How Chemistry Helps Make Blood Transfusion Safer

Read the following article and answer the questions below. You should submit your answers as a Word document to the Synergy drop box by the end of class.

1. Why can’t human blood simply be transferred from one person to any other person?
2. What are the advantages of plastic bags for collecting and storing blood (compared with glass bottles that used to be used)?
3. What is the difference in storage life for blood that is at room temperature versus refrigerated blood versus frozen blood?
4. How are viruses detected that may be present in donated blood?
5. What determines blood types A, B, AB and O?
6. What is the difference between the function of red blood cells and platelets?
7. How might nitric oxide gas be used to monitor the age and quality (condition) of donated blood?
How Chemistry Helps Make Blood Transfusion Safer

By Natasha Bruce

Helen was driving home when a car hit hers from the back. Her head hit the wheel so hard that she lost consciousness and started bleeding. A few minutes later, an ambulance rushed her to the emergency room of the closest hospital. The doctors quickly treated her wounds to stop the bleeding and then decided to do a blood transfusion. She had lost too much blood and could die within the next half-hour.

A nurse checked Helen’s purse for information about her blood type. She found a card indicating that Helen’s blood was of type A. She gave the card to another nurse, who went to a cold room and came back a few minutes later with a bag of blood. Then both nurses slowly inserted a tube called a cannula in her arm, which drew blood from the bag into her body. Nearly four hours later, Helen became conscious again and started regaining her strength.

Helen may have died if not for the blood transfusion, a practice that routinely saves the lives of not only victims of accidents but also surgery patients and people affected with certain blood diseases—such as anemia and hemophilia—who have lower-than-normal blood levels.

Although the idea of transferring blood from one person to another may seem simple, putting it into practice is not. The human body tends to reject blood from other individuals, and even when the blood is accepted, the presence of a virus in the donated blood can be fatal to its recipient.

Thanks in large part to the work of chemists and physicians over the past two centuries, blood transfusion is now relatively safe and widely available. Various techniques are now used to store blood, screen it against deadly diseases, make sure it is compatible between a donor and a recipient, and sometimes process it to make it suitable for specific patients.

Donating blood

People can donate blood voluntarily by going to a blood-collecting center, which is usually set up by the American Red Cross or another blood-collecting organization at a high school, shopping center, church, or various other locations.

Before donating blood, people are screened to make sure that they are not infected with various diseases, such as AIDS and mad cow disease. For those who are allowed to donate their blood, around 450 milliliters—about one U.S. pint—of it is drawn through a needle. The blood is then stored in a bag containing acid citrate dextrose, a mixture of citric acid, sodium citrate, and dextrose, which prevents blood clotting and preserves blood for up to 42 days.

People can also donate some components of their blood while keeping others. First, whole blood is drawn from the donor, then the blood's components are separated, its desired components are removed, and the remaining components are returned to the donor. One of the benefits of this process, called apheresis, is that more of the desired components can be donated, and the donor can donate more frequently than if whole blood had been removed. (In the United States, whole blood donors must wait at least 56 days between donations.)

Preserving blood

Chemists and chemical engineers have developed plastics to protect and store blood. Among the most common chemicals used to store blood is polyvinyl chloride (PVC), a plastic widely used to make disposable syringes, surgical gloves, and catheters—tubes inserted into the body to drain or inject fluid or keep a passage open.

PVC (\((CH_2\cdotCHCl)\)) is made of a long chain of small molecules called vinyl chloride monomers (\(CH_2\cdotCHCl\)). This material is chemically stable, inert, and extremely versatile. It is also relatively simple to assemble into products that do not crack or leak. Because PVC is transparent, flexible, easy to process, and easy to sterilize, blood can be safely packaged in bags that extend the shelf-life of blood products. Also, PVC is disposable, which dramatically reduces the spread of infectious diseases from contaminated blood.

Platelets can only survive at room temperature for no more than five days because they can be attacked and destroyed by blood cells called macrophages, within that time period.
Red blood cells, which transport oxygen and carbon dioxide throughout the body, can last for a maximum of 42 days under refrigeration and up to 10 years if frozen with solutions designed by chemists to preserve blood and prevent it from clotting.

**Keeping viruses away**

Although donors have been screened for infectious diseases, donated blood may still be contaminated. So it is screened again for microorganisms that cause AIDS, blood cancer, hepatitis, syphilis (a sexually transmitted disease), and West Nile virus (a virus that causes a brain inflammation called encephalitis).

One way to screen against viruses is by measuring the presence of proteins called antibodies, which usually fight viruses. Because different antibodies destroy separate viruses, scientists look for antibodies that are specific to each virus. For example, a person infected with HIV—the virus that causes AIDS—produces antibodies that fight HIV. So detecting these antibodies shows that this person is infected with the HIV virus. But it can take several weeks for antibodies to build up, and recently infected persons may not show that they are infected, although they could still transmit the virus. So another test has been developed to detect proteins produced by bacteria and viruses during infection. These proteins are produced not long after the infection starts, so they can reveal that a person is infected early on. In the case of HIV, a commercially available test measures the presence of an antigen called P24.

**Different types of blood**

Physicians also need to check that a donor and a recipient are compatible, meaning that proteins on their red blood cells—called A and B antigens—are the same. The red blood cells of some people have only A antigens on their surface, while the red blood cells of other people have only B antigens. Their blood is either of type A or type B. Other people have neither A nor B antigen on their blood cells, while others have both, making their blood of type O and AB, respectively (see Table 1).

Blood also consists of other proteins called antibodies that attach to antigens. The two most important antibodies, called anti-A and anti-B antibodies, bind to the A and B antigens, respectively. People have only anti-bodies that attach to the antigens they don’t have. For example, people with type A blood (with A antigens) have only anti-B antibodies and those with type B blood (with B antigens) have anti-A antibodies.

The reason is that antibodies are released by the immune system, whose main role is to protect the body from foreign molecules. So if a person with type A blood receives type B blood, the anti-B antibodies present in his/her blood will bind to the B antigens of the donated red blood cells, causing the donated blood to clot and possibly leading to the death of the recipient. Instead, if this person receives type A blood, the B antibodies it contains will be harmless.

People can receive more than one blood type, as long as the donated blood does not have a foreign antigen. For example, a type A recipient may receive not only type A blood, but also type O; type B may receive types B or O; type AB may receive any type; and type O may receive only type O.

**Advantages of blood transfusion**

Blood contains a pale yellow liquid portion called plasma. Suspended within the plasma are two types of cells called red and white blood cells and cell fragments called platelets. The red blood cells carry oxygen to the body tissues and remove carbon dioxide from it, while the white blood cells mostly fight off infection. The platelets are involved in clotting, which stops or helps control bleeding.

Scientists have shown how these blood components help patients heal after a blood transfusion. In particular, red blood cells mostly help in trauma, surgery, and anemia by delivering oxygen to all parts of the body and regulating blood pressure. Platelets collect into clusters that plug small holes in blood vessels, and plasma carries chemicals and proteins that are either needed or must be removed in massive surgeries and severe burns.

**Future prospects: Making blood transfusion safer**

Despite all of the safety measures surrounding blood transfusion, many patients still develop heart disease that can be fatal. Scientists are now trying to understand how this happens. One of them, Jonathan Stammer, a professor of medicine at Duke University Medical Center, Durham, NC, and his team have recently found that nitric oxide, a gas present in donated blood, drops steadily over time.

The scientists had previously shown that the gas helps red blood cells to carry oxygen to tissues by triggering chemical reactions.
Hemoglobin: The Blood’s Oxygen Carrier

To understand some of the difficulties faced by scientists trying to create synthetic blood, below is a description of how actual blood carries oxygen and carbon dioxide throughout the body. Synthetic blood needs to both replicate these mechanisms and be tolerated by the body with as few side effects as possible.

Red blood cells can carry up to one liter of oxygen per minute throughout the body, thanks to a molecule called hemoglobin that is present inside blood cells. One red blood cell contains about 280 million hemoglobin molecules, each made of four subunits. Each subunit contains a central molecule called a heme with an iron atom in the middle that binds to oxygen.

When a person breathes in, the oxygen that is brought inside the lungs attaches to hemoglobin (abbreviated Hb) as follows:

\[
\text{Hb} + \text{O}_2 \rightarrow \text{HbO}_2
\]

When the red blood cells reach the tissues, about 45% of the \(\text{HbO}_2\) decomposes back to Hb and \(\text{O}_2\), releasing the oxygen to the tissues:

\[
\text{HbO}_2 \rightarrow \text{Hb} + \text{O}_2
\]

This oxygen is then picked up by other iron-containing proteins called myoglobin that are present in tissue cells. (Note that these myoglobin molecules are similar to the subunits that make up hemoglobin, except that they are not attached—as in hemoglobin—but they move freely.)

About 90% of the oxygen molecules attach to myoglobin (abbreviated Mb) as follows:

\[
\text{Mb} + \text{O}_2 \rightarrow \text{MbO}_2
\]

When tissues have used the oxygen, they produce carbon dioxide that is carried back to the lungs by hemoglobin. Not only does the carbon dioxide bind to hemoglobin, but it also dissolves in surrounding water, releasing hydrogen ions (\(\text{H}^+\)) as follows:

\[
\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{HCO}_3^- + \text{H}^+
\]

Hemoglobin molecules then bind to hydrogen ions, which prevents the formation of carbonic acid and allows more carbon dioxide to dissolve in the bloodstream, which helps eliminate them from the tissues.

\[
\text{Hb} + \text{CO}_2 \rightarrow \text{HbCO}_2
\]

This way, the carbon dioxide can leave the lungs when a person breathes out.

Knowing how hemoglobin and myoglobin carry oxygen and carbon dioxide throughout the body has been helping scientists and engineers to devise artificial blood that uses similar mechanisms. The two main types of artificial blood developed so far—called hemoglobin-based oxygen carriers and perfluorocarbons—still don’t work as successfully as actual blood, but they have great potential: They have a longer shelf-life than blood and they don’t need to be refrigerated. So even if artificial blood does not end up replacing blood, its properties may lead to promising medical applications.

Inside the cells, which expands blood vessels and allows blood to flow more freely. Stamler hypothesizes that without nitric oxide, red blood cells cannot easily flow through blood vessels; instead, they pile up and block blood flow rather than increasing it. This new discovery, if confirmed, would require monitoring nitric oxide levels for safer blood transfusions.

Other scientists are working on an alternative to blood called synthetic blood. Made entirely in the laboratory, this new substance would have all the qualities of blood—carrying oxygen and carbon dioxide, warding off infectious disease, and being able to clot to seal wounds—while being free of disease (see sidebar “Hemoglobin: The Blood’s Oxygen Carrier” for more information on how blood cells carry oxygen and carbon dioxide). Also, this ideal blood substitute would require neither refrigeration, nor the safety measures mentioned before and could be produced in unlimited amounts (see ChemMatters, April 1998, p. 13).

Synthetic blood has not lived up to its promise yet because it cannot replicate all the chemical and physical properties of blood and cannot stay in the body long enough. But research in this field is still active and may lead to early versions of synthetic blood in the near future.

Despite these limitations, blood transfusion is now saving the lives of millions of people. With the continuing advances made by researchers around the world, it will probably save even more lives in the future. Next time you donate blood, you may want to reflect on the progress made so far and the number of lives that your blood will probably save.

Natasha Bruce is a senior Web editor in the Education Division of the American Chemical Society. This is her first article in ChemMatters. (More information on the components of the blood can be found in ChemMatters, Feb. 1984, p. 6.)