Measurement Location Influences Reflectance Pulse Oximetry During Sleep

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Peripheral oxygen saturation (SpO_2) plays a key role in diagnosing sleep apnea (SA). SpO_2 is mainly measured via transmission pulse oximetry at the fingertip, an approach poorly suited for long-term monitoring over several nights. In view of a more patient-friendly solution, we evaluated the accuracy of a proprietary watch-like device that measures SpO_2 via reflectance pulse oximetry in a cohort of 9 patients with suspected SA. Two measurement locations were investigated: the upper arm and the wrist. The upper arm provided more robust and accurate SpO_2 estimates than the wrist. These findings suggest that the upper-arm location is optimal for an unobtrusive and long-term SA detector using reflectance pulse oximetry.

Sleep apnea (SA) has a high prevalence in the general population [1], is associated with arterial hypertension, and contributes to the development of cerebral and cardiovascular comorbidities. The measurement of peripheral oxygen saturation (SpO_2) via pulse oximetry is crucial for the detection and diagnosis of SA. However, state-of-the-art SpO_2 sensors at the fingertip are not well suited for the long-term monitoring over several nights which is crucial to capture night-to-night variations and provide a correct diagnosis of SA [2]. In view of less obtrusive SA monitoring, we have evaluated our proprietary reflectance pulse oximeter (see Figure 1) at two body locations (wrist vs. upper arm) and compared to fingertip SpO_2 in SA patients.

Figure 1: CSEM proprietary watch-like reflectance pulse oximeter device.

Our study (BASEC Nr. 2019-00450) was conducted at the sleep laboratory of the Cantonal Hospital St. Gallen (Switzerland) on 9 patients with suspected SA. Each participant underwent a full overnight polysomnography (PSG) recording, including SpO_2 reference measurements via a fingertip sensor. In parallel, each patient wore two watch-like reflectance pulse oximeter devices, one at the wrist, and the other at the upper arm. The three SpO_2 devices (2 watch-like devices at wrist and upper arm, 1 reference at fingertip) were placed on the same arm. The data were processed with CSEM's algorithm [3] providing SpO_2 estimates together with a quality index (QI) indicating the reliability of the corresponding estimates. Unreliable SpO_2 estimates with a QI below 75% were automatically rejected from analysis. This threshold represents the best trade-off between a high acceptance rate and a low A_{RMS} error. SpO_2 estimates (SpO_{2Est}) were compared to fingertip SpO_2 reference measurements (SpO_{2Ref}) using the amplitude of the root-mean-square error (A_{RMS}) as recommended by ISO 80601-2-61:2017 standard.

Recordings on 9 SA patients led to a total monitoring duration of 51 h. After the automatic rejection of unreliable data by our algorithm [3] a total of 38.1 h (75%) and 41.1 h (81%) of data were available for analysis from the wrist and upper arm, respectively (Table 1). When compared with the gold-standard fingertip, our SpO_2 estimations showed an error of A_{RMS} = 2.5% at wrist vs. A_{RMS} = 1.8% at upper arm (Table 1 and Figure 2). Even though both are compliant with ISO 80601-2-61:2017 standard and FDA guidance for reflectance type sensors (acceptance limit at 3.5%), SpO_2 data acquired at the upper arm are of better quality than those from the wrist and lead to more accurate estimations.

When combined with other vital signs, an upper-arm-based SpO_2 sensor can allow for an unobtrusive solution for long-term monitoring of SA, as well as other diseases involving respiratory symptoms.

Table 1: Performance of SpO_2 estimations at wrist vs. upper arm.

Performance Metric	Wrist	Upper Arm
SpO_2 A_{RMS} Error	2.5%	1.8%
Acceptance Rate	75%	81%
Data Duration	38.1 h	41.1 h

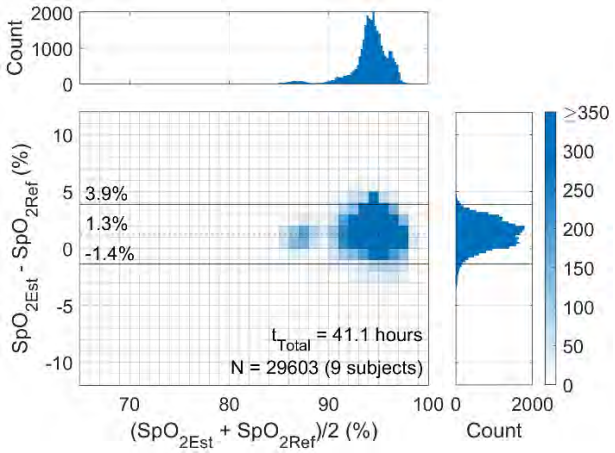

Figure 2: Bland-Altman analysis for SpO_2 measured at the upper arm (SpO_{2Est}) compared to fingertip SpO_2 (SpO_{2Ref}). The density of data points is highlighted using color-coded rectangles with their color saturation proportional to the number of data points (white: low density vs dark blue: high density, see color gradient bar). Less populated rectangles are emphasized by saturating the color scale at a superior threshold of 10% of the maximal number of data points of all rectangles.

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