DOI: https://doi.org/10.3329/cardio.v14i1.55375

Review Article

Vascular Duplex Study: A Historical Perspective

Abul Hasan Muhammad Bashar

Department of Vascular Surgery, National Institute of Cardiovascular Diseases, Dhaka

Keywords: Medical history, Ultrasound, Echocardiography, Doppler.

Abstract

Ultrasound is a key investigating tool aiding diagnosis and treatment in the day-to-day medical practice nowadays. Like any other invention, ultrasound technology also has a long history strewn with successes and setbacks. From its modest beginning, it has come a long way to be applied not only in medical science but also in many other areas including navigation and warfare. Scientists-engineers, physicists, mathematicians, biomedical engineers and physicians worked relentlessly over centuries to bring about developments in the field of ultrasound technology as a whole. Medical ultrasound has a relatively recent history that has seen great dedication and commitment from researchers to achieve the degree of finesse we see today. The present article looks back on the historical aspects of ultrasound technology with a focus on medical ultrasound.

(Cardiovasc j 2021; 14(1): 55-60)

History of Ultrasound: The Early Milestones Ultrasound technology has been a major breakthrough in the history of mankind. It has been utilized not only in medical science but also in communication, engineering, navigation, mining and warfare. The history of ultrasound dates as far back as the 6th century BC when Greek mathematician Pythagoras described the mathematical properties of stringed instruments that emit sound. Ever since sound has been studied extensively by scientists for the benefit of mankind. Study of sound in the modern era began in 1790 when Lazzaro Spallazanni, an Italian priest and biologist discovered and documented the echolocation used by bats through high-frequency sound they emit and receive to detect objects in the dark.[1]

Nineteenth century saw some of the important milestones in the development of ultrasound technology. In 1816, Rene Laennec, a French physician invented stethoscope with a rolled ream of paper that amplified the sound of a patient's heart. Jean-Daniel Colladon, a Swiss physicist, used a Church bell under the water of Lake Geneva to determine the speed of sound in water. His experiment carried out in 1826 revealed that sound travels faster through water than air. In 1842, Christian Andreas Doppler, an Austrian mathematician and physicist published a treatise entitled 'Concerning the Colored Light of Stars'. In this article, he described what is now known as the 'Doppler Effect'. Doppler observed that the frequency of a sound wave depends on the speed of the source. This phenomenon is also called the 'Doppler Frequency Shift'. The discovery of Doppler effect was a significant breakthrough and it has been applied to astronomy, medicine, and meteorology.[1-4]

Christian Andreas Doppler (1803-1853)

Address of Correspondence: Dr. Abul Hasan Muhammad Bashar, Department of Vascular Surgery, National Institute of Cardiovascular Diseases, Dhaka, Bangladesh. email: ahmbashar@gmail.com

In 1876, Francis Galton created his 'Galton whistle' that was able to produce high frequency sound inaudible to human ear. A major breakthrough in ultrasound technology came in 1880 when physicist Pierre Curie and his brother Jacques Curie noted that electricity may be created in a crystal of quartz under mechanical vibration.[5] This phenomenon was termed the 'piezoelectric effect'. The Curie brothers also discovered the 'inverse piezoelectric effect', the ability of the liquid crystal to produce electricity under the vibrations produced by ultrasound wave. These discoveries were the scientific basis of the first transducer that generated a high-frequency sound and then received its echo.

The tragic sinking of Titanic in 1912 spurred scientific efforts to develop a system to visualize underwater structures. During the first world war, the French government commissioned **Paul Langevin**, a French physicist and co-workers to study the possible use of high-frequency sound waves to find German submarines. While their efforts ended in failure, the U.S. Navy was able to develop SONAR (SOund Navigation And Ranging) that utilized piezoelectric properties. Industrial use of ultrasound predates its use in medical science. In 1928 SY Sokolov, a Soviet physicist proposed the idea of using the technology to find flaws deep in metal structures paving the way to successful use of ultrasound in industries. In 1944, **Floyd Firestone**, an American acoustical physicist and innovator patented his Reflectoscope, the first system in which the same transducer generated ultrasound waves and also detected the reflected waves.

History of Medical Ultrasound

Attempts to use ultrasound in medical science began in 1947-1948 when **Karl Dussik**, an Austrian neurologist and psychiatrist and his brother **Friederick**, a physicist, introduced 'hyperphonography', a technique which used ultrasound to visualize the cerebral ventricles.[6,7] Although, their experiment was not much successful, the work of American professor **George Ludwig** in 1949 that was focused on the interactions between ultrasonic waves and animal tissues laid the foundations for the later successful use of ultrasound in medical practice.

Ian Donald, a Scottish physician is credited with the introduction of ultrasound in diagnostic purposes and in medicine. In 1956, he used the one-dimensional A-mode (amplitude mode) to measure the parietal diameter of the fetal head. In 1957, Thomas Graham Brown, a Scottish engineer, along with Donald invented the first Compound B-Mode contact scanner with an operating transducer frequency of 2.5 MHz. The commercial use of ultrasound devices started in 1963 when the B mode (brightness mode) devices were introduced, enabling the examiner to visualize the two-dimensional image. This was called the Diasonograph, the first ever obstetric ultrasound device.[8-10] In 1973, George Kossoff, and co-workers develop a new scan converter with gray-scale technologies which allowed for the identification of different tissue textures.

Sir Ian Donald (1910-1987)

Doppler application is an integral part of any modern ultrasound machines that are used today. Shigeo Satomura, a Japanese physicist and his team was the first to introduce medical application of the Doppler Effect.[11] In 1955, they implemented Doppler shift techniques in monitoring the pulsations of heart and peripheral blood vessels. However, it would take another couple of decades for the Doppler applications to be incorporated in the ultrasound machines to examine circulating blood and blood vessels.

Shigeo Satomura (1919-1960)

History of Vascular Ultrasound

The history of vascular ultrasound resonates with the names of Dr Eugene Strandness Jr, Donald W. Baker and Dr Robert Frazer Rushmer. Dr Strandness Jr. was an American professor of cardiovascular surgery who facilitated much of the early works in vascular ultrasound. It was his idea that Doppler ultrasound could be used to diagnose vascular diseases. To test this concept, he teamed up with a group of innovators and bioengineers in the sixties through seventies of the last century and their efforts culminated in the development of some of the early devices used for cardiovascular imaging. The journey began when Donald W. Baker, an electrical engineer who had served in US air force and studied radar signals to detect low-flying aircrafts came to work in the cardiovascular instrumentation development program of the University of Washington, Seattle in 1958. The program was being headed by Dr. Robert Rushmer, a pediatrician and physiologist who was keen on documenting cardiovascular functions in animals. Dr. Rushmer arranged necessary funds and recruited personnel for the program. The aim of the program was to design and build hardware and methodologies that would facilitate the study of cardiovascular dimensions, pressures and flow. Dean Franklin, an engineer, Dick Ellis, an expert in sonar techniques joined Donald Baker in this project under Dr Rushmer. The first outcome of their research was a multichannel transit-time flowmeter which measured the velocity of blood flow in a blood vessel by determining the time interval between two electric pulses along the vessel. This was an invasive device that needed to be attached to the vessel wall. The group published their work with the title of 'A pulsed ultrasonic flowmeter' in the IRE Transactions in Medical Electronics in 1959.[12] It was also included along with other early findings of the project in Dr Rushmer's book "Cardiovascular Dynamics" published in 1961.

In 1962 and 1963, Franklin published their initial discovery on the use of Doppler in the measurement of blood flow and velocity.[13-15] Franklin had left for NASA and Baker was now leading the technical team at University of

Robert Rushmer (1914-2001)

Donal Baker (1932)

Eugene Strandness (1928-2002)

Washington and continued his research with the instrument development project. The team refined the Continuous wave applications, made them transcutaneously applicable and applied to humans. They also introduced silicon transistor circuitory to replace the old vacuum tube designs.

By the year 1963, Baker and his team had developed spectral analysis from the continuous wave Doppler which he published in 1964 with the title 'a sonic transcutaneous flow-meter'. Meanwhile, on a separate project, Wayne Johnson worked with Rushmer and reported on the detection of fetal cardiac pulsations with continuous wave Doppler in 1964. The technology was transferred to Smith Kline Instruments and the first fetal pulse detector, Doptone was marketed in 1965. With this instrument, it was generally possible to detect cardiac pulsations in the audio format in live fetuses after 12 weeks of gestation. In 1966 and 1967, Rushmer, Baker, Johnson and Strandness published a series of articles describing various properties of continuous wave Doppler and their clinical applications of fetal life, blood flow through the uterine vasculature, fetal movements and placental location using continuous wave Doppler.[16-18]

Early model of transistorized continuous wave transcutaneous Doppler used by Dr. Strandness which later evolved in to 'Doptone'

One of the shortfalls of continuous wave Doppler was that it did not provide precise information about the distance between the ultrasonic transducer and the moving target. Baker embarked on solving this issue, his inspiration coming from an article that studied the motion of snow and raindrops in the clouds using a pulsed Doppler radar and came up with a phased-coherent pulsed-Doppler design that was capable of obtaining flow and positional information at a particular sample volume. This was the beginning of today's pulsed wave Doppler, an essential function of Doppler applications in vascular evaluation. Baker published his landmark articles: "A phase coherent pulse Doppler system for cardiovascular measurement" in 1967 followed by "Pulsed Ultrasonic Blood Flow Sensing" in 1969.[19,20]

Subsequently, the group was joined by John Reid from the University of Pennsylvania who had grayscale 2D and M-mode imaging technology with him. They went on to implement 'flow mapping'. The first 2D and M-mode cardiac echographic machine was developed in 1970. By 1972, they were able to produce 2D and Doppler images of femoral and carotid arteries. The probe was moved manually by hand over the area of the underlying blood vessel. The Doppler shift information was displayed as white dots overlaid on the B-mode image - the display method used by modern color Doppler instruments. This early instrument had the disadvantage that it required many cardiac cycles to acquire an image and was therefore difficult to operate.

John Reid (1926-)

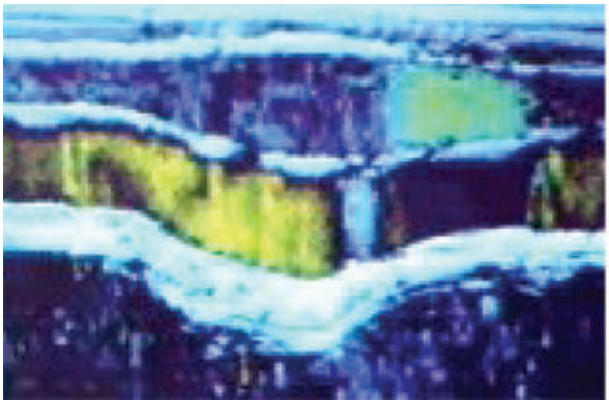
Reid helped to develop their first "rotor-mechanical" duplex scanner where 2D imaging and pulsed-Doppler interrogation could be performed together although not simultaneously. The advent of the phased and linear arrays that finally allowed

simultaneous duplex operation. In 1972, Reid published his article entitled 'Ultrasonic Doppler technique for imaging blood vessels' in 'Science'.[21] The technology was acquired through Fritz Thurstone at Duke University whose group was working on linear and phased array focusing electronics and scan converters. In 1975, velocity waveform and flow images were encoded in color and superimposed on M-mode and gray scale 2-D anatomical images. Marco Brandestini from Zurich made the project come together.

Subsequent developments in vascular ultrasound instruments took place under the guidance and leadership of Baker.[22,23] Between 1973 and 1974, Baker transferred the technology of the Doppler instruments to a newly-founded company named ATL (Advanced Technology Laboratories). ATL produced the first ATL pulsed Doppler scanner in 1974. The Mark I Doppler scanner was commercially available in 1975. The well-known ATL Mark V duplex scanner made its debut in 1978.

Duplex Doppler was way ahead of its time and most physicians did not know what to do with it. Baker realized that in order to sell the duplex Doppler to the cardiovascular physicians, they would need a better M-mode in their instruments. This was accomplished by applied physics engineers hired by ATL who refined the M-mode functions and traces and incorporated them with grayscale. Baker travelled throughout the world and promoted the duplex devices. ATL produced the Mk 300 and 500 in '80 and '81 respectively (followed by the MK 600 in '82 and the MK 100 in '83). The Mk 500 and 600 had probably the best real time duplex Doppler at that time.

Donald Baker retired from the University of Washington in 1979. He was a full-time consultant to Squibb Medical Systems, the international division of ATL and had taught extensively on the application of Doppler ultrasound. He was honored with the Pioneer award from the American Institute of Ultrasound in Medicine (AIUM) in 1987 and the Pioneer Award from the Society of Vascular Technology in 2000. In 2002, he received the Alumnus Summa Laude Dignatus award from the University of Washington for an outstanding alumnus, distinguished for service and achievement over a period of years since graduation. Baker held a number of important patents and authored over 30 articles and book chapters on Ultrasonic Instrumentations. Donald Baker who died in 2018 was inducted as an inaugural member of the Washington Life Science Hall of Fame in 2016. A few of his original continuous wave Doppler and the pulsed-Doppler devices are still exhibited in the Smithsonian Museum of American Medical History. Dr. Rushmer passed away in July 2001at the age of 86. Rushmer lecture is given annually at the university in honor of him. Eugene Strandness retired from the Head of Vascular Surgery in 1995. He passed away in January 2002 at the age of 73. John Reid was Emeritus and Research Professor at Drexel University, and Affiliate Professor of Bioengineering at the



Color flow image of the carotid artery and jugular vein created in 1975.

Third version of the duplex scanhead 1976. The plunger on the right moves in and out to adjusts the range gate.

The ALT Mark V marketed in 1978

University of Washington. Other engineers who took part in the early development of Doppler ultrasound at the University in the 1970s such as Barber, Eyer, Brandestini and others, also had very promising careers in various fields of advanced engineering and inventive technology.

Conflict of Interest - None.

References:

1. Sprawls P. *Physical Principles of Medical Imaging*. Madison, Wis.: Medical Physics Pub.; 1995.
2. Thomas A, Banerjee A. *The History of Radiology*. Oxford: OUP Oxford; 2014. ISBN 0199639973, 9780199639977
3. Thomas AMK, Banerjee AK, Busch U. *Classic Papers in Modern Diagnostic Radiology*. Springer; 2004. ISBN: 9783540219279.
4. Christian Andreas Doppler." Clavius Biography, www-groups.dcs.st-and.ac.uk/history/Biographies/Doppler.html.
5. Mould R. Pierre Curie, 1859–1906. *Current Oncology*. 2007;14(2):74-82. DOI: 10.3747/co.2007.110
6. Eisenberg R. *Radiology. St. Louis u.a.*: Mosby Year Book; 1992.ISBN: 9780801615269.
7. Dussik KT. On the possibility of using ultrasound waves as a diagnostic aid. *Neurol Psychiat*. 1942; 174:153-168.
8. Looking at the Unborn: Historical Aspects of Obstetric Ultrasound" *(PDF). The History of Modern Biomedicine Research Group. Wellcome Institute for the History of Medicine: Wellcome Trust. 10 March 1998. pp. 17–19.* Retrieved 6 August 2019.
9. Willocks, James; Barr, Wallace. I*an Donald: a memoir*. London: RCOG Press. 2004: 70–73.
10. Donald I. Apologia: how and why medical sonar developed. Ann R Coll Surg Engl. 1974;54(3):132-140.
11. Satomura S. Ultrasonic Doppler Method for the Inspection of Cardiac Functions. *J Acoust Soc Am*. 1957;29(11):1181-1185. DOI:10.1121/1.1908737
12. Franklin D, Baker D, Ellis R, Rushmer R. A Pulsed Ultrasonic Flowmeter. *IRE Trans Med Electron*. 1959; ME-6(4):204-206. DOI: 10.1109/iret-me.1959.5007965
13. Franklin D, Schlegel W, Rushmer R. Blood Flow Measured by Doppler Frequency Shift of Back-Scattered Ultrasound. *Science*. 1961;134(3478):564-565. DOI: 10.1126/science.134.3478.564
14. Franklin D, Watson N, Van Citters R. Blood Velocity telemetered from Untethered Animals. *Nature*. 1964;203(4944):528-530. DOI: 10.1038/203528a0
15. Franklin D, Baker D, Rushmer R. Pulsed Ultrasonic Transit Time Flowmeter. *Ire Trans Biomed Electron*. 1962;9(1):44-49. DOI: 10.1109/tbmel.1962.4322948.
16. Rushmer R, Baker D, Stegall H. Transcutaneous Doppler flow detection as a nondestructive technique. *J Appl Physiol*. 1966;21(2):554-566. DOI: 10.1152/jappl.1966.21.2.554.
17. Strandness DE Jr, McCutcheon EP, Rushmer RF. Application of a transcutaneous Doppler flowmeter in evaluation of occlusive arterial disease. *Surg Gynecol Obstet*. 1966;122(5):1039-45.
18. Rushmer R. Clinical Applications of A Transcutaneous Ultrasonic Flow Detector. *JAMA: The Journal of the American Medical Association*. 1967;199(5):326. DOI :10.1001/jama.1967.03120050068015
19. D. W. Baker and Watkins. A phase coherent pulse Doppler system for cardiovascular measurement, in Proc. *20th Ann. Conf. on Eng. in Med. and Biol*., 1967.
20. Baker D. Pulsed Ultrasonic Doppler Blood-Flow Sensing. *IEEE Transactions on Sonics and Ultrasonics*. 1970;17(3):170-184. doi:10.1109/t-su.1970.29558
21. Reid J, Spencer M. Ultrasonic Doppler Technique for Imaging Blood Vessels. *Science (1979)*. 1972;176(4040):1235-1236. doi:10.1126/science.176.4040.1235
22. Barber F, Baker D, Nation A, Strandness D, Reid J. Ultrasonic Duplex Echo-Doppler Scanner. *IEEE Transactions on Biomedical Engineering*. 1974;BME-21(2):109-113. DOI:10.1109/tbme.1974.324295
23. Barber FE, Baker DW, Strandness DE Jr, Ofstad JM, Mahler GD. Duplex Scanner II: for simultaneous imaging of artery tissues and flow. *Ultrasonics Symposium Proceedings*, IEEE Press, 1974; 744-748.