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ORIGINAL ARTICLE

Peripheral Oxygen Saturation and Regional Cerebral Oxygenation Analysis in Adults for Healthy and Diseased Conditions

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Abstract

Objectives: To investigate the association between SpO_2 and $rScO_2$ and to determine whether age and health status influence cerebral oxygenation measured using the developed prototype. **Method:** Observational research was performed with a total of 45 adults divided into two age categories: 18–30 years and 31–60 years consisting health status as normalcy, diabetes, and thyroid. Peripheral oxygen saturation (SpO2) from commercially available device and regional cerebral oxygen saturation (rScO2) from our developed prototype device were measured non-invasively during a tranquil resting phase in a domestic or communal environment using a prototype device that measure both the parameters. Repeated paired assessments were collected from every subject. Descriptive statistics and regression analysis elucidate the correlation between SpO_2 and $rScO_2$. **Findings:** Among 45 adults, SpO_2 showed a weak positive correlation with $rScO_2$ ($r = 0.238$, $R^2 = 0.057$, $p = 0.116$). The diabetes subgroup demonstrated a stronger positive association ($r = 0.543$, $R^2 = 0.294$, $p = 0.055$), compared with the apparently healthy ($r = -0.131$, $p = 0.581$) and thyroid disorder ($r = 0.152$, $p = 0.637$) groups. The findings provide preliminary observations on the relationship between SpO_2, and prototype-derived $rScO_2$. **Novelty:** This study presents a prototype-based, non-invasive approach for simultaneous assessment of peripheral oxygen saturation and regional cerebral oxygenation, demonstrating its potential for practical cerebral oxygenation monitoring across different health groups and age profiles.

Keywords: Peripheral oxygen saturation; Regional cerebral oxygenation; Adults; Physiological monitoring

1 Introduction

Peripheral oxygen saturation (SpO_2), assessed via pulse oximetry, serves as a prevalent non-invasive marker of systemic arterial oxygen levels. Nonetheless, systemic oxygen saturation does not accurately reflect the oxygenation condition of brain tissue. Regional cerebral oxygen saturation ($rScO_2$), typically evaluated using near-infrared spectroscopy (NIRS), offers a non-invasive assessment of the equilibrium between cerebral oxygen supply and utilization, hence furnishing additional insights alongside traditional systemic monitoring [1].

Cerebral NIRS has evolved from a primarily perioperative monitoring method to more widespread uses in critical care, patients without brain damage, and physiological studies in recent years. Although its promise for continuous, non-invasive cerebral oxygenation monitoring has been recognized in recent studies, physiological and technical factors continue to influence its therapeutic interpretation. The data on the clinical benefits of cerebral NIRS is still unclear, according to a systematic review of 25 randomized trials with 2606 individuals. This highlights the need for more research assessing the measuring properties and clinical relevance of cerebral NIRS [2]. The recorded signal may be impacted by extracerebral tissues, such as the scalp and skull, which is a significant restriction of cerebral NIRS. The contribution of extracerebral tissue to continuous-wave NIRS data was shown to be highly unclear in a comprehensive assessment of 34 adult investigations, underscoring the need for better measuring and analysis techniques [3]. Recent advancements in technology have made an effort to overcome this constraint. For example, hyperspectral time-resolved NIRS has been investigated for improved estimation of adult cerebral oxygenation by accounting for extracerebral-layer contamination [4]. These advancements highlight the ongoing need for accessible and useful methods for assessing cerebral oxygenation. The relationship between systemic and regional oxygen saturation also appears to be more complex than a direct equivalence between SpO_2 and $rScO_2$. Mizukoshi et al. developed an NIRS-based regional oxygen saturation measurement system and simultaneously compared regional oxygen saturation with pulse-oximeter SpO_2 in women aged 20–60 years. There was no discernible association between the two metrics, despite the fact that both showed age-related fluctuation ($r = 0.18$, $p = 0.16$) [5]. More recently, a study involving 100 adults during hypoxia testing compared cerebral NIRS with conventional pulse oximetry and demonstrated that the two measurements behaved differently during hypoxic exposure [6]. These results imply that measures of peripheral and brain oxygen saturation are not always interchangeable. Recent studies have demonstrated altered cerebral oxygenation and hemodynamic responses in individuals with type 2 diabetes. During cardiopulmonary exercise testing, individuals with type 2 diabetes exhibited altered cerebral haemoglobin responses compared with healthy controls [7]. The idea that metabolic dysfunction may affect cerebral oxygen supply is supported by more recent data showing reduced cerebral hemodynamic and oxygenation in people with type 2 diabetes. Thyroid status may similarly affect cerebral circulation. A large population-based study of 5142 adults reported an inverse U-shaped association between free thyroxine levels and global brain perfusion, while a 2020 meta-analysis identified regional reductions in cerebral blood flow and glucose metabolism in thyroid dysfunction [8], [9].

The significant contributions:

The principal contribution of this study is the prototype-based assessment of the relationship between peripheral oxygen saturation (SpO_2) and regional cerebral oxygen saturation ($rScO_2$) in adults with different health conditions. Unlike studies primarily focused on either systemic oxygenation or cerebral NIRS protype-based monitoring independently, the present study provides quantitative comparative evidence from 45 adults, including apparently healthy, diabetes, and thyroid disorder groups.

The novelty of this paper is as below:

The novelty of this study lies in the prototype-based evaluation of forehead $rScO_2$ with SpO_2 across heterogeneous adult health groups. The study specifically examines whether the SpO_2–$rScO_2$ relationship varies among apparently healthy, diabetes, and thyroid disorder groups, providing a health-group-specific perspective on the interpretation of cerebral oxygenation obtained from a non-invasive optical prototype device.

2 Methodology

Early study demonstrated that near-infrared light is used to measure oxygenation in biological tissue [10]. Later studies have shown that NIRS could provide continuous information on cerebral oxygenation with a relatively high temporal resolution [11]. In our designed system optical sensors are located on the forehead of the subject for estimation of regional cerebral oxygen saturation. Modern systems use various wavelengths and source-detector setups to extract information from deeper tissue, while attempting to compensate for the contribution from surface tissue [12], [13], [14], [15].

2.1 Study design and participants

The suggested research is a cross-sectional observational study that evaluates adult subjects in a home or community setting while at rest. Participants particularly belong from nearby our university area (Ahmedabad, Gujarat, india) are selected for the study. A total of 45 participants were included in the study, comprising 20 apparently healthy participants, 13 participants with diabetes mellitus, and 12 participants with thyroid disorders. Participants, who were diagnosed with either thyroid or diabetes were under the treatment with medications and are found stable during the experiment. Participants were recruited according to predefined eligibility criteria. The study sample comprised 45 participants and was determined based on the feasibility of recruiting participants from the predefined health groups and the exploratory nature of the prototype evaluation. Because the primary objective was to characterize the association between SpO_2 and $rScO_2$ and to assess its variability across health groups, the study was designed as a preliminary observational evaluation of the developed prototype.

Adults aged 18-60 years who were able to undergo non-invasive optical measurements were considered eligible. Participants were excluded if they had severe hemodynamic instability, significant peripheral perfusion impairment, inability to tolerate the measurement procedure, or incomplete measurements. The written informed consent was obtained from all participants before data collection.

2.2 Prototype and measurement principle

A forehead optical prototype was developed for non-invasive measurement of regional cerebral oxygen saturation. The prototype employed near-infrared optical sensing components i.e. optode geometry of pair of light emitting diodes and photodiode in near-infrared region (800nm – 1000nm) to obtain cerebral oxygenation information from the forehead. A sensor probe and processing unit constitutes whole system, displaying $rScO_2$ values on graphical liquid crystal display. The system works on the principle of Beer-lambert's' law for the detection of light absorption from underlying tissue i.e. oxygenated haemoglobin and deoxygenated haemoglobin at the forehead and further derive $rScO_2$.

The overall experimental protocol used for simultaneous measurement of peripheral oxygen saturation (SpO_2) and regional cerebral oxygen saturation ($rScO_2$) is illustrated in Figure 1. Prior to measurement, the participant was allowed to rest for an adequate period to minimize the influence of physical activity and transient physiological variations. The measurements were performed under resting conditions in a quiet environment. Subsequent to the repose interval, a commercially obtainable pulse oximeter was affixed on the index digit for the assessment of peripheral SpO_2. Conventional pulse oximetry was used as the comparator method for peripheral oxygen saturation (SpO_2). SpO_2 values were recorded concurrently with prototype-derived $rScO_2$ measurements. The optical sensor of the created prototype was delicately placed on the participant's forehead and kept in consistent contact with the skin during the assessment. Precautions were implemented to prevent undue pressure on the probe, as variations in probe pressure or positioning could alter the measured optical signal and subsequently impact the computed $rScO_2$ value. The optical probe remained stationary during the whole measurement duration, and any significant movement or alterations in its position were prevented to reduce motion-induced and optical anomalies. Participants were instructed to remain in a comfortable and stable position during data acquisition and to minimize movement and talking during the measurement period.

Repeated physiological measurements were obtained during a short observation period. Twenty repeated readings were obtained from each participant. The mean of valid readings was calculated to generate a participant-level SpO_2 and $rScO_2$ value for the primary between-participant analysis. Repeated observations were not considered independent observations. The identical measuring protocol was adhered to for all three participant cohorts. The paired observations of SpO_2 and $rScO_2$ were further analysed using descriptive statistics, Pearson's correlation, and linear regression to assess the connection between peripheral and regional cerebral oxygen saturation.

The demographics of the participant subjects are as per Table 1. Mean Heart Rate (HR) and SpO2 were obtained with a commercially available pulse oximeter, Body Mass Index (BMI) was manually calculated by measuring the subject's weight and height, and rScO2 was assessed using developed prototype device. Figure 1 presents the experimental setup and workflow for concurrent SpO_2 and $rScO_2$ monitoring.

3 Results and Discussion

Peripheral oxygen saturation serves as an important indicator of arterial oxygen levels and is commonly utilized due to its non-invasive nature, cost-effectiveness, and accessibility. However, during crucial cardiac or brain surgery, it does not specifically monitor the oxygenation status of cerebral tissue $rScO_2$. Regional cerebral oxygenation $rScO_2$ is affected by the supply of oxygen and the consumption of oxygen in the brain. Consequently, $rScO_2$ may offer insights that enhance traditional peripheral

Table 1. Demographic and clinical characteristics of study participants

Parameter	Apparently healthy (n=20)	Diabetes (n=13)	Thyroid (n=12)
Age (years), mean±SD	32±12	33±11	33±6
Male	11	5	6
Female	9	8	6
Mean HR (bpm), mean±SD	73.04±11	73±8	71±12
BMI, mean±SD	23±2	26±2	24±2

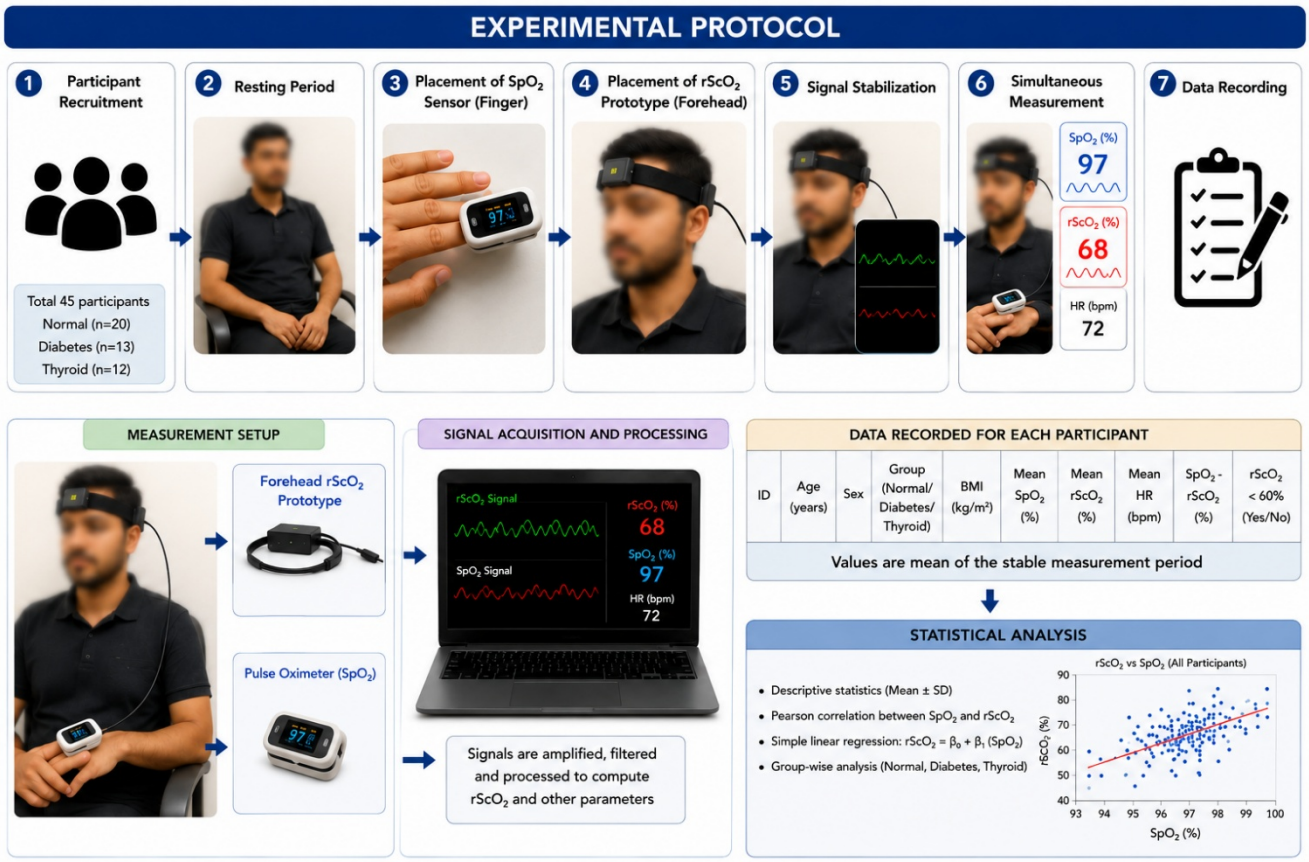


Fig 1. Experimental setup and workflow for concurrent SpO_2 and $rScO_2$ monitoring

oxygen saturation measurements. The relationship between peripheral oxygen saturation (SpO_2) and regional cerebral oxygen saturation ($rScO_2$) was evaluated in 45 participants comprising 20 apparently healthy subjects, 13 subjects with diabetes, and 12 subjects with thyroid disorders [16].

The mean SpO_2 was 97.60 ± 0.37% in the apparently healthy group, 97.03 ± 0.73% in the diabetes group, and 97.59 ± 0.52% in the thyroid group as shown in Table 2. The corresponding mean $rScO_2$ values were 67.86 ± 3.53%, 67.23 ± 4.48%, and 67.80 ± 4.68%, respectively. Across all 45 participants, the mean $rScO_2$ was 67.66 ± 4.05%. Thus, although peripheral oxygen saturation remained close to 97% in all groups, $rScO_2$ demonstrated comparatively greater variability. The diabetic cohort exhibited the lowest average SpO_2; yet, the absolute disparity from the apparently healthy cohort was minimal. The thyroid cohort exhibited a mean $rScO_2$ value nearly equivalent to that of the control group. The average $rScO_2$ for the entire study cohort was 67.66 ± 4.05%.

The principal finding was a weak positive association between SpO_2 and $rScO_2$ in the overall population ($r = 0.238$, $R^2 = 0.057$, $p = 0.116$) in Figure 2. Although the overall association was not statistically significant, the diabetes subgroup demonstrated a comparatively stronger positive association ($r = 0.543$, $R^2 = 0.294$, $p = 0.055$) this association in the diabetes subgroup ($p = 0.055$) was not statistically significant at the 5% level and should be interpreted as an exploratory finding, whereas weak

Table 2. SpO_2 and $rScO_2$ measurements according to health group

Health group	N	SpO2 (%) Mean±SD	rScO2 (%) Mean±SD
Apparently healthy	20	97.6±0.37	67.86±3.53
Diabetes	13	97.03±0.73	67.23±4.48
Thyroid	12	97.59±0.52	67.80±4.68
Overall	45	97.43±0.58	67.66±4.05

associations were observed in the apparently healthy (r = −0.131, R^2 = 0.017, p = 0.581) and thyroid (r = 0.152, R^2 = 0.023, p = 0.637) groups as shown in Figure 3 and Table 3. These findings indicate that

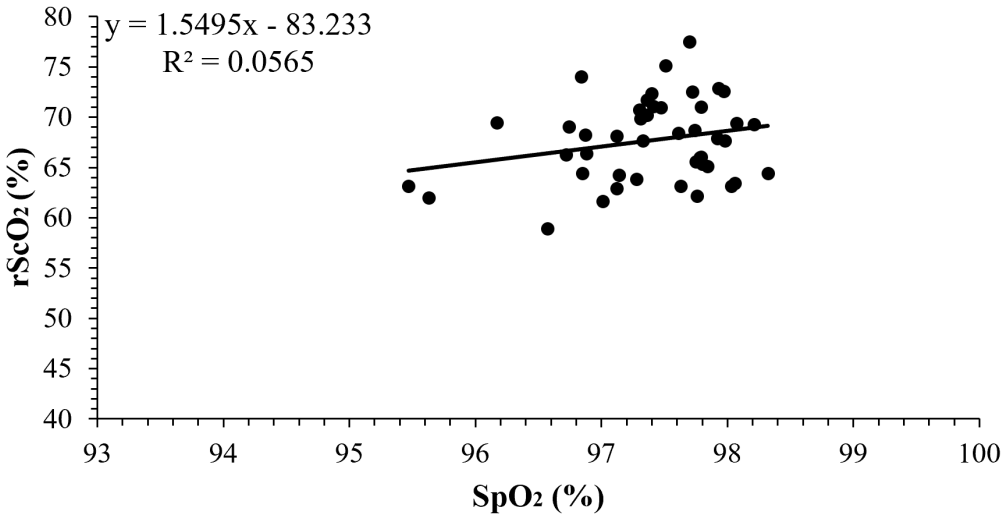


Fig 2. Linear regression relationship (a) SpO2(%), (b) rScO2(%)

Table 3. Correlation and regression analysis between SpO_2 and $rScO_2$

Health group	N	Pearson r	R^2	p-value
Apparently healthy	20	-0.131	0.017	0.581
Diabetes	13	0.543	0.294	0.055
Thyroid	12	0.152	0.023	0.637
Overall	45	0.238	0.057	0.116

peripheral and regional cerebral oxygen saturation should not be considered interchangeable measures and that their oxygen saturation ($rScO_2$) in the overall study population (n = 45) relationship may vary according to participant characteristics and health status.

The prototype-derived $rScO_2$ value of total population is 67.66 ± 4.05% fell within the wide range of values previously documented in adults utilizing well-established NIRS/cerebral oximetry systems.

Both age demographics exhibit elevated and comparatively restricted SpO_2 levels, often ranging from 97% to 98%. As shown in Figure 4(a), the box-plot analysis, the median SpO_2 levels are quite comparable between the 18–30 age group and the 31–60 age group. Also, any variation noted in cerebral oxygenation cannot be solely ascribed to a significant disparity in systemic oxygen saturation between the two cohorts. As per Figure 4(b) and Table 2, the median $rScO_2$ seems to be around 68% for both age categories. It illustrates that brain tissue oxygenation is not merely synonymous with peripheral arterial oxygen saturation. This is biologically plausible as $rScO_2$ measured by NIRS indicates the oxygenation of tissue microcirculation and is affected by the equilibrium between cerebral oxygen supply and utilization, rather than solely depicting arterial oxygen saturation.

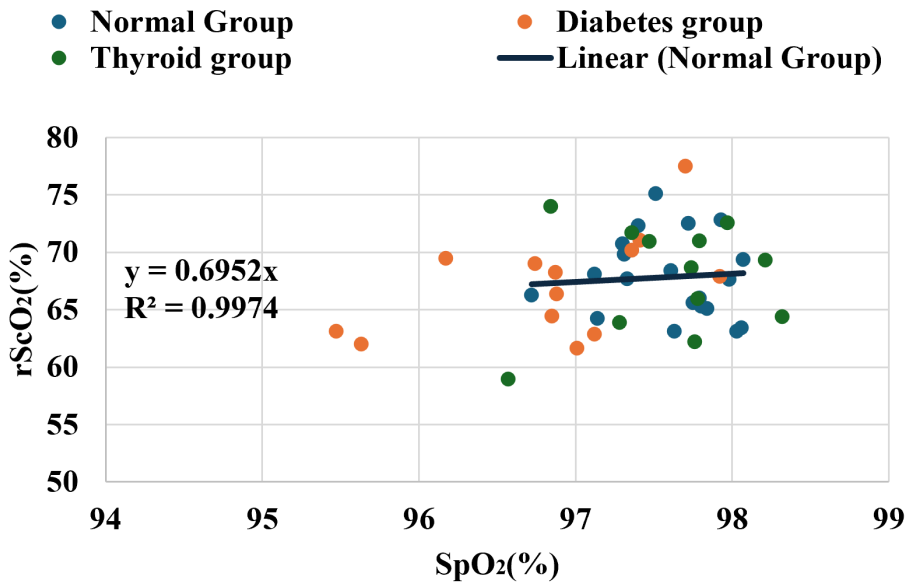


Fig 3. Groupwise linear regression analysis between rScO2 and SpO2

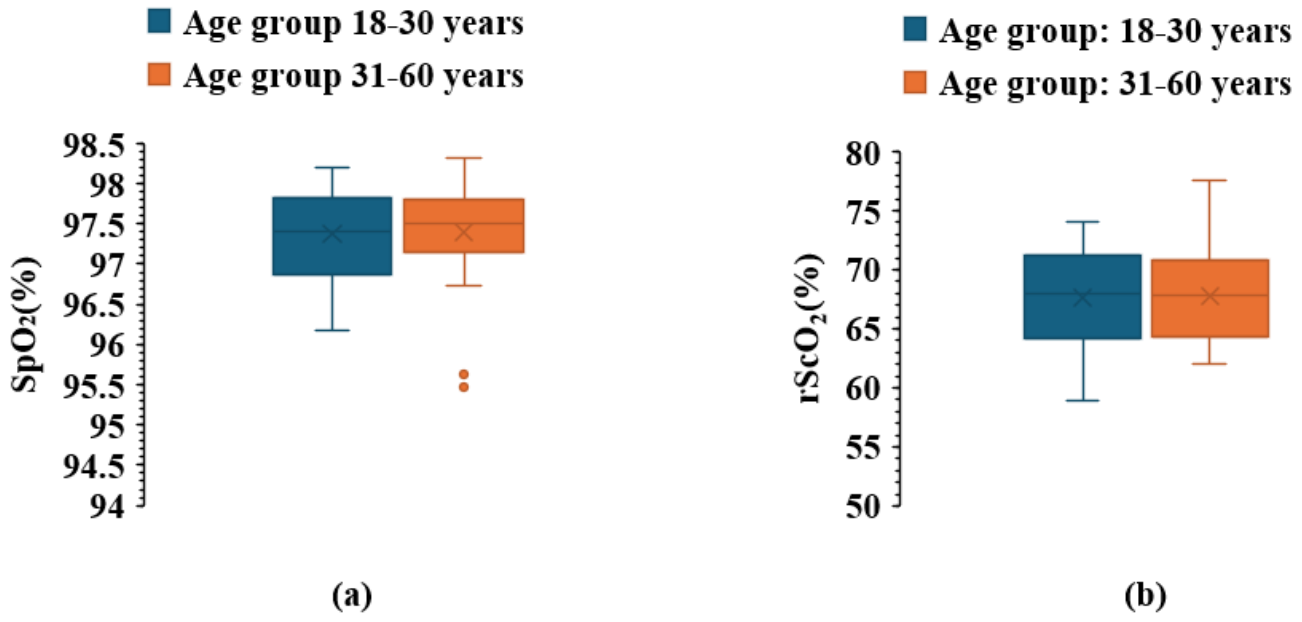


Fig 4. Age group wise box plot analysis of (a) SpO2(%), (b) rScO2(%)

The weak overall correlation observed between SpO_2 and $rScO_2$ suggests that peripheral oxygen saturation alone may not adequately reflect cerebral oxygenation[17]. These findings indicate that the relationship between systemic oxygen saturation and regional cerebral oxygenation was not consistent across health groups in the study. Although arterial oxygen saturation contributes to cerebral oxygen availability, cerebral oxygenation is additionally influenced by cerebral blood flow, oxygen extraction, haemoglobin concentration, and the balance between arterial and venous blood within cerebral tissue. Therefore, variability in $rScO_2$ despite relatively preserved SpO_2 may be physiologically plausible.

The overall $rScO_2$ value in our study ($67.66 \pm 4.05\%$) is comparable to previously reported adult cerebral oxygenation values. Lian et al. reported an adult baseline rSO_2 of $69.76 \pm 6.02\%$, which is close to the mean value observed using our prototype. Age may affect baseline cerebral oxygenation, too, since their study also showed a significantly lower value in older subjects ($62.69 \pm 3.14\%$). This observation is also supported by Gu et al., who studied 661 healthy individuals and found that rSO_2 was associated with several demographic and physiological characteristics, including age and BMI[18]. Differences in sensor placement, source-detector geometry, optical path length, tissue composition, and signal-processing algorithms and even anatomical location investigates may contribute to differences in rSO_2 values[19]. In our study, diabetes subgroup showed the strongest observed association between SpO_2 and $rScO_2$ ($r = 0.543$, $R^2 = 0.294$, $p = 0.055$), supporting previous research that reported lower cerebral oximetry values in diabetic patients compared with non-diabetic patients during cardiac surgery.

According to the NIRS literature, cerebral blood flow, cerebral metabolic demand, hemoglobin concentration, arterial-to-venous blood volume contributions, and regional vascular features are some of the parameters that affect cerebral oxygenation in addition to systemic arterial oxygen saturation. Consequently, individuals with comparable SpO_2 readings may demonstrate varying levels of brain oxygenation. This interpretation is particularly supported by the study of Alevizakos et al., in which simultaneous NIRS and pulse oximetry demonstrated different responses during hypoxia. Their use of Bland–Altman analysis and concordance measures also illustrate why correlation alone is insufficient when comparing oxygenation measurements. However, similarity between our prototype-derived values and published NIRS values should not be interpreted as formal validation. Diverse cerebral oximeters may produce varying absolute rSO_2 readings due to discrepancies in optical wavelengths, source-detector spacing, sensor configuration, algorithms, and assumptions about tissue optical characteristics[19],[20]. In the present study, SpO_2 and $rScO_2$ should therefore be interpreted as complementary physiological measurements rather than interchangeable measurements. The research should thus be considered a preliminary prototype characterisation investigation instead of a conclusive clinical validation examination.

4 Conclusion

The present study investigated the relationship between SpO_2 and prototype-derived $rScO_2$ in 45 adults, including 20 apparently healthy, 13 diabetes, and 12 thyroid participants. A weak positive overall association was observed ($r = 0.238$, $R^2 = 0.057$, $p = 0.116$), while the diabetes group demonstrated a comparatively stronger association ($r = 0.543$, $R^2 = 0.294$, $p = 0.055$); the apparently healthy and thyroid groups showed weak, non-significant relationships. The mean $rScO_2$ values across the three groups were approximately 67%, broadly consistent with previously reported adult cerebral NIRS measurements, supporting the physiological plausibility of the developed prototype. The novelty of this work lies in the prototype-based assessment of systemic and regional cerebral oxygenation across heterogeneous adult health groups, demonstrating that SpO_2 and $rScO_2$ should not be considered interchangeable measures. The prototype has potential as a complementary non-invasive cerebral oxygenation monitor; however, larger studies with direct comparison against validated cerebral oximetry devices, formal agreement and repeatability assessment, age-stratified cohorts, and clinically relevant validation conditions are required before clinical application.

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Author details: Pooja L. Gohel is a Research Scholar; Dr.Vijay P. Dave is an Assistant Professor.

Data availability statement: The dataset generated during the current study are not publicly available but are available from the corresponding author on reasonable request.

References

1) Robba C, Battaglini D, Rasulo F, Lobo FA, Matta B. The importance of monitoring cerebral oxygenation in non brain injured patients. *Journal of Clinical Monitoring and Computing*. 2023;37:943–949. https://doi.org/10.1007/s10877-023-01002-8.

2) Hansen ML, Hyttel-Sørensen S, Jakobsen JC, Gluud C, Kooi EMW, Mintzer J, et al. The clinical effects of cerebral near-infrared spectroscopy monitoring (NIRS) versus no monitoring: a protocol for a systematic review with meta-analysis and trial sequential analysis. *Systematic Reviews*. 2021;10(1). https://doi.org/10.1186/s13643-021-01660-2.
3) Eleveld N, Esquivel-Franco DC, Drost G, Absalom AR, Zeebregts CJ, de Vries JPPM, et al. The Influence of Extracerebral Tissue on Continuous Wave Near-Infrared Spectroscopy in Adults: A Systematic Review of In Vivo Studies. *Journal of Clinical Medicine*. 2023;12. https://doi.org/10.3390/jcm12082776.
4) Cohen DJF, Li NC, Ioussoufovitch S, Diop M. Fast estimation of adult cerebral blood content and oxygenation with hyperspectral time-resolved near-infrared spectroscopy. *Frontiers in Neuroscience*. 2023;17:1020151.
5) Mizukoshi K, Hamanaka Y, Niwayama M. Investigation of oxygen saturation in regions of skin by near infrared spectroscopy. *Skin Research and Technology*. 2022;28(5):695–702. https://doi.org/10.1111/srt.13169.
6) Alevizakos V, Werner A, Schiller LM, von See C, Schiller M. Comparing NIRS and Pulse Oximetry for Cerebral Oxygen Saturation During Hypoxia Testing. *Medical Sciences*. 2024;12(4). https://doi.org/10.3390/medsci12040059.
7) Besnier F, et al. Acute Effects of a Maximal Cardiopulmonary Exercise Test on Cardiac Hemodynamic. *International Journal of Environmental Research and Public Health*. 2023;20(8):5552.
8) Fani L, Roa Dueñas O, Bos D, Vernooij MW, Klaver CCW, Ikram MK, et al. Thyroid Status and Brain Circulation: The Rotterdam Study. *Journal of Clinical Endocrinology and Metabolism*. 2022;107(3):E1293–E1302. https://doi.org/10.1210/clinem/dgab744.
9) Jlali I, Touil I, Amor HH, Tagougui S. Impaired cerebral hemodynamics and oxygenation in type 2 diabetes: insights into insulin resistance and hyperglycemia effects. *Journal of Diabetes and Its Complications*. 2025;39(9):109102. https://doi.org/10.1016/j.jdiacomp.2025.109102.
10) Si J, He Y, Yao J, Yu J, Jing R, He Q, et al. High-altitude cerebral oxygen saturation detection using wireless wearable cerebral oximeter. *Frontiers in Neurology*. 2024;15. https://doi.org/10.3389/fneur.2024.1445563.
11) Gohel P, Dave V. A review on applications of near infrared spectroscopy technique for neonatal monitors: A review on applications of NIRS technique for neonatal monitors. *International Journal of Medical Engineering and Informatics*. 2024;16.
12) Juliana N, Yazit NAA, Kadiman S, Hafidz KM, Azmani S, Teng NIMF, et al. Intraoperative cerebral oximetry in open heart surgeries reduced postoperative complications: A retrospective study. *PLoS One*. 2021;16(5). https://doi.org/10.1371/journal.pone.0251157.
13) Massari D, Modestini M, Niezen CK, Yeh L, Zoutman AC, Scheeren TWL, et al. Intraoperative renal and cerebral tissue oxygen saturation measurements to predict postoperative acute kidney injury in pediatric cardiac surgery: a prospective observational study. *Journal of Clinical Monitoring and Computing*. 2026;40(2):405–416. https://doi.org/10.1007/s10877-025-01345-4.
14) Dave V, Patel Y. Detection of diabetic peripheral neuropathy from index finger using vibration mechanism. *Journal of Medical Engineering & Technology*. 2025;49(5):171–178. https://doi.org/10.1080/03091902.2025.2508229.
15) Gohel P, Dave V. Development of an Optical Measurement System for Plethysmographic Blood Volume Changes. *International Journal of Scientific Development and Research*. 2026;11. Available from: www.ijsdr.org.
16) Lian C, Li P, Wang N, Lu Y, Shangguan W. Comparison of basic regional cerebral oxygen saturation values in patients of different ages: a pilot study. *Journal of International Medical Research*. 2020;48(8). https://doi.org/10.1177/0300060520936868.
17) Dixon B, Macleod DB. Assessment of a non invasive brain oximeter in volunteers undergoing acute hypoxia. *Medical Devices: Evidence and Research*. 2020;13:183–194. https://doi.org/10.2147/MDER.S250102.
18) Gu G, Jiang J, Zheng B, Li Y, Luo Y, Pu Y, et al. Regional cerebral oxygen saturation in the healthy population of western Sichuan: a multicenter cross-sectional study. *Journal of Clinical Monitoring and Computing*. 2025;39(2):283–289. https://doi.org/10.1007/s10877-024-01244-0.
19) Lubkowska A, Radecka A, Pluta W, Wieleba K. Reference Values of Regional Oxygen Saturation (rSO2) Determined by Near-Infrared Spectroscopy (NIRS) for 18 Selected Regions of Interest (ROIs) in Young and Elderly Healthy Volunteers. *Applied Sciences*. 2024;14(3). https://doi.org/10.3390/app14031307.
20) Ali J, Cody J, Maldonado Y, Ramakrishna H. Near-Infrared Spectroscopy (NIRS) for Cerebral and Tissue Oximetry: Analysis of Evolving Applications. *Journal of Cardiothoracic and Vascular Anesthesia*. 2022;36(8):2758–2766. Available from: https://www.sciencedirect.com/science/article/pii/S1053077021005863.