Historical Review

HISTORY OF BLOOD GAS ANALYSIS.
VII. PULSE OXIMETRY

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ABSTRACT. Pulse oximetry is based on a relatively new concept, using the pulsatile variations in optical density of tissues in the red and infrared wavelengths to compute arterial oxygen saturation without need for calibration. The method was invented in 1972 by Takuo Aoyagi, a bioengineer, while he was working on an ear densitometer for recording dye dilution curves. Susumu Nakajima, a surgeon, and his associates first tested the device in patients, reporting it in 1975. A competing device was introduced and also tested and described in Japan. William New and Jack Lloyd recognized the potential importance of pulse oximetry and developed interest among anesthesiologists and others concerned with critical care in the United States. Success brought patent litigation and much competition.


Within the last four years, pulse oximetry has become widely used in anesthesiology and many critical-care situations; at least 15 manufacturers are now marketing pulse oximetry instruments. Severinghaus and Astrup’s review of the history of oximetry in a preceding issue of this journal [1] contained several errors relating to the origin and development of pulse oximetry. Perhaps because of the difficulty of uncovering original Japanese sources, its origin has been ascribed variously to the anesthesiologist Yoshiya and his colleagues in 1980 [2] or to the surgeon Nakajima and his colleagues in 1975 [1], and the development of the pulse oximeter has been attributed to the wrong company as well. Corrections to and further details of the history of pulse oximetry are presented here.

ORIGIN OF PULSE OXIMETRY

The idea of using pulsatile light variation to measure arterial oxygen saturation was conceived by the Japanese physiological bioengineer Takuo Aoyagi (Fig 1). Aoyagi was born February 14, 1936, in Niigata Prefecture, Japan. In 1958, he was graduated from the Faculty of Engineering at Niigata University, where his specialty was electrical engineering. Initially he worked at the Shimazu Corporation on instrumentation, and in February 1971 he joined the Research Division of Nihon Kohden Corporation, one of Japan’s leading medical electronics firms. His research interests have been instrumentation for monitoring fetal heart rate during childbirth, electrical bio-impedance monitoring of ventilation, the phenomenon of airway closure at low lung volume, pulmonary circulation, and cardiac output.
measurement by dye dilution using an improved earpiece.

In the early 1970s, Aoyagi's research concerned the measurement of cardiac output by dye dilution, a well-developed technology in which light of specified wavelengths is passed through blood, usually as it flows from an artery through an external cuvette, and is detected by photocells. Various investigators had attempted to use ear oximeters "for dye measurement to avoid the need for arterial blood sampling. The transmitted light signal was noted to exhibit pulsatile variations, which made it nearly impossible to compute cardiac output accurately from these noninvasive dye dilution curves.

To effectively use the earpiece for dye densitometry, Aoyagi devised a method of cancelling the pulsatile variations by electrically subtracting a pulse signal detected at 900 nm (infrared), where the cardiogreen dye is transparent, from the dye-sensing 630 nm red signal. However, he and his associate noted that this cancellation was fickle (probably due to changes in the oxygen saturation). Fortunately, instead of choosing the isobestic 805 nm infrared light, Aoyagi continued to use 900 nm because he hoped to make an earpiece that would have a dual purpose, not only measuring oxygen saturation but also recording dye dilution curves.

Aoyagi also was aware of the principle of compressing the tissue to set a bloodless zero, first introduced in 1940 by Squire and Goldie [1]. He was well prepared to recognize the opportunity inherent in the noise in his dye dilution curves: to create from it a signal for oxygen measurement. Credit thus belongs to Aoyagi for the idea of measuring only the pulsatile changes in light transmission through living tissues to compute the arterial saturation. He realized that these changes of light transmission at all wavelengths would solely be due to pulsatile variations of the intervening arterial blood volume. Thus, the unpredictable absorption of light by tissue, bone, skin, and pigments would be eliminated from analysis. It was this key idea that permitted the development of instrumentation that required no calibration after its initial factory setting, as all human blood has essentially identical optical characteristics in the red and infrared bands used in oximetry.

In early 1973, Susumu Nakajima, a surgeon then working at the Sapporo Minami National Sanatorium, heard about Aoyagi's idea from Aoyagi's supervisor, Y. Sugiyama. Nakajima placed an order with Nihon Kohden for the apparatus, which he wanted to test in patients.

In January 1974, an abstract in Japanese describing the invention, titled "Improvement of the Earpiece Oximeter," was submitted to the Japanese Society of Medical Electronics and Biological Engineering by the developing team of Aoyagi and associates Michio Kishi, Kazuo Yamaguchi, and Shinichi Watanabe of the Second Division of Technology, Nihon Kohden Corporation [3]. The new oximeter used an incandescent lamp with filters at 630 and 900 nm and analog detection of the pulsatile optical signal ratio at these wavelengths. The paper was presented by Aoyagi on April 26, 1974. On March 29, 1974, a patent application titled "Apparatus for Photometric Blood Analysis" was submitted to the Japanese Patent Office by the Nihon Kohden Corporation, naming Aoyagi and Kishi as inventors. The application was publicly disclosed on October 9, 1975 and published on August 2, 1978 (No. 53-26437), and the patent was granted on April 20, 1979 (No. 947714).