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Usability of Pulse Oximetry During Severe Physical Exercise at High Altitude

Einsetzbarkeit der Pulsoxymetrie während schwerer körperlicher Tätigkeit in großer Höhe

SHORT REPORT

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Summary

- **Introduction:** Pulse oximetry is widely used to measure blood oxygens saturation (SpO_2) and acclimatization status in order to assess acclimatisation status at altitude and there is evidence suggesting that SpO_2 during exercise is more relevant than measurements at rest. But movement, especially of the hands, can lead to incorrect measurements and artefacts, when the oxymeter is attached to a finger, which in turn might limit the use of pulse oximetry.
- **Key question:** We aimed to evaluate the rate of incorrect measurements during extreme exercise (ice climbing) in order to assess the applicability of pulse oximetry during activity.
- **Material and Methods:** We analyzed an extreme ice-climb to the summit of Les Courtes (3856 m; NE-gully: 800 m; 50°) in a male 32-years old mountain guide. The pulse oximeter (PalmSat 2500®; Nonin) logs the measured values for SpO_2 and pulse every 4 seconds and detects incorrect data, allowing calculate the proportion of incorrect measurements.
- **Results:** During the whole tour 24.8% (1333/5368) of incorrect measurements were detected, 34.5% (778/2252) during the ice climb. The highest proportion of incorrect measurements occurred during the preparation for the ice-climb, 55.6% (81/145). For a normal alpine activity (total tour without ice-climb and the associated preparation time) the rate of incorrect measurements was 16.8% (510/3028).
- **Discussion:** Even during exercise in extreme conditions like ice-climbing, pulse oximetry provides approx. 33% valid SpO_2 values, allowing a meaningful monitoring of blood oxygenation.

KEY WORDS:
Acute Mountain Sickness, Oxygen Saturation, Moving Artifact, PalmSat 2500, Ice Climbing

Zusammenfassung

- **Einleitung:** Bei Höhenaufenthalten wird die Pulsoxymetrie häufig zur Beurteilung des individuellen Akklimatisationszustands verwendet. Im Vergleich zur Messung in Ruhe hat die Messung während körperlicher Belastung eine höhere Aussagekraft. Allerdings können Bewegungsartefakte, vor allem Handbewegungen, zu Fehlmessungen führen, was wiederum die Verwendbarkeit der Pulsoxymetrie einschränkt.
- **Fragestellung:** Um die grundsätzliche Verwendbarkeit der Pulsoxymetrie während „normaler" körperlicher Aktivität bewerten zu können, untersuchten wir die Rate an Fehlmessungen während einer Extrembelastung (Eisklettern).
- **Material und Methode:** Wir werteten einen extremen Eisanstieg auf den Gipfel der Les Courtes (3856 m; NO-Colour; 800 m; 50°) eines 32-jährigen Bergführers aus. Das verwendete Pulsoxymeter (PalmSat 2500®; Nonin) speichert die Messwerte für SpO_2 und Puls alle 4 Sekunden und markiert alle Fehlmessungen. Daher konnten wir deren Verhältnis bezogen auf die Gesamtzahl der Messungen berechnen.
- **Ergebnisse:** Für die Gesamttour lag der Anteil der Fehlmessungen bei 24,8% (1333/5368), für den reinen Eisklettertеil bei 34,5% (778/2252). Die höchste Fehlmessungsrate trat während der kurzen Vorbereitungsphase für den Eisklettertеil auf: 55.6% (81/145). Für normale alpine Aktivität (Gesamttour ohne Eisklettertеil und ohne die zugehörige Vorbereitungsphase) liegt der Anteil an Fehlmessungen bei 16,8% (510/3028).
- **Diskussion:** Sogar unter diesen extremen Bedingungen sind 33% der pulsoxymetrisch bestimmten SpO_2-Werte verwendbar. Für die praktische Anwendung reicht dies aus.

SCHLÜSSELWÖRTER:
Höhenkrankheit, Sauerstoffsättigung, Bewegungsartefakt, PalmSat 2500, Eisklettern

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Introduction

During sojourns at high altitude blood oxygen saturation (SpO_2) is frequently measured by pulse oximetry, aiming to assess individual acclimatization status and to facilitate the diagnosis of acute mountain sickness (4, 5, 8, 11). With regard to the acclimatization status there is good evidence that measurements during physical exercise have a higher relevance compared to measurements at rest (2, 6, 7, 9, 10).

But physical exercise, especially moving hands and fingers may influence the validity of the measurements (3), raising the question whether body movements compromise the use of pulse oximetry during physical exercise (1). In order to evaluate the robustness of pulse oximetry to errors and thus its usability during alpine physical activities, it is necessary to know about the proportion of incorrect measurements during extreme exercise. Since we couldn't find any data in the literature, we tested a modern pulse oximeter device under the extreme conditions of a steep ice-gully-climb that requires severe manual work with ice-axes.

The aim of this study was to investigate the proportion of incorrect SpO_2-measurements during this ice-climb at high altitude and to compare it to a more usual alpine activity like hiking or ski-touring. ›

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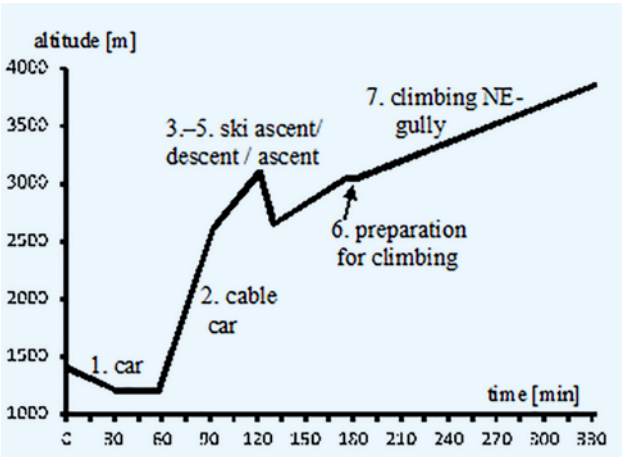

Figure 1

Altitude profile of ascending Les Courtes (3856 m).

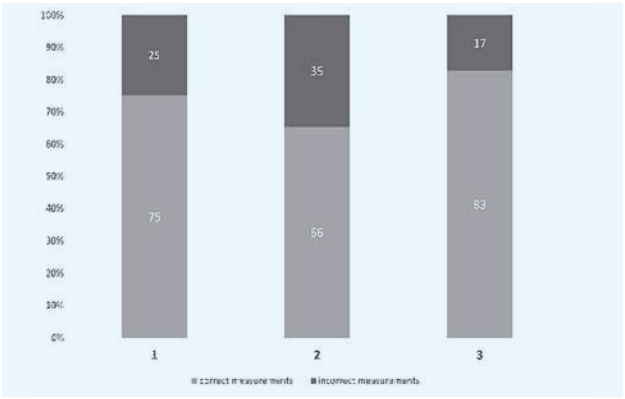

Figure 2

Percentage of incorrect measurements; 1: complete tour; 2: ice climb of the gully; 3: ascent with cable car and ski-touring without the ice climb and without the 6 min of preparation for it.

Material and Methods

The study was performed in the area of Mont Blanc. An experienced ice-climber (mountain guide, 32 yrs., 72 kg) climbed the north-east gully (800 m; 50°) to the summit of Les Courtes (3856 m) . The whole ascend can be divided in several parts (Fig 1):

1. The car drive to the bottom station of the cable car (1210 m) and the administrative work there (7:32-8:30 a.m.)
2. The ascend by cable car to 2620 m (8:30-9:04 a.m.)
3. The fast ascend by ski touring to 3100 m (9:04-9:29 a.m.)
4. The descent by ski to the glacier d'Argentiere at 2650 m (9:29-9:38 a.m.)
5. The ascent by ski touring to the bottom of the gully at 3050 m (9:38-10:24 a.m.)
6. The preparation for the ice climb at 3050 m (10:24-10:30 a.m.)
7. The ice-climb of the north-east-gully of Les Courtes to 3856 m (10:30 a.m.-13:00 p.m.)

We used the pulse oximeter PalmSat 2500® (Nonin). This device logs the data for SpO_2 and pulse every 4 seconds and has a capacity of 72 hours. The measurement started at 7:32 a.m. and ended at 1:29 p.m. at the summit. We used the adult FlexSensor® that is soft and flat and can be worn under gloves. The hands were covered with gloves during the whole time except car drive. We attached the FlexSensor not on the index but on the fourth finger because the index finger is required for proper alpine climbing techniques like e.g. rope work.

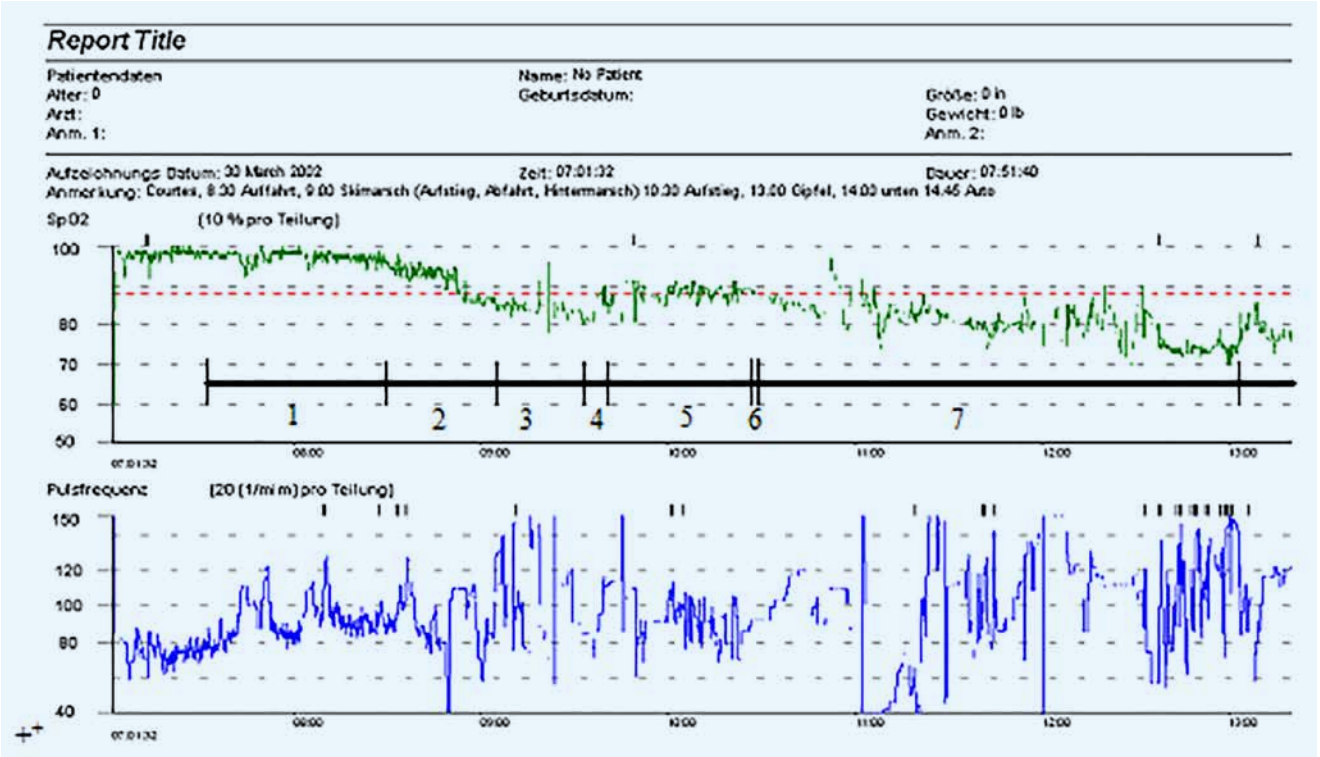

Figure 3

SpO_2-course of the tour (1: car, 2: cable car, 3 + 5: ski ascent 4: ski descend, 6: preparation for climbing, 7: climbing NE-gully). Incorrect measurements ("500-values") are not displayed and are expressed by gaps. These gaps do not disturb the visual impression.

The PalmSat 2500® assigns the figure "500" to each incorrect (missing or suspect) measurement and stores this value, too, thereby allowing the identification of incorrect values and ensuring one datapoint each 4 seconds. All data were transferred to Excel for evaluation. We calculated the proportion of these "500"-values compared to the total number of data points for the extreme situation during the ice-climb (part 7.) as well as for the complete tour (part 1.-7.).

Results

We collected 5368 data points for SpO_2 during the whole tour, thereof 2252 during the ice-climb. In total (part 1-7) we had 24.8% (1333/5368) of incorrect measurements (inc-meas) and 34.5% (778/2252) (Fig. 2) for the ice climb (part 7). The highest rate of inc-meas occurred during the short preparation time for the ice-climb (part 6). Eating, drinking, putting on crampons as well as rope preparation were very demanding manually and caused an inc-meas-percentage of 55.6% (81/145). As expected we found the lowest rate of inc-meas during part 1, the car drive and during the administrative work at the bottom of the cable car: 5.5% (72/1312).

If we exclude the ice-climb (part 7) the rate of inc-meas for part 1-6 is 17.8% (555/3116). Further excluding the 6 min for preparation (part 6) immediately before the ice-climb the proportion of inc-meas decreases to 16.8% (510/3028), reflecting a standard alpine activity (Fig. 2).

Discussion

Even during extreme conditions like ice-climbing, pulse oximetry at the finger tip provides meaningful results. This is consistent with the conclusions of Yamaya et al. (12), even though their study was conducted on a cycle ergometer and has other methodological differences like e.g. blood derived measurements of oxygen saturation. For outdoor activity and physical exercise at high altitude a missing value percentage of 17% can serve as best practice estimate for the proportion of incorrect measurements of pulse oximetry during this kind of activity.

Beside movement artefaccts, poor perfusion of cold fingers is another possible reason for invalid data during such activity. The investigated ice-climber stated, not to have suffered from cold fingers during the whole tour. The fast ascent has certainly favored a good blood circulation in the fingers. Therefore, these results are only partially transferable to people who suffer from cold fingers, especially when ascent is slower or rests are longer.

Notably, the standard user of such pulse oximeters does not recognize the data rated as invalid by the Nonin algorithm. The pulse oximeter notifies the user of a weak signal by changing the pulse synchronic green flash light to yellow or red. In these cases, the measurement situation should be optimized by stopping movements, adjusting the sensor to a proper position, warming the fingers, etc. Notably, the inc-meas do not impede analysis when the Nonin software is used, because they are not displayed and do not corrupt the visual impression (Fig. 3).

In scientific research, these invalid data are far more problematic. If statistical measures have to be calculated, the inc-meas must be removed. Otherwise, they considerably affect the calculation and change statistical measures. Deleting values causes an error when data are averaged over time, but this error is neglectable compared to their influence on statistical measures if they are included. In line charts, we recommend to interpolate them by the adjacent values , to prevent a shrinking of the x-axxis.

Conclusion

In conclusion, pulse oximetry with the FlexSensor® put on the fourth finger allows to measure meaningful SpO_2-values even during extreme conditions like ice climbing. During moderate alpine activity like e.g. ski-touring, the percentage of incorrect measurements decreases further.

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Conflict of Interest

The authors have no conflict of interest.

References

(1) **KAMAT V.** Pulse oximetry. Indian J Anaesth. 2002; 46: 261-268.

(2) **LAZIO MP, VAN ROO JD, PESCE C, MALIK S, COURTNEY DM.** Postexercise peripheral oxygen saturation after completion of the 6-minute walk test predicts successfully reaching the summit of Aconcagua. Wilderness Environ Med. 2010; 21: 309-317. doi:10.1016/j.wem.2010.09.003

(3) **LEE J, JUNG W, KANG I, KIM Y, LEE G.** Design of filter to reject motion artifact of pulse oximetry. Comput Stand Interfaces. 2004; 26: 241-249. doi:10.1016/S0920-5489(03)00077-1

(4) **LUKS AM, SWENSON ER.** Pulse oximetry at high altitude. High Alt Med Biol. 2011; 12: 109-119. doi:10.1089/ham.2011.0013

(5) **ROACH RC, GREENE ER, SCHOENE RB, HACKETT PH.** Arterial oxygen saturation for prediction of acute mountain sickness. Aviat Space Environ Med. 1998; 69: 1182-1185.

(6) **ROACH RC, MAES D, SANDOVAL D, ROBERGS A, ICENOGLE M, HINGHOFER-SZALKAY H, LIUM D, LOEPPKY JA.** Exercise exacerbates acute mountain sickness at simulated high altitude. J Appl Physiol. 2000; 88: 581-585. doi:10.1152/jappl.2000.88.2.581

(7) **SAITO S, SHIMADA H, IMAI T, FUTAMATA Y, YAMAMORI K.** Estimation of the degree of acclimatization to high altitude by a rapid and simple physiological examination. Int Arch Occup Environ Health. 1995; 67: 347-351. doi:10.1007/BF00385651

(8) **TANNHEIMER M, THOMAS A, GERNGROSS H.** Oxygen saturation course and altitude symptomatology during an expedition to Broad Peak (8047 m). Int J Sports Med. 2002; 23: 329-335. doi:10.1055/s-2002-33144

(9) **TANNHEIMER M, ALBERTINI N, ULMER HV, THOMAS A, ENGELHARDT M, SCHMIDT R.** Testing individual risk of acute mountain sickness at greater altitudes. Mil Med. 2009; 174: 363-369. doi:10.7205/MILMED-D-01-3308

(10) **TANNHEIMER M, BUZZELLI MD, ALBERTINI N, LECHNER R, ULMER HV, ENGELHARDT M.** Improvement in altitude performance test after further acclimatization in pre-acclimatized soldiers. Mil Med. 2013; 178: 507-510. doi:10.7205/MILMED-D-12-00410

(11) **TANNHEIMER M, VAN DER SPEK R, BRENNER F, LECHNER R, STEINACKER JM, TREFF G.** Oxygen saturation increases over the course of the night in mountaineers at high altitude (3050–6354 m). J Travel Med. 2017; 24. doi:10.1093/jtm/tax041

(12) **YAMAYA Y, BOGAARD HJ, WAGNER PD, NIIZEKI K, HOPKINS SR.** Validity of pulse oximetry during maximal exercise in normoxia, hypoxia, and hyperoxia. J Appl Physiol. 2002; 92: 162-168. doi:10.1152/japplphysiol.00409.2001