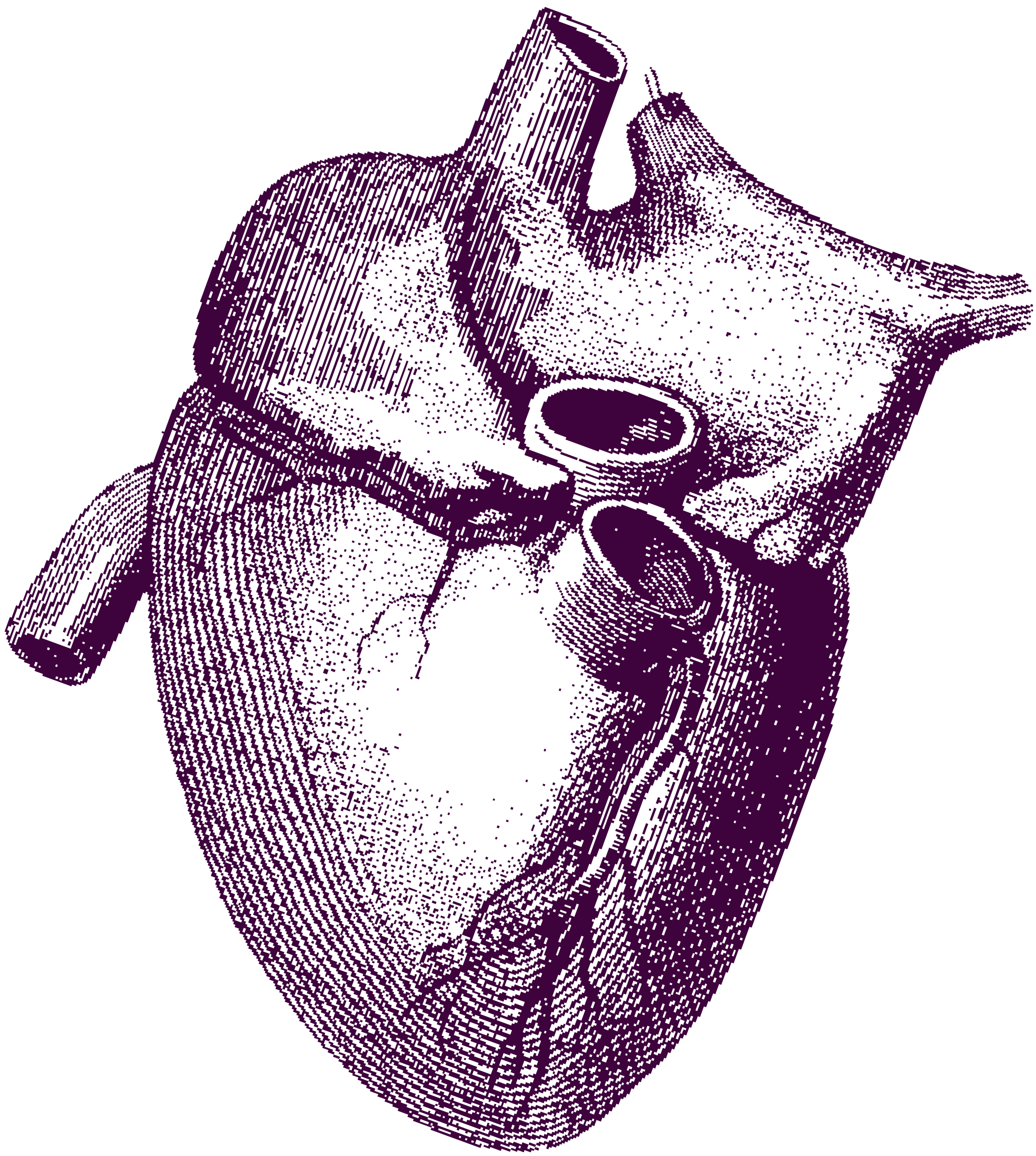


Perfusion: A HISTORICAL PERSPECTIVE

William J Horgan, CCP, CCA

In medieval cultures, the heart was viewed as the center of wisdom, and somehow earlier societies understood its importance. Through the centuries, medical scientists struggled with misconceptions of the heart's function, from early beliefs that blood contained "vital spirits" to the myth that the heart was the repository of man's soul. In the late 16th century, Andrea Cesalpino first used the term circulation, considered a closed circulatory system, and postulated that blood did not move freely but through a network of tiny vessels that connected the venous and arterial systems. A later contemporary, William Harvey, an English physician in the early 17th century, was the first scientist to understand that blood flowed within a contained system and is credited with the modern understanding of blood circulation[4] (Table 1).

The effects of technology

More than 400 years later, the increase in heart disease has become pandemic, and Harvey's theories formed the basis of modern cardiology that developed in response to this challenge. Few fatalities from heart disease occurred prior to the beginning of the 19th century—and now, it is the number one killer in the United States.[3]

The rise in fatalities can be attributed to the unanticipated effects of technology. The desire to make life easier also meant less physical stress. Instead of walking, people drove; instead of scrubbing laundry, they used washing machines; instead of climbing stairs, people rode escalators; instead of beating carpets, they switched on vacuum cleaners. In essence, physical activity decreased.

At the same time, diets changed. Technology was used to process cheese, homogenize milk, fry potatoes and produce ice cream. Foods high in fat became a standard part of the American diet. Together, the decrease in physical activity and a diet high in fat showed disturbing results—clogged blood vessels that led to more heart attacks and strokes.[3]

Again, technology came into play and culminated in a new innovation to counteract these consequences—the heart pump oxygenator that permitted the heart-lung bypass procedure. Essentially, the heart is stopped and repaired while the blood continues to flow with the aid of this apparatus. Concurrently, the lungs may be deflated to enhance access to the heart and to major vessels.

This device, often called the heart lung machine, is used during surgery to remove unoxygenated blood from the venous system, oxygenate and filter the blood, and return it to the arterial system (Figure 1). Simply, a plastic tube (cannula) is inserted into the right atrium and shunted through an oxygenator(Figure 2). The oxygenator includes a reservoir and heat exchanger, which may increase (or decrease) the temperature of the blood. Once the blood has received oxygen, a roller pump moves it from the reservoir back to the arterial system. The process is termed "perfusion;" therefore, the clinical professionals who operate the pump oxygenator are "perfusionists."

Table 1: Perfusion historical timeline[2]

1813
LA GALLOIS
- Concept of artificial circulation

1828
KAY
- Introduced re-perfusion

1868
LUDWIG AND SCHMIDT
- Performed arterial infusion

1882
VON SCHRODER
- Invented bubble oxygenation

1885
VON FREY AND GRUBER
- Devised pump and film oxygenator

1895
JACOBJ
- Researched cross circulation

1902-1935
ALEXIS CARREL
- Devised vascular suture techniques
- Performed aortocoronary grafts
- Proposed heart transplantation
- Designed first American pump oxygenator

1937
JOHN GIBBON
- Developed concept of pump oxygenator
- Increase support for heart surgery

1945-1955
WILLEM J KOLFF
- Invented first clinical renal dialysis
- Designed clinical membrane oxygenator
- Proposed artificial heart

1946-1952
CHARLES HUFNAGEL
- Designed first aortic valve prosthesis

1952
ANDREASEN AND WATSON
- Suggested Azygos Flow principle

1957
CW LILLEHEI
- Initiated clinical use of Azygos Flow for surgery

1958-1995
RICHARD SARNS
- Redesigned disk oxygenator and blood pump
- Standardized parts for heart-lung machines

Related history

Although perfusion officially began in 1953, scientists in the 19th century made substantial contributions to the development of this clinical service. For example, La Gallois proposed the concept of artificial circulation in 1813, and Kay hypothesized the practice of re-perfusion in 1828. Forty years later, Ludwig and Schmidt devised external arterial infusion. Bubble oxygenation was developed by von Schroder in 1882, and the team of von Frey and Gruber created the first pump and film oxygenator in 1885.[2]

Cross circulation research was spearheaded by Jacobj in 1895, and the famed Alexis Carrel spent 33 years (1902-1935) developing vascular suturing techniques, aortocoronary grafts, heart transplantation, and the first American pump oxygenator. In 1937, John Gibbon was the first to see the pump oxygenator as a support in heart surgery, and performed his first successful bypass case in 1951.[2]

Later developments included the first clinical renal dialysis, artificial heart, and the aortic valve prosthesis to name just a few. Now this 47-year-old technique predates most of the certified clinical perfusionists practicing today.

Surgical preparation

In the early 1960s, hospitals did not have critical care units, so patients were admitted to the internal medicine service. After a surgical diagnosis was made, the patient was moved to the thoracic and cardiovascular service. Following the procedure, the patient was returned to the same area. (Recovery rooms and intensive care areas were yet to be introduced.)

In addition, there was not enough equipment to do more than two cases a week. Operations were performed on Tuesdays and Thursdays. Equipment was "put up" (prepared, packaged, and sterilized) on Mondays, Wednesdays and Fridays. Hours were required to cut tubing to make packs, assemble the oxygenator and cardiotomy reservoirs, and prepare everything else needed. An emergency procedure was almost impossible because there was often no equipment ready. System sterilization required eight

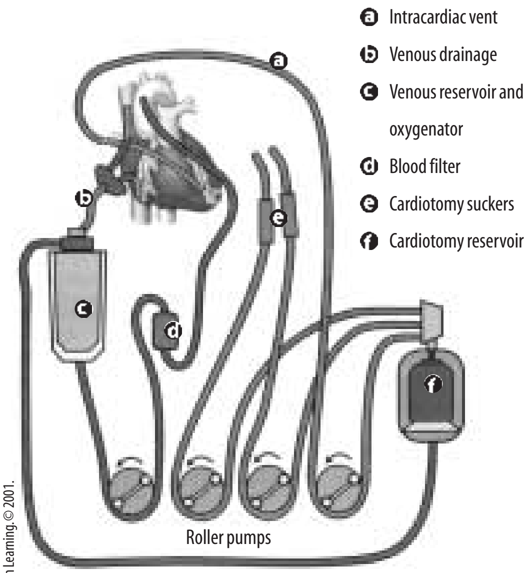


FIGURE 1 The reservoir and heat exchanger oxygenates the blood and maintains its temperature.

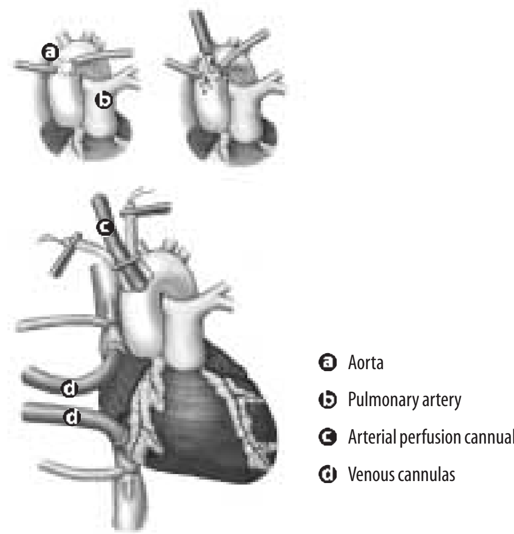


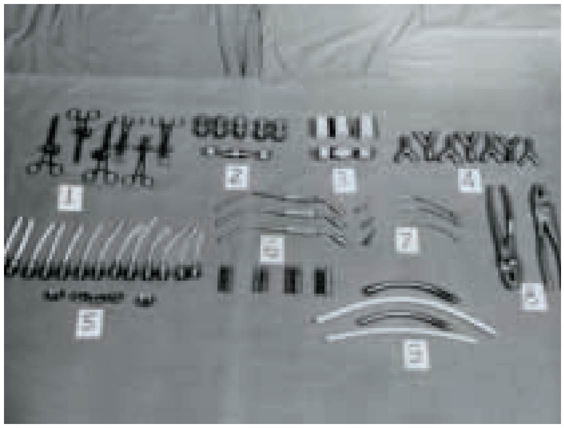
FIGURE 2 shows arterial and venous cannulation. Purse-string sutures are placed in the ascending aorta and then tightened over rubber catheters to secure the aortic cannula.

Figures 1 and 2. Illustrations from Surgical Technology for the Surgical Technologists: A Positive Care Approach. Delmar Thomson Learning. © 2001.

FIGURE 3 Tubing was the only disposable item in early pump supply baskets.

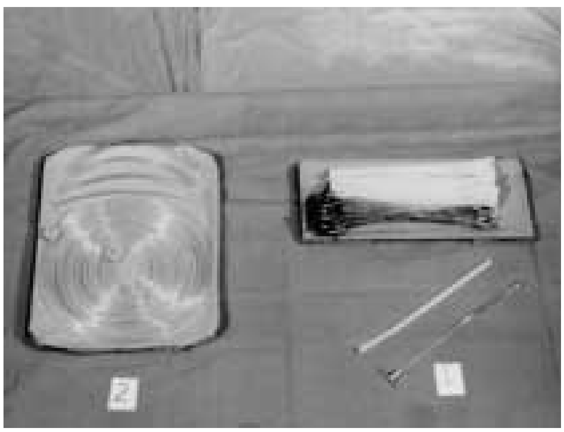
Figures 3-12. Photography courtesy of William J Horgan.

FIGURE 4



Many of the parts on the cannula and connector tray had to be made by a machinist.

FIGURE 5



Tubing for venous cannula and suction lines had to be bought in bulk and cut to size.

FIGURE 6

The first Naval pump system was used from 1959 to 1963.

hours, and it couldn't be used for another three days due to the lengthy aeration process.[1]

A typical pump supply basket (Figure 3) included the tubing pack, pumping chamber, dampening chamber, venous reservoir and cardiotomy reservoir. Tubing was the only disposable item in the basket. All other supplies were reused case after case. Another basket held the oxygenator. Both baskets were gas sterilized at the same time in the gas chamber.

During these early years, one of the most important members of the cardiac team was the machinist who made the pump and most of the other equipment required for the cases. "Pump techs" would discuss ideas with him and describe what they were trying to do. These talented machinists would then apply their talents and eventually return with equipment that was better than ever anticipated.

Machinists made the connectors, including the plastic ones (Figure 4, number 3) and metal obturators (Figure 5, number 1). The femoral arterial cannulas (Figure 4, number 5) were made up by the scrub nurse and replaced only after they were damaged. Every size of femoral arterial cannula and venous cannula was on the field for every case. No single pack system existed at the time, so tubing was purchased in bulk quantities and cut to size. Venous cannula were only available unsterilized and in bulk quantities.[1]

Progression of the heart lung machine

The first pump system built by the Navy was used clinically from 1959 to 1963. There were no cardiotomy reservoir or roller pumps. The main pump was a pulsatile pump with two one-way valves and is located at the bottom near the front (Figure 6.)

Another pump used from 1963 through 1967 utilized the pulsatile pumping chamber as the first pump. This updated model also employed two roller pumps for cardiotomy suction. On either side of the IV pole were two glass chambers behind the oxygenator. The roller pump (Figure 7) was not only used for cardiotomy suction but also to turn the disc oxygenator. This was accomplished through a cable that originated in the center of the roller pump and terminated at the end plate of the oxygenator. This system had two major drawbacks: the rotating speed of the oxygenator determined the rate of suction, and the disc oxygenator required eight pints of blood for priming.[1]

The glass-chamber venous reservoir (front right of pump) featured a hand crank that was used to set the venous return level. A small reservoir (front left of pump) was used as a dampening reservoir to remove the pulse wave before the blood entered the oxygenator.

The roller pump seen in Figure 8 was used for cardiotomy suction and served as the main suction pump because its speed could be increased in case of excessive bleeding. A better view of the cardiotomy reservoirs and a second roller pump used for cardiotomy suction are illustrated in Figure 9. Interestingly, the fabric in the glass chambers used for cardiotomy reservoirs was a "Tuffy sponge" purchased at local grocery stores. The sponge was opened up, soaked in a silicon solution, dried, and placed in cardiotomy reservoirs. These sponges served as filters with a defoaming agent.

The next heart-pump innovation was a heater-cooler unit, one of which featured two chambers (Figure 10). One chamber included a thermal element to heat the water bath; the other contained ice water for cooling. Some later models used tap water, but the water remained too warm in the summer, and a cooling system was eventually added to the cold water supply.[1]

The final component was the disc oxygenator (Figure 11). Blood entered the oxygenator on the venous side. As the discs rotated, they pulled up a film of blood and exposed the blood to a mixture of 98.5% oxygen and 1.5% carbon dioxide, which was blown across the top of the oxygenator. By the time the blood reached the arterial outlet, the blood was oxygenated.

The heat exchanger, located in the blood path at the bottom of the oxygenator, was subsequently added (Figure 12). One of the unanticipated problems that occurred from the heat and rotation of the discs was the production of foam.

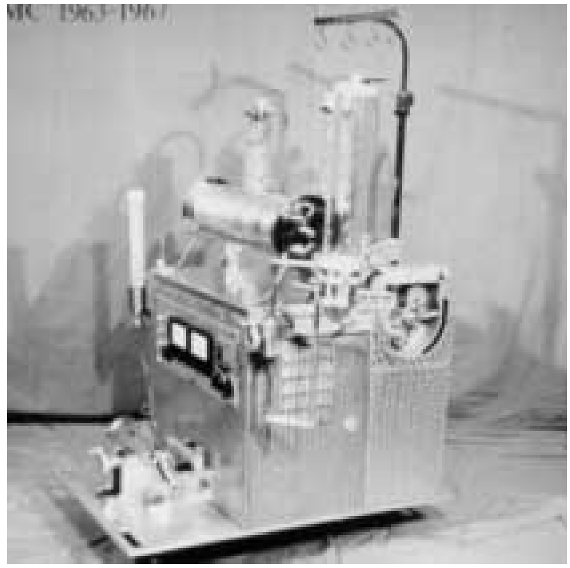


FIGURE 7

This heart lung machine (1963-1967) required eight units of blood to prime the pump.

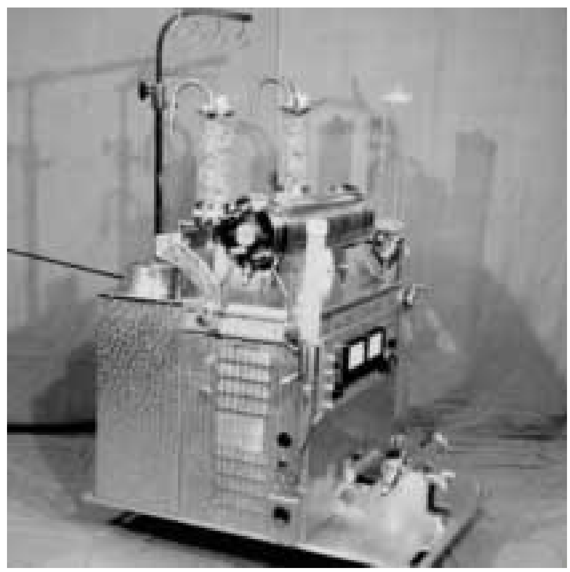


FIGURE 8

The roller pump on this machine was used as the main suction pump.

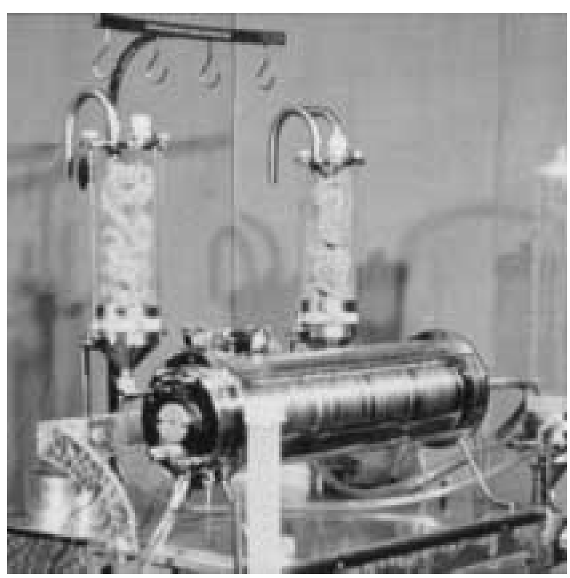


FIGURE 9

Cardiotomy reservoirs were filled with a treated sponge purchased at local grocery stores.

In order to break up the foam, the inside of the oxygenator was sprayed with a silicon spray.[1]

Conclusion

Even today, technology and its influence are playing a crucial role in the history of profusion. Bloodless surgery and beating heart procedures are on the horizon; however, the need for advanced perfusion equipment and perfusionists will remain. Patients will continue to require open-heart surgery to treat congenital defects, undergo valve replacement, and repair traumatic injuries.

About the author

William J Horgan began his career in perfusion 35 years ago at the United States Naval Hospital in Bethesda, Maryland, and was chief perfusionist at the naval hospital and later at Porter Memorial Hospital in Denver, Colorado. In 1974, he established Rocky Mountain Perfusionists and is currently serving as president of the organization. He is a member of the American Society of Extracorporeal Technology, charter member of the American Academy of Cardiovascular Perfusion, and has served on both the executive board and board of directors of CAAHEP. He will share this retrospective at the AST 1st Cardiovascular Forum in Denver, Colorado, February 9-11, 2001.

References

1. Horgan WJ. "A look back." Presented at the Annual Seminar American Academy of Cardiovascular Perfusion, San Antonio, Texas, January 22-25, 1999. Published in: *Proceedings of the American Academy of Cardiovascular Perfusion.* Jan 22-25, 1999. Reprinted in: *Perfusion.* Vol 15. 2000: 91-96.
2. *The History of Perfusion, 1800-1970.* American Academy of Cardiovascular Perfusion. ***members.aol.com/amaccvpe/history/history.htm*** Accessed 12/27/2000
3. The Franklin Institute Online. ***sln.fi.edu/biosci/history/history.html*** Accessed 1/8/2001
4. Lyons AS, Petrucelli JR. *Medicine: An Illustrated History.* New York: Harry N Abrams Inc; 1987.

FIGURE 10

In the heater-cooler unit one chamber had a heating element and the other held ice water.

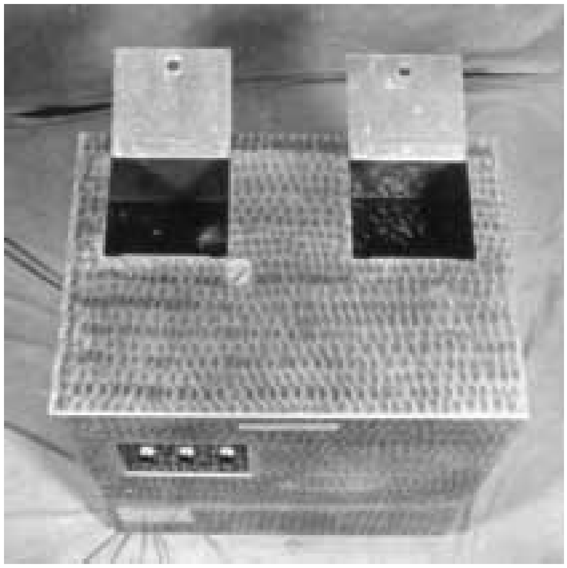


FIGURE 11

The disc oxygenator exposed the patient's blood to oxygen and carbon dioxide.

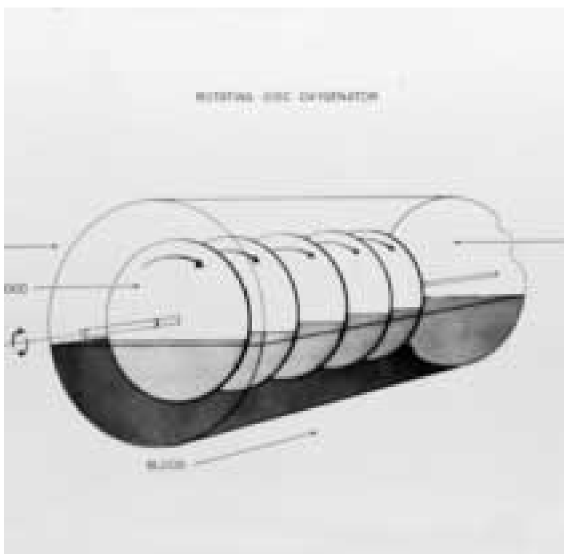


FIGURE 12

A heat exchanger was later added to the oxygenator to regulate body temperature.