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Photoplethysmography

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The photoplethysmographic (PPG) waveform, also known as the pulse oximeter waveform, is one of the most commonly displayed clinical waveforms. First described in the 1930s, the technology behind the waveform is simple. The waveform, as displayed on the modern pulse oximeter, is an amplified and highly filtered measurement of light absorption by the local tissue over time. It is optimized by medical device manufacturers to accentuate its pulsatile components. Physiologically, it is the result of a complex, and not well understood, interaction between the cardiovascular, respiratory, and autonomic systems. All modern pulse oximeters extract and display the heart rate and oxygen saturation derived from the PPG measurements at multiple wavelengths. "As is," the PPG is an excellent monitor for cardiac arrhythmia, particularly when used in conjunction with the electrocardiogram (ECG). With slight modifications in the display of the PPG (either to a strip chart recorder or slowed down on the monitor screen), the PPG can be used to measure the ventilator-induced modulations which have been associated with hypovolemia. Research efforts are under way to analyze the PPG using improved digital signal processing methods to develop new physiologic parameters. It is hoped that when these new physiologic parameters are combined with a more modern understanding of cardiovascular physiology (functional hemodynamics) the potential utility of the PPG will be expanded. The clinical researcher's objective is the use of the PPG to guide early goal-directed therapeutic interventions (fluid, vasopressors, and inotropes), in effect to extract from the simple PPG the information and therapeutic guidance that was previously only obtainable from an arterial pressure line and the pulmonary artery catheter.

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Introduction

The photoplethysmographic (PPG) waveform is the core technology of the pulse oximeter. This wave is displayed on monitors throughout the critical care areas of the hospital (operating room (OR), emergency room (ER), postanesthesia care unit (PACU), intensive care unit (ICU), etc.). Unlike the electrocardiogram (ECG), it is rarely recorded or analyzed. This chapter endeavors to make the PPG waveform more useful to the practicing clinician. In addition, it explores some of the exciting research presently being carried out to expand its clinical usefulness.

At its heart, the PPG technology is remarkably simple consisting of a light source on one side of the tissue bed and a light detector on the other. Holding one hand in front of a bright light and looking at the red glow creates a PPG in its simplest and most accessible form. If your eyes were a bit more sensitive, you would see the subtle darkening of your hand with each heartbeat.

History

The PPG is not a new discovery [1,2]. It was first described by Alrick Hertzman in 1937 [3]. This ultimately led to a remarkable series of papers by Hertzman [4–7] examining the physiology and potential uses of this waveform (Fig. 1). It was Hertzman who named it the photoelectric plethysmograph based upon his belief and early observations that its creation was linked to blood volume changes. He chose the term “plethysmos,” which is derived from the Greek word for fullness. This expressed his belief that he was measuring the fullness of the tissue when he measured the amount of light absorption. Subsequent research has demonstrated he was not far off on his assumption with a close correlation ($r = 0.9$) between the PPG and the more traditional strain gauge plethysmograph [8].

It is important to note that Hertzman was working from the simplistic model of light that was prevalent at the time. This was before the quantum complexities and scattering characteristics of light were generally appreciated [9]. His theories were derived from Beer–Lambert’s law of light, whose primary assumptions were that light absorption is directly proportional to the path length, concentration of substances, and the light absorption by each of those substances [10]. The modern day theory of light/tissue interaction is more complex and well laid out by Paul Mannheimer [11]. There are two major take-home messages to the practicing clinician: (1) there is more to the pulse oximeter waveform than a simple representation of the cardiac pulse (e.g., not just a “poor man's

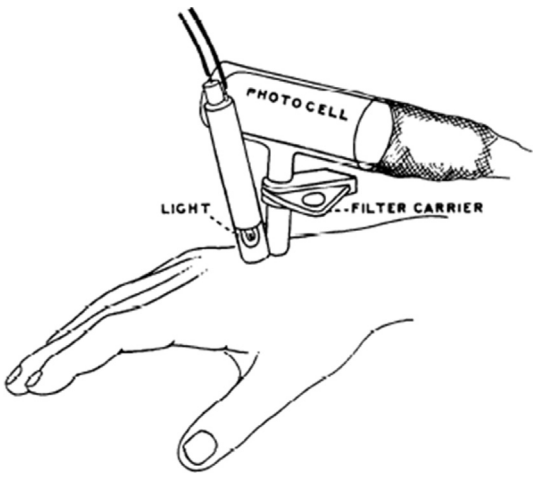

Fig. 1. The photoelectric plethysmograph in position over the skin of the hand. From 1938 showing Hertzman's original setup for measuring the PPG (Used with permission from The American Physiology Society via Rightslink) [4].