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Short paper

Feasibility of pulse oximetry after water immersion

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Abstract

Objective: This study aimed to determine if pulse oximetry could reliably be used after immersion in water, and if so, which of the finger, earlobe or nose most reliably produced a functional waveform.

Method: Pulse oximetry data was recorded from the ear, nose and finger before and after 30 min of immersion in water. The primary outcome was the ability to measure pulse oximetry at any of the sites.

Results: A total of 119 participants were enrolled (with a median age of 16 years, 55% male). A useful pulse oximetry waveform was obtained after immersion from at least one of the measurement sites in 118 (99.2%) participants. Waveforms were usable after immersion in 96% of participants at the nostril, compared to 92% at the finger, and 41% at the ear lobe. The likelihood of success at the ear was significantly lower than either the finger or the nose (41% vs 92% and 96% respectively, $p < 0.0001$ for both comparisons). The finger and nostril were similar. Oxygen saturations were not significantly different after immersion at the nostril (100% vs 100%, $p = 0.537$) and finger (100% vs 100%, $p = 0.032$) sites but were different at the ear (100% vs 96%, $p < 0.0001$).

Conclusion: This study demonstrates that pulse oximetry is feasible and reliable in a large cohort of participants who have been immersed in water for 30 min. The results support the nostril as the most reliable location. Only pulse oximeters registered for clinical use should be employed for patient care.

Keywords: Immersion, Drowning, Pulse oximetry, Equipment

Introduction

Pulse oximetry non-invasively calculates the percentage saturation of haemoglobin molecules in real time.[1] Pre-hospital practice uses pulse oximetry to guide oxygen therapy, which is commonly required when a patient has drowned.[2] Pulse oximetry is recommended as part of the decision algorithm for discharging patients recovering from drowning.[3] Existing literature addressing pulse oximetry in drowned patients is sparse.

Two trials studied pulse oximetry after cold water immersion. A study of twelve volunteers demonstrated cold water immersion decreased the waveform at the immersed fingertip, but not at the ear,[4] suggesting that aberrant pulse oximetry readings could be due to local vasoconstriction. Another study with ten participants compared six brands of pulse oximeters after brief submersion in 21 and 16 °C water and following 10 min of swimming. If pulse oximetry readings were above 94% they were judged accurate.[5] In 21° water, 5.8% of measurements were outside the acceptable range, compared to 34% in cold water[5] and there was significant variability between the brands.

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http://dx.doi.org/10.1016/j.resplu.2021.100147
Received 14 April 2021; Received in revised form 6 June 2021; Accepted 10 June 2021

Other literature suggested perfusion impairment reduced SpO_2 measurement precision.[6] Guidelines recommended not using pulse oximetry in the pre-hospital management of drowning,[5] despite potential benefits in reducing unnecessary use of oxygen, detecting hypoxia and guiding escalation of oxygen therapy.

Pulse oximetry is most commonly measured at the finger tip,[7] and alternatively the earlobe or the nose.[8] In ICU settings, the fingertip waveform is often lost due to poor perfusion, whereas the ear and nasal waveforms may be preserved due to higher blood flow.[4,9] Hypoperfusion has been suggested as a cause of variation in pulse oximeter performance.[10] Pulse oximetry measurement accuracy was also affected by motion and ambient light and peripheral hypoperfusion,[11] problems that are commonly seen on beaches.

The overall failure rate for pulse oximetry was 8.7% in ICU,[12] which forms a reasonable basis for an pre-specified threshold for success of pulse oximetry. This study aimed to determine if pulse oximetry could reliably be used after immersion in water, and to establish which site was most likely to produce a functional waveform.

Methods

Design

The study was a prospective observational feasibility trial of pulse oximetry after water immersion. The trial was reviewed and approved by the Austin Health Human Research Ethics Committee and was performed in accordance with the ethical standards laid down in the Declaration of Helsinki. All participants or their guardians gave their written informed consent prior to their participation in the study. Participants under 18 years of age provided assent to participate in the study in addition to their guardians providing written informed consent.

Participants

Participants were volunteer surf lifesavers aged more than 15 years who were able to give written informed consent themselves or obtain consent from their guardian.

Devices

The pulse oximeters used in the study were Philips M3001A Multi Measurement Server (MMS) pulse oximeters, connected to a Philips M4 monitor (Koninklijke Philips N.V. Amsterdam, The Netherlands). The same MMS provided blood pressure readings. Finger readings used a Philips Adult Soft Tip SpO_2 probe, while ear and nostril recordings used a Philips Ear Probe. This pulse oximeter was chosen because it was approved on the Australian Register of Therapeutic Goods, and was the oximeter in use by the state ambulance service where the trial was conducted. The manufacturer's information quotes an accuracy of $\pm$2% for the pulse oximetry value, and an operating temperature of zero to forty degrees Celsius.

Procedure

Demographic details were recorded and baseline pulse oximetry readings were simultaneously obtained at the right finger, right ear and one nostril by registered healthcare professionals (a critical care doctor and a paramedic). Waveforms were assessed and judged by the experienced clinicians as either "useful" if they displayed a distinct systolic hump and diastolic notch or "unusable" (all other waveform shapes, for example damped waveforms or movement artefact). This approach was chosen as it is in common use in clinical practice in Australia and is suggested by the device manufacturer.

Participants spent 30 min undertaking lifesaving training activity (swimming for 10 min, followed by 10 min treading water and applying rescue equipment, followed by swimming for a further 10 min) in the open ocean. A total of three trial locations were used. Participants returned to the beach where pulse oximetry assessment was repeated and blood pressure was measured. The measurement area was set up 25 m from the waterline, and participants walked this distance in less than a minute.

Sources of bias

The beach environment includes factors that can affect the accuracy of pulse oximetry readings, including bright light and movement, typically preventing readings from being obtained. To minimize the risk of bias, a highly homogenous participant population who were highly physically fit and without significant medical comorbidity was recruited. No participant wore nail polish. The duration and type of water activity was precisely controlled and the measurement protocol and environment was carefully controlled to ensure repeatability. Measurement was conducted inside a portable tent on the beach to limit the effect of sunlight, wind, and other environmental effects on oximeter accuracy. Identical pulse oximeters were used for all measurements to limit equipment variation.

Outcomes

The primary outcome was the ability to measure a usable pulse oximetry waveform at any of finger, nose or ear locations after thirty minutes of immersion in water. The pre-specified threshold for success was being able to obtain a waveform at one of the sites, in at least 91.3% of participants.[12] The secondary outcomes included the recorded peripheral oxygen saturations and frequency of success at each site, and the ability to measure a waveform at each site.

Statistical analysis

Results were presented descriptively as a proportion of enrolled participants, assessed for normality using the Shapiro–Wilk test and were found to be not normally distributed. The frequency of success at each of the measurement sites was assessed using Cochran's Q test. Change in oxygen saturation before and after immersion was assessed using the Wilcoxon signed ranks test. Statistical significance was defined as a p-value <0.05. For secondary outcomes a Bonferroni correction produced a corrected threshold for significance of 0.00083.

Results

A total of 119 participants were enrolled and complete data was obtained for all. The median age was 16 (IQR 15–17) years and median BMI was 21.5 (IQR: 20.2–24.8), median height was 174 cm (IQR: 168–179) and the median weight was 65 kg (IQR: 60–73). The

Table 1 – Pulse oximetry values before and after immersion.

Parameter	Pre-immersion Median (IQR)	Post-immersion Median (IQR)	P value
SpO_2 at finger	100% (99–100%)	100% (100–100%)	0.032
SpO_2 at nose	100% (98–100%)	100% (99–100%)	0.537
SpO_2 at earlobe	100% (99–100%)	96% (83.5–100%)	0.0001*

* Indicates that the observed difference is statistically significant at the level of $P < 0.0001$, and exceeds the pre-specified threshold for significance.

water temperature at all sites on all measurement days was 18 °C and the air temperature ranged between 18 and 35 °C.

A useful pulse oximetry waveform was obtained after immersion from at least one of the measurement sites in 118 (99.2%, 95%CI, 97–100%) participants. The median systolic blood pressure after immersion was 134 mmHg (IQR 124–143 mmHg) and no participants were hypotensive. Useful pulse oximetry waveforms were obtained after immersion in 109 (92%, 95%CI, 87–97%) participants at the finger, compared to 49 (41%, 95%CI 32–50%) at the ear and 114 (96%, 95%CI 92–99%) at the nose. Success was significantly lower at the ear than the finger or nose ($p < 0.0001$). There was no difference between the finger and nose ($p = 0.166$).

Median pulse oximetry values were significantly different at the earlobe after immersion compared to before (96 vs 100%, $p < 0.0001$), and were similar at the finger (100 vs 100%, $p = 0.032$) and nostril (100 vs 100%, $p = 0.537$).

Full details are presented in Table 1.

Discussion

This is the largest study to assess the utility of pulse oximetry after water immersion. The study demonstrated that the use of pulse oximetry was feasible in 99.2% of participants. The largest previous study had 10 participants with similar demographics and methods. Many factors could be responsible for the difference between our results and previous studies, but the most likely is that by enrolling a larger number of participants, the influence of individual variation and equipment problems has been reduced. This study used regulatory approved pulse oximeters, which may have a higher success rate than unapproved devices. The nose and the finger were found to be reliable sites with useable waveforms. The nose site had the smallest degree of difference between pre and post immersion pulse oximetry values and as such could be considered the most reliable of the sites. Waveforms were found in only 41% of participants at the ear. Consequently, ear pulse oximetry is not recommended after immersion. The absence of hypotension suggests that the observed results are likely to be due to local vasoconstriction rather than poor cardiac output states or hypotension.

Clinically approved pulse oximetry probes used on the fingertip are a reasonable choice given the success rate in this trial. Nasal pulse oximetry probes are less commonly available, but are an attractive option given usable waveforms were detected in 96% of participants.

Whilst this is the largest study of its kind, it remains a single centre study where the water temperature was 18 °C, limiting generalizability to colder temperatures. Formal testing of the pulse oximetry value against a gold standard such as arterial blood gas analysis was not possible with the available equipment and the ethical approval of the study, and consequently the study cannot guarantee the obtained pulse oximetry value is precise. Drowned patients were not studied, and participants were young, fit and healthy, with good base-line oxygenation and the results may not be generalizable to all patients.

Conclusion

This study demonstrates that pulse oximetry is feasible in participants who were immersed water for 30 min. The majority of participants had a useable waveform at one measurement site. The nostril was the most reliable measurement location. Only clinically approved pulse oximeters should be used to measure pulse oximetry for patients in the first aid setting.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Lachlan Holbery-Morgan: Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Funding acquisition. **James Carew:** Conceptualization, Resources, Investigation, Writing - review & editing. **Cara Angel:** Investigation, Writing - review & editing. **Nick Simpson:** Conceptualization, Methodology, Writing - review & editing. **Dan Steinfort:** Conceptualization, Methodology, Writing - review & editing. **Sam Radford:** Conceptualization, Methodology, Writing - review & editing. **Michelle Murphy:** Conceptualization, Methodology, Writing - review & editing. **Ned Douglas:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Project administration, Data curation, Funding acquisition, Supervision. **Douglas Johnson:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Project administration, Funding acquisition, Supervision.

Acknowledgments

The study was supported by a grant from the Australian Resuscitation Council — Victorian Branch. The funder had no role in study design, collection, analysis and interpretation of data, writing of the report, nor in the decision to submit the article for publication.

In regards to conflicting interests, all authors state they have none to declare.

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