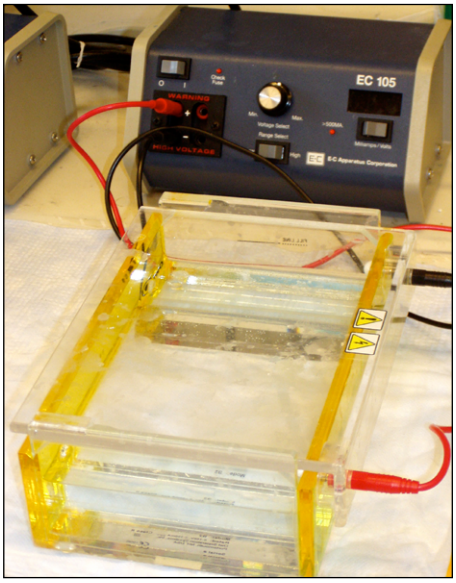

Figure 8.1: Photograph of the equipment used for gel electrophoresis

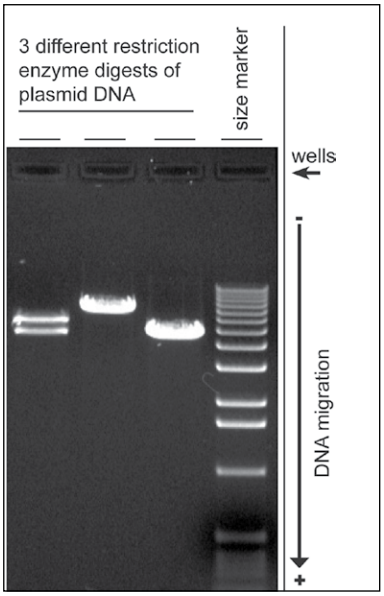

Figure 8.2: Image of DNA fragments separated by gel electrophoresis

DNA Ligase

Often, biologists will cut out a portion of DNA and insert a new portion. DNA ligase performs the opposite function of gel electrophoresis—it is used as a type of glue to bind the DNA fragments together, especially when they were cleaved by restriction enzymes.

Methylases

Methylases are specific enzymes found in eukaryotes and prokaryotes that help cells distinguish their DNA from foreign DNA. In prokaryotes, they modify a base sequence by adding a methyl group (CH_3). This prevents the cell from digesting its own DNA with its restriction enzymes. Molecular biologists use methylases as a tool when they want to protect a gene fragment from being cleaved by restriction endonucleases. In this way, they can choose exactly which gene fragment they want cleaved.

Plasmids

Genetic engineering began in the early 1970s with work conducted on the bacteria *Escherichia coli*. These bacteria (and many others) contain small loops of DNA called plasmids, which can exit and enter the cell (Figure 8.3).

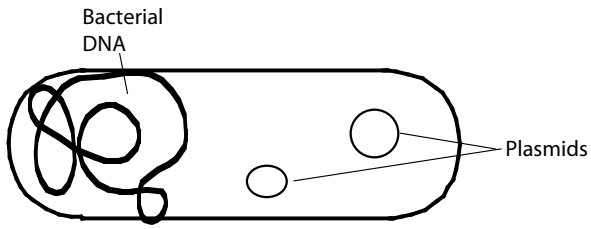

Figure 8.3: In addition to their own DNA, bacteria cells contain plasmids, which can enter and exit cells.

Bacteria are able to express foreign genes inserted into plasmids and sometimes even incorporate them into their main DNA. Biotechnologists use plasmids as transport vehicles to insert new genes into bacteria. Scientists make recombinant plasmids by placing plasmids in a test tube together with fragments of DNA from another organism, then adding DNA ligase to glue the fragments together.

Inserting new DNA into eukaryotic cells (such as human cells) uses a different transport vehicle, but works using a similar principle. Instead of plasmids, special kinds of viruses can be genetically altered and inserted into cells. The DNA in these special viruses eventually gets inserted into the genome of the host cell to produce recombinant DNA in the host.

Gene Therapy

Gene therapy is essentially a procedure in which defective genes are replaced with normal or healthy genes in an attempt to cure genetic disorders. There are currently three possible strategies for gene therapy: insertion, modification, and surgery.

Gene Insertion

With gene insertion, a normal copy of the defective gene is inserted alongside the defective gene on the chromosome within an affected cell. (A virus or other agent may be used to do this.) Insertion can be limited to those cells in which the gene would be active rather than inactive. For example, a person suffering from diabetes would only need the normal gene for insulin production inserted into their pancreas, not their muscle or skin cells. The inserted normal gene would make the proteins necessary to regulate blood sugar, and thus replace the lost function in the defective gene.

Gene Modification

With gene modification, the gene is chemically modified in order to recode the genetic message. This method is much more delicate than gene insertion, and requires a greater knowledge of the chemical composition of the normal and defective genes.

Gene Surgery

With gene surgery, the defective gene is actually removed, then replaced with a normal gene. The defective gene may need to be removed if it is making a protein that is somehow harming the patient. This type of gene therapy is the most risky of the three because it involves two steps (deletion and insertion). The biggest challenge with gene surgery is ensuring that the normal gene is inserted in the correct place, so that other genes are not affected.

Support Questions

Be sure to try the Support Questions on your own before looking at the suggested answers provided.

29. What is recombinant DNA technology? What are its uses in genetics? Suggested answer

Cloning

Cloning involves the production of identical copies, whether of molecules, genes, cells, or an entire organism. Simple cloning of plants has been done in agriculture for thousands of years using plant cuttings or root division to create genetically identical individuals. These methods use a fragment of the parent that naturally grows into an identical organism by the process of asexual reproduction. Modern cloning goes beyond these techniques to create clones of any organism, not just asexually-reproducing plants.

Cloning of sexually-reproducing organisms like mammals is much harder, and required the invention of new techniques. In 1997, the first ever sexually-reproducing organism was cloned: a sheep named Dolly. Figure 8.4, below, shows the process used to clone Dolly.

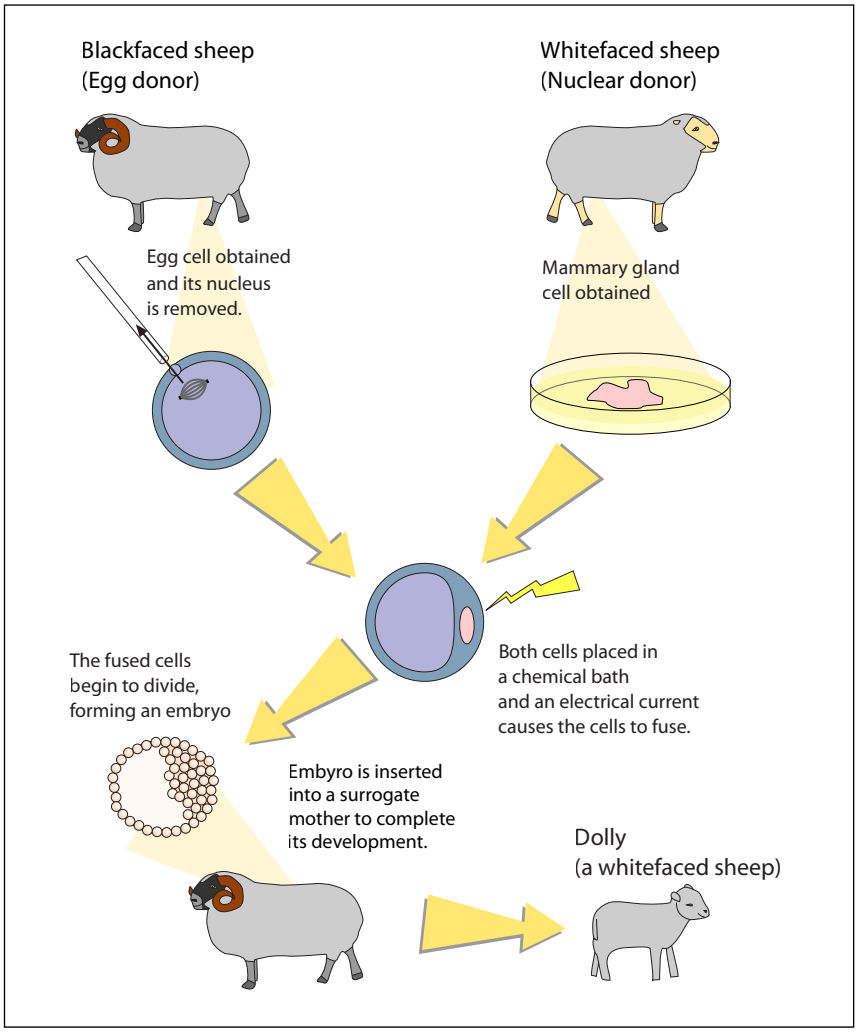

Figure 8.4: Diagram of the cloning process that created Dolly the sheep

Source: Wikipedia

Dolly was born an exact genetic copy (clone) of the whiteface sheep that provided the nucleus in the mammary gland cell. The cloning process involved combining the nucleus from a somatic cell with an egg cell from which the nucleus had been removed (enucleated). An electric shock was given to the combined cells to cause them to fuse and start developing as an embryo. The embryo was then inserted into a surrogate mother who gave birth to Dolly. The birth of Dolly caused a sensation because it opened the door to cloning of humans, since the process used to clone a human would be very similar to the one used to clone sheep.

The Cloning Debate

Cloning has many applications in the fields of agriculture, medicine, and forestry, but the prospect of cloning humans is an especially hot topic of debate. The idea of cloning humans has been discussed for many years. Cloning superstar athletes, scientists, or celebrities seems like a good idea to some people. But others think cloning people is wrong and goes against the course of nature; they believe that we should celebrate diversity, and that evolution of characteristics should be dictated by nature, not humans.

As you can see, there is a strong ethical component to biotechnology. The study of ethical and moral issues in the fields of medical treatment and research is known as bioethics.

Agree/Disagree

All human genetic technologies are potentially controversial. There are ethical, medical, social, legal, and political factors to consider for all of them. For example, gene therapy is one that has created a lot of controversy. Is it fair to insert athletic genes to enhance performance? Will this lead to "designer genes" for humans? One way to summarize the arguments for and against any particular biotechnology is by using a point-form Agree/Disagree list like the following one (for gene insertion):

Agree

- Gene therapy has the potential to save patients from life-threatening diseases.
- It could prevent a child from developing a crippling genetic disease.
- It could save the health care system a lot of money by fixing problems without using expensive drugs and surgery.

Disagree

- The insertion of new genes is unnatural and immoral.
- There is a risk that the new gene will have serious side effects.

Support Questions

30. The following statement concerns an issue that society may have to deal with, as gene therapy and genetic screening become more commonplace. Read the statement, and make a point-form Agree/Disagree list to consider both sides of the issue.

"Prospective parents who have a family history of a genetic condition that can be identified in prenatal testing should be required to undergo genetic screening."

Suggested answer

Applications of Biotechnology in Human Biology

Humans have benefited from various aspects of biotechnology for more than just food production. Couples who have difficulty conceiving have benefited from the use of biotechnology to help them conceive. You will examine some of those techniques in the next section.

Human Reproductive Technology

There are many reasons a couple may have trouble conceiving. A man may not produce enough sperm, or a woman's oviducts may be blocked. There may be a hormone imbalance that prevents the follicle from developing properly. Some of the options a couple may explore to help them conceive, employing various techniques in biotechnology, are described below.

Fertility Drugs

Ovulation disorders account for about 25% of female infertility cases. The first line of treatment for most women with ovulation problems is medication. Fertility drugs can help a woman ovulate 80% of the time. Clomid (clomiphene citrate), a well-known fertility drug, is usually the first drug used in treatment. Nearly half the women using Clomid will get pregnant within six months of use.

Gonadotrophins

Gonadotrophins are hormone replacement medications that are typically used when Clomid doesn't work, or if the pituitary gland cannot create LH (luteinizing hormone) and FSH (follicle-stimulating hormone) on its own.

Cytoplasmic Transfer

In cytoplasmic transfer, the cytoplasm from an egg from a younger woman is placed into the egg of an older woman. The transfer is thought to reduce the probability of genetic defects following fertilization. This does not change the genetics of the child; he or she will still be the genetic offspring of the older woman.

Intrauterine Insemination

Intrauterine insemination (IUI), also known as artificial insemination, is a procedure that involves placing specially washed sperm directly into the uterus. This treatment may be used in some cases of male infertility, if there's a problem with the woman's cervical mucus, or in cases of unexplained infertility. IUI may also be used for donor sperm.

Gametic Intrafallopian Transfer

In this technique, which is a type of IUI, both sperm and egg are placed in the woman's oviduct. This process is thought to increase the odds of successful fertilization occurring. The success rate of IUI is not very high but the advantage of IUI is the cost, which is much less expensive than IVF (see below).

In Vitro Fertilization

In vitro fertilization (IVF) is a process where fertilization takes place outside the body. To begin, the woman takes hormones that will stimulate ovulation. A doctor uses a special instrument called a laparoscope to remove the mature eggs from the woman's oviducts. These eggs are placed in a Petri dish with sperm and some special chemicals. After a period of time, fertilization occurs, and the doctor implants a few embryos back into the uterus. If at least one embryo implants, a normal pregnancy begins.

Egg Freezing and Egg Donation

In egg freezing, multiple eggs are retrieved after fertility drugs are given to a woman, as in IVF, but are frozen for later use. Some women may also choose to donate their eggs.

Embryo Transfer

A woman who has a defective cervix or uterus may have another woman (a surrogate) carry her child through pregnancy and give birth. In this case, the sperm and the egg both come from the biological parents, and fertilization occurs in vitro as in IVF. The embryo is then implanted into the surrogate mother.

Support Questions

31. A woman who had ovarian cancer had to have her ovaries removed. Are there any reproductive technologies that could be used for her to have her own biological child?

Suggested answer

Biotechnology Treatments for Human Disease

Biotechnology can also be used to help diagnose or treat diseases. For example, gene therapy using somatic (body) cells can help a patient with an inherited disease. The insertion of new genes could replace a lost function or repair an existing one. Although this could potentially cure the disease for the affected individual, they could still pass on the defective gene to their offspring unless their gametes (sperm and egg) are also altered.

Cystic Fibrosis

Cystic fibrosis, or CF, is an autosomal recessive inherited disease that affects the secretory glands, including the glands that make mucus and sweat. CF is caused by a mutation in the gene for the protein called the "cystic fibrosis transmembrane conductance regulator" (CFTR). This gene regulates sweat, saliva, and digestive juice production. CF mostly affects the lungs, pancreas, liver, intestines, sinuses, and sex organs.

The symptoms and severity of CF vary from person to person. Some people who have CF have serious lung and digestive problems; other people have milder symptoms that don't appear until adolescence or adulthood. Respiratory failure is the most common cause of death in people who have CF, often because bacterial infections can occur in the thick buildup of mucus in the lungs, leading to inflammation.

Cystic fibrosis is the most common fatal genetic disease affecting Canadians. Approximately 1 in 30 000 Canadians have CF, and it is most common in people of European descent. Currently, there is no way to prevent the disease, but genetic testing can be used to diagnose individuals before birth.

As treatments for CF continue to improve, so does life expectancy for those who have the disease. Today, some people who have CF are living into their forties, fifties, or older. The first major breakthrough for research related to CF came in 1990, when Dr. Lap-Chee Tsui of The Hospital for Sick Children in Toronto discovered the gene responsible for cystic fibrosis. Gene therapy is being explored as a treatment for cystic fibrosis. Scientists are trying to successfully insert a healthy gene for the CFTR protein. Although they have not yet found a treatment that works, research is ongoing. In Canada, the Canadian Cystic Fibrosis Foundation provides information on new research as well as links for people to find support groups to help them and their families cope with the disease.

Support Questions

32. Research Tay-Sachs disease. Write a description of this disease using the following headings:

a) Cause

b) Symptoms

c) Rate of occurrence

d) Prevention

e) Treatment

f) Support groups

Suggested answer

Key Questions

Now work on your Key Questions in the online submission tool. You may continue to work at this task over several sessions, but be sure to save your work each time. When you have answered all the unit's Key Questions, submit your work to the ILC.

(18 marks)

23. The following statement concerns an issue that society may have to deal with as gene therapy and genetic screening become more commonplace. Read the statement, and make a point-form Agree/Disagree list that includes at least two points to consider on each side of the issue. **(4 marks)**

"Private biotech companies that have invested millions of dollars in the Human Genome Project have a right to obtain patents for specific gene sequences. Other private companies or research facilities should have to ask permission, or even pay, to use this information in their studies."

24. A woman has a defective cervix that prevents her from undergoing natural childbirth. What reproductive technologies would you suggest she consider?
(2 marks)

25. Research Huntington's disease. Write a description of this disease using the following headings:

a) Cause

b) Symptoms

c) Rate of occurrence

d) Prevention

e) Treatment

f) Support groups

(12 marks)

This is the last lesson in Unit 2. When you have completed all the Key Questions, submit your work to the ILC. A teacher will mark it and you will receive your results online.