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# PULSE OXIMETRY ANALYSIS AT HIGH ALTITUDE LEH & AT SEA LEVEL OF PORT BLAIR

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## ABSTRACT

**Introduction-** Pulse oximetry is a non-invasive method for monitoring blood oxygen saturation based on Lambert-Beer law (Pulse Oximetry Wikipedia & Carl D. Mottram Ruppel Manual ) Research question was to observe & analyse peripheral oxygen saturation % (SPO2) and Pulse rate in beats per minute at high altitude Leh & at sea level of Port Blair India. **Method-** Research study setting was in two different groups in high altitude at Leh India at altitude of 3,524 meters & near sea level at 0 meters at Port Blair India. Study design was observational ,analytic comparative ,cross sectional study. In ethics written informed consent were taken from randomly & conveniently selected 20 human male subjects, each group consist of 10 subjects between age group of 20-30 years. Inclusion criteria were no abnormality detected in history taking (Hutchison's Clinical Methods). Study period was two years. Instrument Romson's Finger Pulse Oximeter Model MD300C2 Version 1.0 was used to record observation on right index finger ; is a portable non-invasive device intended for spot checking of arterial haemoglobin SPO2 % is a percentage of oxy haemo-globin capacity compounded with oxygen by all combinative haemoglobin capacity in blood and Pulse rate in beats per minute of subject with OLED displays. In interpretation Normally, the SpO2 of a healthy subject is at least 95%, while values <90% are considered low and possibly alarming. Pulse rate ranges Interpretations:60-100 bpm: Normal adult resting range; Below 60 bpm: May be normal for athletes or indicate bradycardia; Above 100 bpm: May indicate tachycardia, stress, or other conditions. Normal SpO2 with elevated pulse might suggest anxiety, while low SpO2 with elevated pulse could indicate respiratory distress. (Broaddus, Murray & Nadel, Duncan, Gwinnet GPS Team). In statistical methods Data were analysed using procedures corresponding to IBM SPSS Statistics 32.0 version. **Result-** Independent-samples t-tests showed that Age was similar between groups (Leh 24.50±2.92 years vs Port Blair 23.10±2.85 years; p=0.292). $SpO_2$ was markedly lower at Leh (90.90±1.91%) than at Port Blair (98.10±0.74%); p<0.001. Pulse rate was higher at Leh (81.90±5.80 bpm) than at Port Blair (73.50±8.29 bpm); p=0.017. At Leh Pearson correlation analysis demonstrated a statistically significant strong inverse correlation between $SpO_2$ and Pulse Rate ($r = -0.712$, $p = 0.021$). Spearman rank correlation produced a similar result ($\rho = -0.746$, $p = 0.013$). While at Port Blair Pearson correlation analysis demonstrated weak negative, statistically non-significant correlation: $r = -0.173$, $p = 0.634$ Spearman correlation: $\rho = -0.139$, $p = 0.703$ **Conclusion-** Pulse oximetry research has given baseline data analysis among healthy adults about peripheral oxygen saturation SPO2 % & pulse rates in beats per minute in environmental challenges at high altitude Leh & near sea level at Port Blair India ; which are helpful in interpretation of various health & disease conditions in context with clinical history , sign & symptoms.

**KEYWORDS :** Pulse Oximetry, High Altitude Leh, Sea Level Port Blair

## INTRODUCTION

The first pulse oximeter was developed in 1972 by Japanese bioengineers Takuo Aoyagi and Michio Kishi at Japanese medical electronic equipment manufacturer Nihon Kohden, using the ratio of red to infrared light absorption of pulsating components at the measuring site. (1) Pulse oximetry is a non-invasive method for monitoring blood oxygen saturation. Peripheral oxygen saturation ($SpO_2$) readings are typically within 2% accuracy (within 4% accuracy in 95% of cases) of the more accurate (and invasive) reading of arterial oxygen saturation ($SaO_2$) from arterial blood gas analysis. The two wavelengths measure the quantities of bound (oxygenated) and unbound (non-oxygenated) haemoglobin, and from their ratio, the percentage of bound haemoglobin is computed. The most common approach is transmissive pulse oximetry. (2)

Pulse oximeters are commonly used to assess oxygenation noninvasively .Pulse oximeters treat Hb as a filter that allows only red and near infrared light to pass . The Lambert-Beer law relates total absorption in a system of absorbers to the sum of their individual absorptions .The light source used in pulse oximetry is the light emitting diode (LED). LED are capable of emitting a very bright light near the 660 nm and 940 nm wavelengths required for analysis of haemoglobin saturation.(3) A standard pulse oximeter passes two wavelengths of light through tissue to a photodetector. Taking advantage of the pulsate flow of arterial blood, it measures the change in absorbance over the course of a cardiac cycle, allowing it to determine the absorbance due to arterial blood alone, excluding unchanging absorbance due to venous blood, skin, bone, muscle, fat, and, in many cases, nail polish. (4) A pulse oximeter shines 2 beams of light through a finger one beam is a red light (which is seen) one is infrared light (invisible) These 2 beams of light can let the pulse oximeter detect what colour the arterial blood is and it can then work out the oxygen saturation. The pulse oximeter measures the percentage of the patient's haemoglobin, which is saturated with oxygen. This provides important clinical data about the patient's oxygenation status, since 97% of oxygen is transported bound to haemoglobin, and only 3% dissolved in plasma. In normal circumstances the SaO2 correlates with the partial pressure of dissolved oxygen (PaO2), which can be represented by the oxyhaemoglobin dissociation curve. However, this relationship is not linear, such that SaO2 does not equal PaO2. (5) The pulse oximeter may be incorporated into a multiparameter patient monitor. Most monitors also display the pulse rate. Portable, battery-operated pulse oximeters are also available for transport or home blood-oxygen monitoring For patients with COVID-19, pulse oximetry helps with early detection of silent hypoxia, in which the patients still look and feel comfortable, but their $SpO_2$ is dangerously low (6) Pulse oximetry also used at intensive care, operating, recovery, emergency and hospital ward settings, pilots in unpressurized aircraft, for assessment of any patient's oxygenation, and determining the effectiveness of or need for supplemental oxygen. However, the use of a pulse oximeter to detect hypoventilation is impaired with the use of supplemental oxygen, as it is only when patients breathe room air that abnormalities in respiratory function can be detected reliably with its use. (7) Air, which has an approximate composition of 79% nitrogen and 21% oxygen. The total pressure of this mixture at sea level averages 760 mm Hg. As molecular basis of pressure ; each gas contributes to the total pressure in direct proportion to its concentration. Therefore, 79% of the 760 mm Hg is caused by nitrogen (600 mm Hg) and 21% by O2 (160 mm Hg). Thus, the partial

pressure of nitrogen in the mixture is 600 mm Hg, and the partial pressure of O2 is 160 mm Hg; the total pressure is 760 mm Hg, the sum of the individual partial pressures. So Atmospheric Air PO2 159 mm Hg (20.84% ) Humidified Air PO2 149.3 mm Hg (19.67%) Alveolar Air PO2 104 mm Hg (13.6%) Expired Air 120 mm Hg (15.7%) (8) The International Society for Mountain Medicine categorizes high-altitude environments into 3 regions based on elevation, as follows: High altitude: 1,500 to 3,500 m (4,900-11,500 ft) above sea level. Very high altitude: 3,500 to 5,500 m (11,500-18,000 ft) above sea level Extreme altitude: At least 5,500 m (18,000 ft) above sea level (9) The atmospheric pressure at any spot on earth is a measure of the weight of a column of air directly over that spot. At sea level the weight (and height) of that column of air is greatest. As one climbs to higher and higher altitudes the height and, of course, the weight of the column are reduced Consequently, atmospheric pressure decreases with increasing altitude, the air is less dense, and each liter of air contains fewer molecules of gas Since the percentages of O2, CO2, and N2 are the same at altitude as at sea level, any change in the partial pressure of each gas is due solely to the change in the atmospheric or barometric pressure The decrease in the partial pressure of O2 (P02) with increasing altitude has a direct effect on the saturation of hemoglobin and, consequently, oxygen transport.

This lower PO2 is called hypoxia, with normoxia being the term to describe the P02 under sea-level conditions The term hyperoxia describes a condition in which the inspired PO2 is greater than that at sea level. In addition to the hypoxic condition at altitude, the air temperature and humidity are lower, adding potential temperature regulation problems to the hypoxic stress of altitude. (10) When mountain climbers ascend to high altitudes where significantly reduced PO2 can substantially impair physical performance and can even jeopardize life.(11) Mountain covers one-fifth of of earth's surface ;140 million people live permanently at altitude > 2500 meters, and 100 million people travel to high -altitude locations each year. Skiers Alps or Aspen ;tourist to La Paz , Ladakh ,or Lhasa; religious pilgrims to Kailash- Mansarovar or Gosainkunda; trekkers & climbers to Kilimanjaro, Aconcagua ,or Everest ; miners working in high altitude sites in South America ; and military personnel deployed in high altitude locations are all at risk of various altitude related diseases (12) Hypoxia, defined as diminished oxygen availability, decreases both the alveolar oxygen partial pressure and arterial partial pressure of oxygen (PaO2). For every 1,000-meter gain in altitude, PaO2 falls by approximately 12 mm Hg. Hypoxemia is defined as a PaO2 below 60 mm Hg or an arterial oxygen saturation less than 90%. In most individuals, hypoxemia begins to occur between 2,000 and 3,000 meters of altitude (13) In context with oxygen loading at altitude the S shaped nature of the oxyhaemoglobin dissociation curve indicates that only a small change occurs in haemoglobin's percentage saturation with oxygen until an altitude of about 3048 meters. At 1981 meter ,for example alveolar PO2 decreases from its sea level value of 100 mm Hg to 78 mm Hg, yet haemoglobin remain 90% saturated with oxygen. This relatively small arterial desaturation exerts little effect on a person during rest or performances of mild exercise but, severely curtails performances in vigorous aerobic activities . The poorer performances of men & women in middle – distance & distance running & swimming during 1968 Mexico city Olympics at altitude of 2300 meters ; resulted from the small reduction in oxygen transport at this altitude. Altitude does not impair the short term anaerobic activities eg. shot put ,hammer throw, javelin & performance in single bout of such activities often improves because of low air densities at altitude than at sea level , although impaired performance has been reported for repeated interval of short term power output in elites athletes. Sympatho-adrenal activity progressively increases with over time during rest & exercise with altitude exposure. Increased blood pressure & heart rate at altitude coincides with study rise in plasma levels & excretion rates of epinephrine. 24 hour urinary excretion of epinephrine changes little but norepinephrine excretion increased by 4th day & remain elevated for approximately 1 week following return to sea level .High altitude hypoxia leads to faster heart rate response because peripheral chemoreceptors also cause stimulation of sympathetic nervous system this responds to stressful situations, such as when ; body realizes it needs to work a little harder to retrieve oxygen. In response, heart rate may increase to deliver more oxygen-filled blood to your body.(14) Research question was to analyse peripheral oxygen saturation (SPO2) and Pulse rate at high altitude & at sea level.

## MATERIAL & METHODS

Research study setting was in two different groups in high altitude at Leh (capital city of Ladakh India at altitude of 3,524 meters /11,562 ft) )(15) & near sea level at 0 meter at Port Blair (officially named Sri Vijaya Puram, is the capital city of the Indian union territory of Andaman & Nicobar Islands )(16)(17) Study design was observational, analytic comparative ,cross sectional study. In ethics written informed consent were taken from randomly & conveniently selected 20 human male subjects, each group consist of 10 subjects between age group of 20-30 years inclusion criteria includes no abnormality detected in history taking (18)(19) & exclusion criteria were any abnormality detected in history taking with any smoking or alcohol intake history. Study period was two years. In this research instrument used was Romson's Finger Pulse Oximeter Model MD300C2 Version 1.0 was used to record observation is a portable non-invasive device intended for spot checking of arterial haemoglobin SPO2 % is a percentage of oxyhaemoglobin capacity compounded with oxygen by all combinative haemoglobin capacity in blood and Pulse rate of subject with OLED displays SPO2 % ,Pulse rate in beat per minute, Pulse bar, & waveform. Following instructions as given in user manual were given to subjects - Place the index finger into the rubber opening of the pulse oximeter, press the switch button one time on front panel to turn the pulse oximeter on, keep your hands still, for the reading, Do not shake your finger during test, Do not move your body while taking a reading, Data was read from the display screen. Principal of Oximeter is as follow. A mathematical formula is established making use of Lambert Beer Law according to spectrum absorption characteristics of reductive haemoglobin and oxyhaemoglobin in red & near infra-red zones. In operational principal of instrument ; photoelectric oxy-haemoglobin inspection technology is adopted in accordance with capacity pulse scanning & recording technology, so that two beams of different wavelength of lights (660 nm red & 905 near infra-red light ) can be focused on to a human nail tip through a clamping finger type sensor. A measured signal obtain by a photosensitive element, will be shown on oximeter display through process in electronic circuits & microprocessor .(20) In interpretation Normally, the $SpO_2$ of a healthy subject is at least 95%, while values <90% are considered low and possibly alarming (21,22) SpO2 ranges & Pulse rate ranges and their meanings :SPO2 95-100%: Normal oxygen levels; 90-94%: Mild hypoxemia, may need assessment ; Below 90%: Significant hypoxemia requiring medical attention; Below 85%: Severe hypoxemia, urgent medical care needed. Pulse Rate ranges Interpretations:60-100 BPM: Normal adult resting range; Below 60 BPM: May be normal for athletes or indicate bradycardia; Above 100 BPM: May indicate tachycardia, stress, or other conditions. Normal SpO2 with elevated pulse might suggest anxiety, while low SpO2 with elevated pulse could indicate respiratory distress. Monitoring your body's response to activity is also essential.SpO2 should remain stable during mild activity, and pulse rate should increase proportionally to exertion level.(23) In statistical methods Data were analysed using procedures corresponding to IBM SPSS Statistics 32.0 version. Continuous variables are summarized as mean ± standard deviation (SD), median, minimum and maximum. Between-group comparisons were performed

using the independent-samples t-test. Welch's t-test is also reported because it does not require equal variances. Mann–Whitney U is provided as a non-parametric sensitivity analysis. Pearson correlation was used to assess linear relationships among variables Age, $SpO_2$ and Pulse Rate. Two-sided $p<0.05$ was considered statistically significant. (24)

### Observation

**Table 1-Descriptive Statistics in Two Different Groups at High Altitude Leh & Sea level Port Blair**

| Group | Variable | Mean | SD | Median | Min | Max |
|---|---|---|---|---|---|---|
| Group 1 High Altitude at Leh N=10 | Age (years) | 24.50 | 2.92 | 25.00 | 20 | 29 |
| | SpO2 (%) | 90.90 | 1.91 | 91.00 | 88 | 93 |
| | Pulse Rate (bpm) | 81.90 | 5.80 | 83.00 | 71 | 92 |
| Group 2 Sea Level at Port Blair N=10 | Age (years) | 23.10 | 2.85 | 22.50 | 20 | 28 |
| | SpO2 (%) | 98.10 | 0.74 | 98.00 | 97 | 99 |
| | Pulse rate (bpm) | 73.50 | 8.29 | 76.50 | 60 | 84 |

**Table 2– Normality Check in Two Different Groups at High Altitude Leh & Sea level of Port Blair**

| Group | Variable | Shapiro-Wilk W | p value |
|---|---|---|---|
| Group 1 High Altitude at Leh N=10 | Age | 0.930 | 0.448 |
| | SpO2 | 0.876 | 0.116 |
| | Pulse | 0.976 | 0.941 |
| Group 2 Sea Level at Port Blair N=10 | Age | 0.839 | 0.043 |
| | SpO2 | 0.833 | 0.036 |
| | Pulse | 0.911 | 0.291 |

**Table 3 - Comparison in two Different Groups at High Altitude Leh & Sea Level of Port of Blair**

Independent-samples results are shown below. The equal-variance t-test is the conventional SPSS independent-samples t-test; Welch results are included when variance equality is questionable.

| Variable | Mean difference (Leh-Port Blair) | t (equal var) | p (equal var) | t (Welch) | p (Welch) | Levene F | Levene p | Mann-Whitney U | MW p | Cohen d |
|---|---|---|---|---|---|---|---|---|---|---|
| Age | 1. 400 | 1. 087 | 0. 292 | 1. 087 | 0. 292 | 0. 045 | 0. 834 | 64. 000 | 0. 304 | 0. 486 |
| SpO2 | -7. 200 | -11. 110 | 0. 000 | -11. 110 | 0. 000 | 20. 238 | 0. 000 | 0. 000 | 0. 000 | -4. 968 |
| Pulse | 8. 400 | 2. 625 | 0. 017 | 2. 625 | 0. 018 | 3. 450 | 0. 080 | 79. 500 | 0. 028 | 1. 174 |

**Table 4 - Correlation Analysis in Two Different Groups at High Altitude Leh & Sea Level of Port of Blair**

| Group | Variable 1 | Variable 2 | Pearson r | p value | N |
|---|---|---|---|---|---|
| Group 1 High Altitude at Leh N=10 | Age | SpO2 | 0.468 | 0.172 | 10 |
| | Age | Pulse | -0.608 | 0.062 | 10 |
| | SpO2 | Pulse | -0.712 | 0.021 | 10 |
| Group 2 Sea Level at Port Blair N=10 | Age | SpO2 | -0.005 | 0.988 | 10 |
| | Age | Pulse | -0.228 | 0.526 | 10 |
| | SpO2 | Pulse | -0.173 | 0.634 | 10 |
| Pooled | Age | SpO2 | -0.124 | 0.602 | 20 |
| | Age | Pulse | -0.183 | 0.441 | 20 |
| | SpO2 | Pulse | -0.623 | 0.003 | 20 |

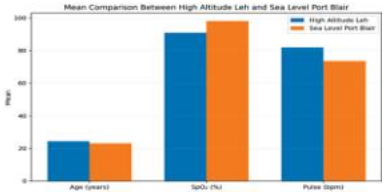



**Figure 1. Graphical presentation of Mean comparison of Age, $SpO_2$ and Pulse Rate variables**

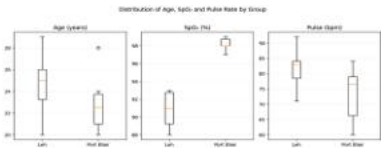


**Figure 2. Boxplots showing distributions in the two groups**

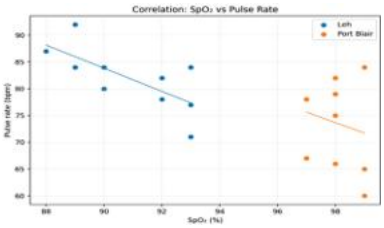



**Figure 3. Relationship between $SpO_2$ and Pulse Rate**

## RESULTS

Independent-samples t-tests showed that Age was similar between groups (Leh 24.50±2.92 years vs Port Blair 23.10±2.85 years; $p=0.292$). $SpO_2$ was markedly lower at Leh (90.90±1.91%) than at Port Blair (98.10±0.74%); $p<0.001$. Pulse rate was higher at Leh (81.90±5.80 bpm) than at Port Blair (73.50±8.29 bpm); $p=0.017$. At Leh Pearson correlation analysis demonstrated a statistically significant strong inverse correlation between $SpO_2$ and Pulse Rate ($r = -0.712$, $p = 0.021$). Spearman rank correlation produced a similar result ($\rho = -0.746$, $p = 0.013$). While at Port Blair Pearson correlation analysis demonstrated weak negative, statistically non-significant correlation: $r = -0.173$, $p = 0.634$ Spearman correlation: $\rho = -0.139$, $p = 0.703$

## DISCUSSION

Pulse oximetry is estimation of arterial saturation by analysis of light absorption of blood pulsating through a capillary bed (finger or ear lobe )(25) Pulse oximeters measure the light absorption of a mixture of two forms of haemoglobin oxy Hb & reduced Hb . The relative absorption at 660 nm (red) & 940 nm of light (near infrared) can be used to calculate the combination of two Hb forms . Absorption of two wavelengths provides an estimate of the saturation of available Hb. Most pulse oximeters use a stored calibration curve to estimate oxygen saturation . Pulse oximetry may be used in any setting in which a non-invasive measure of oxygenation status is sufficient eg. oxygen therapy, ventilator management , bronchoscopy, sleep studies, stress testing, during patient transport, surgical procedures, rehabilitation, continuous monitoring, overnight studies, spot checks etc. Most pulse oximeters use a sensor that attaches to finger , toe (nail bed), or ear . The ear site may be preferred in patient undergoing exercise testing or in whom arm movement precludes the use of the finger site . Both finger & ear sites presume pulsatile blood flow. Most pulse oximeters adjust light output to compensate for tissue density or pigmentation . In some patients impaired perfusion to one site determines which site is preferred . Low perfusion or poor vascularity can cause the oximeter to be unable to detect pulsatile blood flow. Rubbing or warming of site often improves local blood flow & may be indicated to obtain reliable data. Some pulse oximeters use reflective sensors that detect light reflected from bone underlying the tissue bed . These sensors are usually placed on patient forehead and may function when finger & ear sensors are do not and may be preferred site during exercise when motion artefact can be issue. Most pulse oximeters report heart rate also. In context with pulse oximetry ; criteria for acceptability remain following – (A) Documentation of adequate correlation with measured Sao2 should be available. Spo2 & Sao2 should be within 2% from 85% to 100 % saturation. Elevated COHb >3% or MetHb >2% may invalid Spo2. (B) Adequate perfusion of the sensor site should be documented by agreement between oximeter & patient

heart rate ( ECG or by palpation) & reproducible pulse waveforms if available. (C) Known interfering substances or agents should be eliminated or accounted for.(D) Pulse oximeter readings should be stable long enough to answer the clinical question being investigated. Readings should be consistent with the patient's clinical history and presentation.Validity of Spo2 measurement are limited by Interfering substances eg. COHb, Met-Hb,Intra-vascular dyes (indocyanine green),Nail polish or coverings (finger sensor) & Interfering factors eg. Motion artefact, shivering, bright ambient lighting , hypotension, low perfusion (sensor site ),hypothermia, vasoconstrictor drugs ,dark skin pigmentation, artificial nails or dark nail polish. (26) Causes and mechanisms of unreliable SpO2 readings are (A). Causes of intermittent drop-outs or inability to read SpO2 : Poor perfusion due to a number of causes, e.g., hypovolemia, vasoconstriction, etc (B). Causes of falsely normal or elevated SpO2 : Carbon monoxide poisoning, Sickle cell anemia vaso-occlusive crises (overestimation of FO2Hb and underestimation of SaO2) (C) Causes of falsely low SpO2 : Venous pulsations Excessive movement, Intravenous pigmented dyes, Inherited forms of abnormal hemoglobin, Fingernail polish, Severe anemia (with concomitant hypoxemia) (D) Causes of falsely low or high SpO2 are Methemoglobinemia, Sulfhemoglobinemia, Poor probe positioning,Sepsis and septic shock. (E) Causes of falsely low FO2Hb as measured by a co-oximeter are Severe hyperbilirubinemia , Fetal Hb (HbF) (27) Pulse oximeters are routinely used in various medical-grade and consumer-grade applications.

They can be used to estimate, for example, blood oxygen saturation, autonomic nervous system activity and cardiac function, blood pressure, sleep quality, and recovery through the recording of photo-plethysmography signal. Medical-grade devices often record red and infra-red light-based photo-plethysmography signals while smartwatches and other consumer-grade devices usually rely on a green light. At its simplest, a pulse oximeter can consist of one or two photodiodes and a photodetector attached, for example, a fingertip or earlobe. These sensors are used to record light absorption in a medium as a function of time. This time-varying absorption information is used to form a photo-plethysmography signal. (28 ) Mobile app pulse oximeters use the flashlight and the camera of the phone, instead of infrared light used in conventional pulse oximeters. However, apps do not generate as accurate readings because the camera cannot measure the light reflection at two wavelengths, so the oxygen saturation readings that are obtained through an app on a smartphone are inconsistent for clinical use. At least one study has suggested these are not reliable relative to clinical pulse oximeters.(29) The new prototype of smartphone powered pulse oximeter demonstrated better performance compared to the existing low-cost fingertip pulse oximeters. The device could be used for independent monitoring of COVID-19 patients at health institutions and also for home care. (30)Fingertip smart pulse oximeter with wireless Bluetooth with Android & IOS system are also one the recent advances that noninvasively track & trend of oxygen saturation ,pulse rate and perfusion index for health , wellness sport and aviation use (31) In research work A total of 6289 subjects were studied: 47.2% (n=2967) males and 52.8% females (n=3322). The median (IQR) for all SpO2 measurements at each altitude (metre) were respectively: 99 (98–99) at 154 m; 99 (98–99) at 562 m; 98 (97–99) at 1400 m; 97 (96–98) at 2000 m; 97 (96–99) at 2335 m; 96 (95–97) at 2500 m; 95 (94–96) at 2880 m; (92–95) at 3250 m; 92 (90–93) at 3600 m; 90 (88–91) at 3950 m; 87 (85–89) at 4100 m; 87 (85–89) at 4338 m; 87 (85–89) at 4500 m 85(83–88) at 4715 m; 81 (78–84) at 5100 m. in evaluating patients at high altitude, their history and clinical presentation must be incorporated into deciding whether an individual SpO2 measurement should raise concern for a patient at their usual residential altitude. (32) The presented findings from the literature review confirm rather large variations of pulse oximetry measures ($SpO_2$ and HR) during acute exposure and acclimatization to high altitude, related to the varying conditions between studies mentioned above. It turned out that particularly $SpO_2$ levels decrease with acute altitude/hypoxia exposure and partly recover during acclimatization, with an opposite trend of HR. Moreover, the development of acute mountain sickness (AMS) was consistently associated with lower $SpO_2$ values compared to individuals free from AMS. The use of finger pulse oximetry at high altitude is considered as a valuable tool in the evaluation of individual acclimatization to high altitude but also to monitor AMS progression and treatment efficacy. (33) Another research reflected $SpO_2$ at 2900 m and 5050 m on arrival was mean ± SD 93.6 ± 0.5% and 79.9 ± 1.0% ($P < 0.05$ between altitudes) (34) In research arterial oxygen saturation done by pulse oximetry showed at rest & with exercise findings at at sea level (rest 98.5%, 25 w 98.3% and 50 w 98.3%) but declined at rest & more steeply with exercise at 5000 m (rest 88.8 +/-0.6%, 25 w 85.4 +/-0.4% and 50 w 84.4 +/- 0.5%) (35) Elevated heart rate (HR) has been demonstrated in response to acute hypoxia exposure, which is reportedly due to sympathetic nervous system activation (SNS) and concurrent withdrawal of parasympathetic nervous system activity (PSNS)(36)(37) Altitude Impacts on Heart Rate observed after acute exposure of hours to days (resting heart increased, maximum heart rate unchanged or slightly increased, reason peripheral chemoreceptor activation & sympathetic surge). (38)(39)After chronic exposure for weeks to altitude ( RHR elevated, MHR decreased reason beta adrenergic receptor downregulation & autonomic remodelling.(40)(41) While in native highlanders (RHR) normal/adapted, MHR normal /blunted because of genetic adaptations favouring parasympathetic predominance (42)

In research done in 240 subjects Heart Rate at altitude observations were more 72(63, 80) beats/min than heart rate at sea level 65 (59, 71) beats/min ($p < 0.001$) (43) High altitude reasons of the world , once considered remote & accessible to only a few individuals, are in-fact home to over 200 million people living permanently above 2500 meters in Asia, South America, & North America . In South America, miners, astronomers work for long durations at altitude over 4500 meters , while an around equal numbers of tourists spend time at these altitudes in such activities as trekking , skiing ,and pilgrimages. Any one at these altitudes is susceptible to high altitude illnesses which , if not recognized and appropriately treated, can spoil the experience of alpine environments, impair work ability, and in the worst scenarios cause death. In the high altitude environment , although the percentage of oxygen in ambient air remains constant at 21% , barometric pressure decreases with increasing altitude , leading to corresponding fall in partial pressure of oxygen (PO2). At 2500 meters the barometric pressure & inspired PO2 are about 75% of sea-level value . On the summit of Mount Everest at 8848 Meters PO2 is about one-third of sea level value. Altitude related classification & definitions are following. (Intermediate Altitude 1500-2500 Meters – Physiological changes due to hypobaric hypoxia such as reduced exercise performance, increased ventilation, increased haematopoiesis are detectable , but arterial oxygen saturation remain above 90%. Acute altitude illness is unlikely.) (High Altitude 2500-3500 Meters – Acute altitude illness is common following rapid ascent to this altitude.) (Very High Altitude 3500-5800 Meters – Arterial oxygen saturation falls below 90% ,Acute altitude illness is common & marked hypoxaemia can occur during exercise & sleep)( Extreme Altitude > 5800 Meters – Further acclimatization cannot be achieved ,progressive physiological deteriotion occur and survival cannot be maintained permanently, marked hypoxaemia occur at rest (44)Pulse oximetry is sometimes referred to as the fifth vital sign; In most developed countries, pulse oximetry is the standard of care to use pulse oximetry to

monitor oxygen saturation for patients receiving anaesthesia.(45-46) Pulse oximetry is also used in emergency departments, hospital wards, and ambulances to assess blood oxygenation in patients with respiratory difficulties or to monitor the potential respiratory depressant effects of pain medications. Since the widespread use of pulse oximetry in hospitals was instituted, the incidence of unrecognized oxygen desaturation has decreased significantly.(47) Peripheral oxygen saturation (SpO ) decreases with an increase in altitude because of the exponential drop in total barometric pressure, which directly reduces the partial pressure of inspired oxygen (PO ) and limits hemoglobin loading (48) The most important principle is that SpO must be interpreted in relation to altitude, duration of exposure, symptoms, baseline oxygen saturation, and physiological adaptation ; not as an isolated numerical value. An SpO reading around 90% can be entirely normal at high altitudes It is normal for SpO to temporarily dip during sleep or immediately after physical exertion. A resting daytime reading is the most accurate baseline Normal Adaptation Signs: Asymptomatic , Mild, transient headache or slight shortness of breath during physical exertion that quickly resolves with rest . Low oxygen triggers peripheral chemoreceptors (in the carotid bodies), causing an compensatory involuntary increase in both tidal volume (breathing depth) and respiratory rate & slightly elevated but stable respiratory rate and heart rate at rest, it indicates the body is successfully attempting to pull in more oxygen molecules .So in Physiological adaptation to high altitude, $SpO_2$ may be around 88–92%, depending on altitude and acclimatization. Mild increase in respiratory and heart rates. No significant headache, nausea or neurological symptoms. No breathlessness at rest. Stable or improving oxygen saturation over time.

If SPO2 continue to consistently below 90%, it signals failure to adapt. If an SpO2 of 90% or below this level is accompanied by any clinical symptoms & signs then the primary treatment is to stop climbing and immediately descend to a lower altitude. Eg. Acute Mountain Sickness (AMS) -A persistent, throbbing headache after ascent paired with nausea, vomiting, dizziness, extreme fatigue, or insomnia occurs. Drugs used are Acetazolamide, Dexame-thasone,. Medical Emergencies - HAPE High Altitude Pulmonary Edema -Non-cardiogenic pulmonary edema SPO2 drop that is 10% or more below the average reading of peers at the same altitude points to pathological changes such as fluid accumulation impairing alveolar diffusion. Severe shortness of breath at rest, a persistent wet cough, pink or frothy sputum, crackles on auscultation, blueish lips and nail beds occurs.Early Descent & Drugs used are Oxygen, or portable hyperbaric oxygen therapy & chamber (Gamow Bag), Nifedipine, Dexamethasone, Sildenefil, Tadalafil, Salmeterol. HACE High Altitude Cerebral Edema- Confusion, ataxia, inability to walk in a straight line, similar to alcohol intoxication. or blueish lips and nail beds occurs, drowsiness or reduced consciousness. Coma is likely to ensue within 12–24 hours of the onset of ataxia in the absence of treatment or descent. Early Descent & Drugs used are Oxygen, or portable hyperbaric oxygen therapy & chamber (Gamow Bag), Nifedipine, Dexamethasone. If a person has pre-existing conditions like COPD, asthma, or heart failure, a drop to 90% may trigger severe chest tightness, wheezing, or an inability to catch their breath even with minimal movement. Consider clinical investigations Repeat pulse oximetry: Warm the fingers, ensure good peripheral perfusion, minimize movement and check the signal quality. Arterial blood gas (ABG): Measure $PaO_2$, $PaCO_2$ and pH; interpret $PaO_2$ against the altitude and clinical context. Complete blood count: Assess haemoglobin and possible anaemia, infection etc.Chest X-ray: Evaluate suspected pulmonary edema, pneumonia or other lung pathology. ECG: Assess associated cardiac abnormalities. Echocardiography: Consider when pulmonary hypertension or cardiac disease is suspected.(49) High-altitude environments expose travelers to cold, low humidity, increased ultraviolet radiation, and decreased air pressure, all of which can cause health problems. The biggest concern, however, is hypoxia, due to the decreased partial pressure of oxygen ($PO_2$). At around 3,050 m (approximately 10,000 ft), for example, the inspired $PO_2$ is only 69% of that at sea level; acute exposure to this reduced $PO_2$ can lower arterial oxygen saturation to 88–91%. Healthcare professionals should provide international travelers visiting high altitudes with guidance on gradual acclimatization and medications to prevent altitude illness. Acclimatization tips: A checklist for travellers - Ascend gradually. Avoid going directly from low altitude (1,200 m or <4,000 ft) to 2,750 m (>9,000 ft) sleeping altitude in one day. Once above 3,000 m (9,850 ft), move sleeping altitude by no more than 500 m (1,600 ft) per day and plan an extra day of acclimatization for every additional 1,000 m (3,300 ft) of sleeping altitude gain. Consider using acetazolamide to speed acclimatization if abrupt ascent is unavoidable. Avoid alcohol for the first 48 hours at high altitude. If a regular caffeine user, continue using to avoid a withdrawal headache that could be confused with an altitude headache. Participate in only mild exercise for the first 48 hours at altitude. A high-altitude exposure (>2,750 m; >9,000 ft) for ≥2 nights, within 14 days before the trip, is useful but closer to the trip departure is better.(50) Mountainous regions pose unique challenges to sports participation Proper planning before for high altitude tour, special equipment ,medications availability kit ,rates of slow ascent for acclimation & early descent extraction plan are required .(51) In sports medicine ; to overcome various challenges, different models of altitude training have been developed, where the times of training and passive recovery are spent at different altitudes : Live high train high, Live high train low, Live low train high .(52)

## CONCLUSION

Pulse oximetry research has given baseline data analysis among healthy adults about peripheral oxygen saturation SPO2 % & pulse rates in beats per minute in environmental challenges at high altitude Leh & near sea level at Port Blair India ; which are helpful in interpretation of various health & disease conditions in context with clinical history , sign & symptoms & physical examination.

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