REMEMBERING THE WAUD PRINCIPLE

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Introduction

Russell Amos Waud was born in 1893 and grew up in the Canadian province of Ontario. He was a tinkerer at heart, and was enamored with any kind of scientific gadget. In 1921 he achieved his medical degree from the University of Western Ontario. Following an internship at Victoria Hospital in London, Ontario, he opened a practice in family medicine. This was short-lived however, as the prospect of doing research consumed him. He undertook postgraduate studies in physiology, obtaining a Master's degree in 1925 and a Ph.D. in 1927. He then returned to Western and headed up the Departments of Physiology and Pharmacology until his retirement in 1958 (1).

Early Research

In 1902, the British physician Sir James Mackenzie devised the first polygraph to record arterial and venous pulse tracings (2). Seeking to improve upon Mackenzie's design, Waud added additional electronic and magnetic circuitry (see Figure 1). His efforts, published in 1924 (3), resulted in tracings much more discernible and greater in amplitude (see Figure 2).

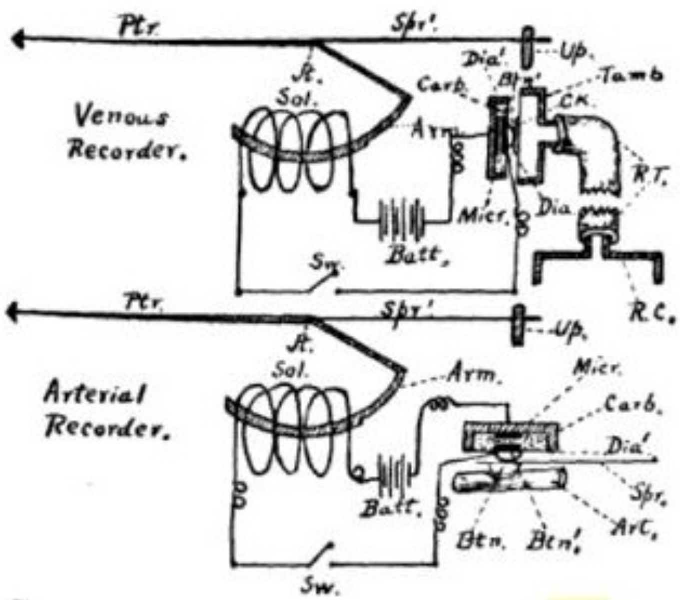

Figure 1. Schematic of Waud's polygraph for recording arterial and venous pulse tracings (circa 1924).

Waud also studied the effects of respiration on the venous pulse (4). In 1927, as part of his doctoral thesis, Waud theorized that the fall in blood pressure during shock was caused by a transient reduction in the blood's viscosity. His research, using rabbits, was lauded as historic and published in the *American Journal of Physiology* (5). As

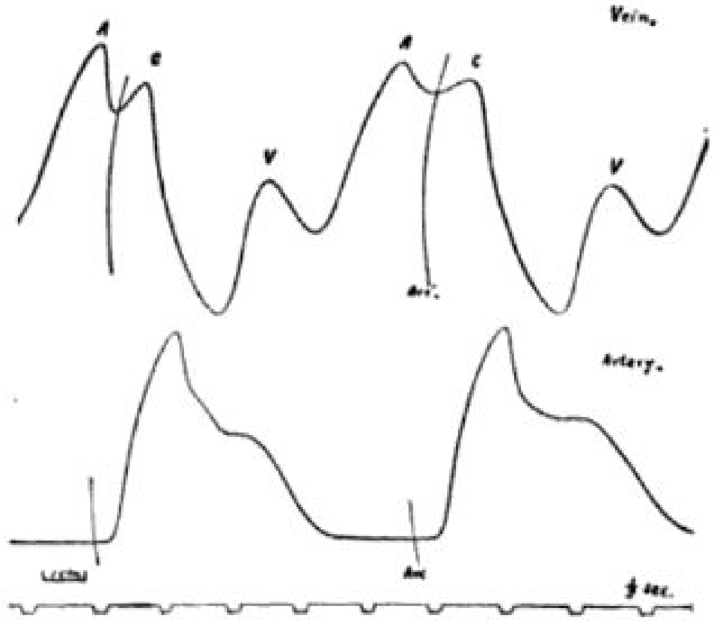

Figure 2. Venous (top) and arterial (bottom) tracings recorded from Waud's polygraph (circa 1924).

a professor, Waud constantly sought ways to better educate his students. In 1930, he constructed an amplifier for listening to heart sounds (see Figure 3). At the time, the carbon microphones used for auscultation hissed and popped. Waud's amplifier, considered revolutionary, used condensers to filter out unwanted white noise and distortion (6). Having never stopped refining his polygraph, Waud in 1936 replaced rubber parts with metal, and included the electrocardiogram as a simultaneous tracing – a major advancement (7).

Figure 3. Waud (far left in lab coat) instructs students about heart sounds using his amplifier (circa 1930).

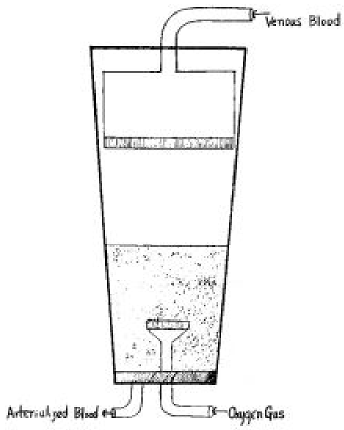

Figure 4. Schematic of Waud's foaming oxygenator (circa 1948).

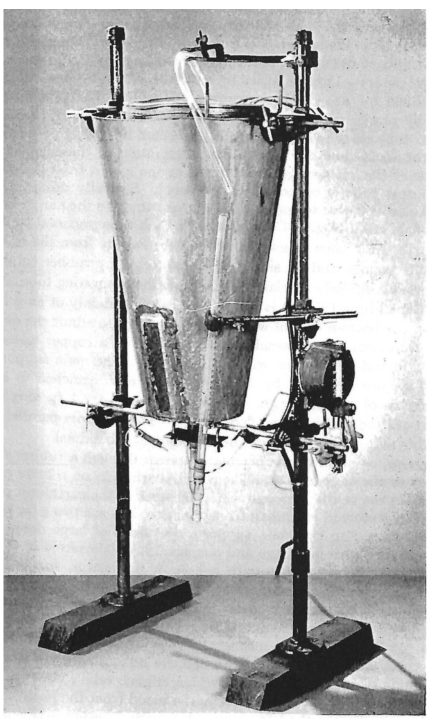

Figure 5 . Photo of Waud's foaming oxygenator. Venous blood enters the top of the glass vessel (housed inside the copper water bath) and oxygen enters the bottom in countercurrent fashion. The resulting foam layer provides a cushion for gas exchange to occur. The arterial blood outlet is seen exiting the bottom of the oxygenator (circa 1951).

Heart-Lung Machine

In 1948, Waud began work on a heart-lung machine to aid his study on the effects of drugs on the circulatory system. Unlike Gibbon, who at the time was still experimenting with the revolving cylinder oxygenator, Waud chose to build a foaming device for gas exchange (see Figure 4). The Russian experimenter Brukhonenko is generally credited with designing the first foam oxygenator in the 1930s. It's not likely that Waud knew of Brukhonenko's accomplishments for two reasons. First, the political climate of the time prevented Brukhonenko's research from being published in North American periodicals. Second, and perhaps more importantly, Waud never referenced any of Brukhonenko's articles or credited him in any way. Waud's oxygenator was an 8-liter glass percolator contained within a copper water bath of similar shape and size (see Figure 5). Venous blood entered the top of the percolator through a perforated showerhead-like manifold. This ensured a downward bloodstream with an evenly distributed pattern. Oxygen, in counter flow fashion, was blown upward from the bottom of the percolator. The resulting foam served as the gas exchange surface for the incoming venous blood. Once arterialized, blood exited the bottom of the percolator through a port adjacent to the oxygen inlet. Waud used two 50 mL glass syringes, a specially designed cam, and an electric motor as his right- and left-sided pumps. In 1951, Waud's heart-lung machine was featured in the *Calgary Herald Newspaper* (9). In 1952, Waud published a lengthy description of his device in the *Canadian Journal of Medical Sciences*, reporting that his apparatus had been used successfully in over 100 dog experiments (8).

The Waud Principle

Using Waud's device as a forerunner, numerous investigators built similar foam oxygenators, each with slightly higher gas transfer rates or enhanced safety features. One of Waud's close colleagues, Peter Salisbury, who himself built a foam oxygenator, coined the phrase *"the Waud principle"* in 1955 (10). Essentially, the Waud principle refers to a foaming device where the oxygen and venous blood flow countercurrent, thus producing a continuously-renewing layer of foam for gas exchange to occur. Salisbury credits Waud with the design, and specifically mentions him in at least three of his publications (10, 11, 12). Reference to the Waud principle is also made in a Master of Science thesis project in Canada in 1958 (13), and by a Japanese researcher studying extracorporeal circulation in 1962 (14).

Later Years

In 1954, Waud was selected as part of an esteemed group of physicians to help form the American Society of Artificial Internal Organs. Other members of this group included Charles Bailey, Leland Clark, Clarence Dennis, Forest Dodrill, John Gibbon, Jr., Willem Kolff, Walt Lillehei, and of course his old friend Peter Salisbury. Waud presented papers at the first two meetings – both focusing on the effects of drugs in the artificial heart and lung preparation (15, 16). In 1958, he retired, and spent his golden years gardening and sailing the nearby Great Lakes. He died peacefully at the age of 79 just a few miles from where he was born.

Though his name is relatively obscure, Russell Waud's medical achievements are significant and deserve to be remembered.

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