MASIMO SIGNAL EXTRACTION PULSE OXIMETRY
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Received Jul 15, 1999. Accepted for publication Jan 13, 2000.
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ABSTRACT. Objective. To describe a new pulse oximetry technology and measurement paradigm developed by Masimo Corporation. Introduction. Patient motion, poor tissue perfusion, excessive ambient light, and electrosurgical unit interference reduce conventional pulse oximeter (CPO) measurement integrity. Patient motion frequently generates erroneous pulse oximetry values for saturation and pulse rate. Motion-induced measurement error is due in part to widespread implementation of a theoretical pulse oximetry model which assumes that arterial blood is the only light-absorbing pulsatile component in the optical path. Methods. Masimo Signal Extraction Technology (SET®) pulse oximetry begins with conventional red and infrared photoplethysmographic signals, and then employs a constellation of advanced techniques including radiofrequency and light-shielded optical sensors, digital signal processing, and adaptive filtration, to measure SpO2 accurately during challenging clinical conditions. In contrast to CPO which calculates O2 saturation from the ratio of transmitted pulsatile red and infrared light, Masimo SET pulse oximetry uses a new conceptual model of light absorption for pulse oximetry and employs the discrete saturation transform (DST) to isolate individual “saturation components” in the optical pathway. Typically, when the tissue under analysis is stationary, only the single saturation component produced by pulsatile arterial blood is present. In contrast, during patient motion, movement of non-arterial components (for example, venous blood) can be identified as additional saturation components (with a lower O2 saturation). When conditions of the Masimo model are met, the saturation component corresponding to the highest O2 saturation is reported by the instrument as SpO2. Conclusion. The technological strategies implemented in Masimo SET pulse oximetry effectively permit continuous monitoring of SpO2 during challenging clinical conditions of motion and poor tissue perfusion.

KEY WORDS. Pulse oximetry; motion artifact; oximetry/instrumentation/methods; signal processing, computer-assisted; adaptive filters; Masimo signal extraction pulse oximetry; signal extraction technology (SET®).

INTRODUCTION

Review of conventional pulse oximetry

Conventional pulse oximetry (CPO) determines arterial oxygen saturation (SpO2) and pulse rate (PR) by using a theoretical model which was developed over twenty-five years ago [1]. This model assumes that arterial blood is the only light-absorbing pulsatile component in the optical path. The ratio of pulsatile transmitted red (RD) to infrared (IR) light - the “optical density ratio” - is used to calculate SpO2 through the use of a calibration...
equation generated by human in vivo calibration studies [2].

A simplified approach to CPO analysis can be described as follows:

We are interested in the photoplethysmographic variations of the ratio of RD to IR light, but the intensity of transmitted light is unknown. Therefore, the transmitted RD and IR light signals are normalized by dividing the pulsatile transmitted light (known as the AC component), by the non-pulsatile transmitted light (the DC component). This can be expressed as:

\[ \text{Normalized light} = \frac{\text{light}_{AC}}{\text{light}_{DC}}. \]

The Optical Density Ratio, \( r \), is a proportionality ratio which is unique for each saturation and wavelength of RD and IR light, and is related to SpO\(_2\) through an empirically derived calibration equation:

\[ r = \frac{\text{normalized RD}}{\text{normalized IR}} \]

\[ \text{RD} = \text{red light} (\sim 660 \text{ nm}) \]

\[ \text{IR} = \text{infrared light} (\sim 905 \text{ nm}) \]

Limitations of conventional pulse oximetry

Continuous and accurate measurement of SpO\(_2\) is difficult in the clinical environment. Excessive ambient light and electromagnetic interference may disrupt the measurement completely [3]. Poor tissue perfusion may produce signal strength below the limit of detection, and this condition may be exacerbated in patients with dark pigmentation or with thick digits. Freund et al. showed that once a pulse oximeter failed intraoperatively, it would not provide data for 32% of the mean anesthesia time [4]. In a study using computerized anesthesia record keeping systems, pulse oximetry failure periods of 10 minutes or longer occurred in 9% of cases [5]. The challenge of obtaining an accurate measurement is greater in sicker patients who may exhibit poor perfusion and a resultant poor signal to noise ratio. Moller et al. demonstrated in a study of 20,802 patients that perioperative pulse oximetry failure rate is positively correlated with the American Society of Anesthesiologists physical status score [6]. In this group of patients, the pulse oximetry failure rate was 2.5% overall, but increased to 7.2% when only physical status 4 patients were considered. The postanesthesia care unit presents a challenging monitoring environment. In a study of postanesthesia care unit performance, the average frequency of pulse oximetry alarms caused by “sensor displacement, motion artifacts, poor perfusion, or a combination of these factors” was once every 8 minutes and 77% of these alarms were false [7]. Clearly, pulse oximetry failures are well documented and interfere with the accepted practice standard of continuous assessment of oxygenation during general anesthesia and conscience sedation.

Effect of motion on pulse oximetry

The effect of motion on pulse oximetry accuracy may be more insidious than causing complete failure to measure SpO\(_2\) or PR dropout. Barker et al. evaluated pulse oximetry accuracy during controlled oxygen desaturation in volunteers while introducing specific arm motions with a mechanical motion generator [8]. During motion, CPO exhibited dropout rates of up to 46%, and more ominously, the CPO values were erroneous up to 20% of the measurement time.

Figure 1 is illustrative of the comparative performance of three oximeters during adult volunteer testing in one of the author's laboratories (Barker). This test was performed with IRB approval to characterize pulse oximetry performance. An adult female breathing room air had three oximeter sensors applied to the motion (test) hand, and a control oximeter (Nellcor N-200, Nellcor PB, Pleasanton, CA) placed on the stationary hand. Saturation data was collected continuously with a com-