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LETTER TO THE EDITOR

# Limitations of near infrared spectroscopy (NIRS) in neurosurgical setting: our case experience

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**Abstract**
One of the primary goals of anaesthesia in neurosurgical procedures is prevention of cerebral hypoxia leading to secondary neurological injury. Cerebral oximetry detects periods of cerebral hypoxemia and allows intervention for prevention of secondary brain injury and its sequelae. This can be achieved by the use of Near Infrared Spectroscopy (NIRS). In this regard, we present two cases where erroneous values of NIRS were shown which hindered monitoring of cerebral oxygenation in the intraoperative setting. In a neurosurgical setting, the erroneous values on the operative side could be attributed to altered tissue boundary conditions resulting in a changed optical path, which is normally held as a constant in NIRS measurements. The altered tissue boundary conditions could be due to the presence of air or blood between the myocutaneous flapskull, skull-dura, dura-brain interphases. It could also be that the sensors' penetrating depth was inadequate to compensate for the increased distance between sensor and brain tissue, thereby resulting in inaccurately higher values (> 80%).

**Keywords** Near infrared spectroscopy · Neurosurgery · Cerebral oxygenation

## 1 Introduction

One of the primary goals of anesthesia in neurosurgical procedures is prevention of cerebral hypoxia leading to secondary neurological injury. Cerebral oximetry detects periods of cerebral hypoxemia and allows intervention for prevention of secondary brain injury and its sequelae. This can be achieved by the use of Near Infrared Spectroscopy (NIRS). As much as the technology of NIRS appears promising, there are insufficient studies and randomized controlled trials to support and validate the use of NIRS in the neurosurgical setting. In this regard, we present two cases where erroneous values of NIRS hindered monitoring of cerebral oxygenation in the intraoperative setting. Informed consent was obtained from the individual participants included in the study. Even though theoretical possibility of erroneous NIRS values in neurosurgical settings has been mentioned in literature; to our best knowledge, this is the first case report describing the same.

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## 2 Case report

### 2.1 Case 1

A 49 year old female posted for right pterional craniotomy and anterior communicating artery aneurysm clipping, underwent standard induction with routine monitoring. NIRS was used to monitor brain oxygenation and intraoperative brain ischemia during the period of temporary clipping. NIRS probe (Root with O3 monitor; Masimo Corporation, USA) was applied to right and left side of the forehead according to company manual specifications. The probe was attached to the scalp with adhesive tape to reduce the motion of optode on the skin (Fig. 1). She was ventilated with Air:Oxygen (50:50) mixture and anaesthesia

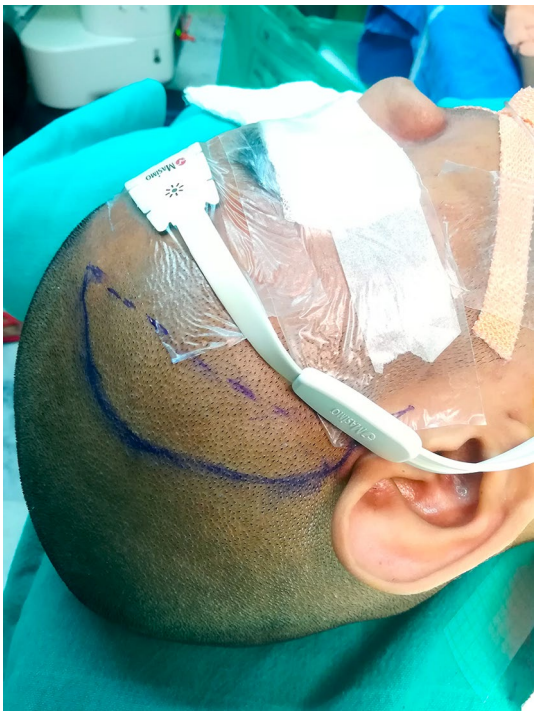

**Fig. 1** The position of the NIRS sensor placement in the forehead as per manufacturer instructions. The blue marked line shows the intended craniotomy flap (pterional craniotomy). The second interrupted line shows the extent to which the myocutaneous flap will be reflected anteiorly. Kindly note that the sensor is not a part of reflected scalp

was maintained with sevoflurane 2% (MAC 0.7–0.9) and an infusion of Fentanyl 1 µg/kg/h and Atracurium 0.5 mg/kg/h. Baseline cerebral oxygen saturation ($rSO_2$) was 61% on left side and 55% on right side (Fig. 2). After craniotomy, the right side $rSO_2$ rose abruptly to > 80% with Δ base (percentage difference between the current $rSO_2$ and the baseline) of up to 49%. All through the procedure, the right side $rSO_2$ remained > 80%, whereas on left side it remained near

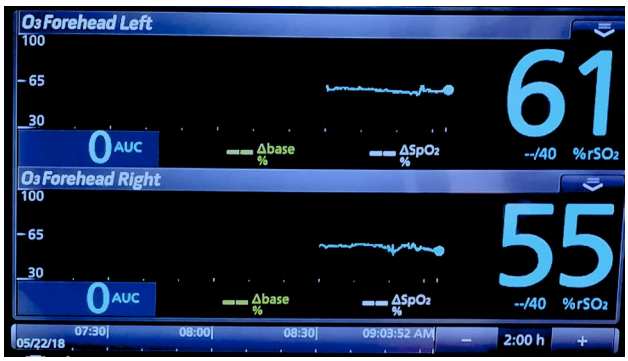


**Fig. 2** Near infrared spectroscopy monitor showing regional cerebral oxygenation ($rSO_2$) of right and left frontal lobes in the post induction phase

baseline values of 62–67% (Fig. 3). Post clipping, during closure phase, the right side $rSO_2$ returned to near baseline value (60–65%).

### 2.2 Case 2

A 50 years old female patient posted for right pterional craniotomy and excision of arteriovenous malformation (AVM) of frontal lobe, underwent standard induction with routine monitoring. NIRS was monitored to detect intraoperative ischemia and post AVM excision hyper perfusion. NIRS probe (Root with O3 monitor; Masimo Corporation, USA) was secured to right and left side of her forehead with adhesive tapes. She was ventilated with Air: Oxygen (50:50) mixture and anaesthesia was maintained with sevoflurane 2% (MAC 0.7–0.9) and an infusion of Fentanyl 1 µg/kg/h and Atracurium 0.5 mg/kg/h. Baseline $rSO_2$ were noted as 61% on the right side and 63% on the left side. After craniotomy, values on the right side were found to raise to values above 85 with Δ base of > 50%; whereas on the left side, $rSO_2$ values were near baseline. This trend persisted till the closure phase after which $rSO_2$ of both sides were near baseline values.

## 3 Discussion

NIRS based cerebral oximetry technology is essentially based on two principles, firstly on the high degree of transparency of cerebral tissue to infrared spectrum (700–950 nm) and secondly, the differential absorption spectra of different chromophores (mainly the oxyhemoglobin

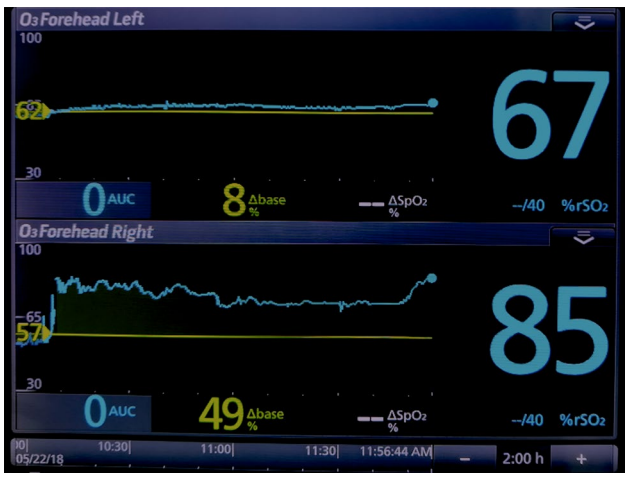


**Fig. 3** Near infrared spectroscopy monitor showing regional cerebral oxygenation($rSO_2$) of right and left frontal lobes after reflection of myocutaneous flap. Note that the right $rSO_2$ is > 80% with a Δ base (percentage difference between the current $rSO_2$ and the baseline) of 49%

and deoxyhemoglobin). NIRS uses infrared light of wavelength 700–950 nm, which pass through the layered structure of head (ie scalp, skull and brain) in an elliptical banana or boomerang shaped path. NIR light on its path is absorbed by molecules of oxygenated and deoxygenated haemoglobin and other chromophores causing attenuation of the NIRS light intensity. The amount of light attenuation is determined by the modified Beer Lambert law and is dependent on the optical pathlength and the concentration: extinction coefficient of chromophores [1].

Optical pathlength (OPL) is an important factor in spectrophotometry and is influenced by many factors [1–3]. Firstly, the NIRS penetration depth depends on the distance between the light source and the detector. Secondly, OPL depends on the absorbing and scattering properties of the underlying tissue [2]. OPL is also influenced by tissue boundaries, which, in the head, include interfaces among scalp, skull, cerebrospinal fluid, and brain. This can alter the path of NIRS light depending on whether it is scattered or absorbed thus affecting brain $rSO_2$ measurements from surface of head [1, 3, 4].

Another factor which confounds the $rSO_2$ measurement is that it reflects the combined oxygen saturation of blood in the skin, scalp, skull, and brain [1, 3, 4]. Extra cerebral contribution to $rSO_2$ values may become a confounding variable in neurosurgical settings such as when there is presence of hematoma or when a scalp flap is raised as in a craniotomy. All these physical limitations can render the application of NIRS in neurosurgical scenarios problematic. The normal range of NIRS in adult brain is 60 to 80 and any difference of $rSO_2 > 20\%$ between both sides or values more than 80% or less than 50% are considered significant [1, 5–8].

In both our cases, after raising the myocutaneous flap prior to craniotomy, the $rSO_2$ on the operative side drastically changed to $> 20\%$ with $\Delta$ base of $> 40\%$ when compared to the non-operative side. We had used NIRS in aneurysm case so as to monitor cerebral oxygenation and detect ischemic episodes during temporary clipping. In the case of AVM resection, we had used NIRS to detect ischaemia and post resection hyper perfusion. But in both our cases, monitoring $rSO_2$ on the operative side did not serve its pertinent purpose. Erroneous values on the operative side could be attributed to altered tissue boundary conditions resulting in a changed optical path, which is normally held as a constant in NIRS measurements. The altered tissue boundary conditions could be due to the presence of air or blood between the myocutaneous flap-skull, skull-dura, dura-brain interphases. It could also be that the sensors' penetrating depth was inadequate to compensate for the increased distance between sensor and brain tissue, thereby resulting in inaccurately higher values ($> 80\%$). The tissues underlying the probe which contribute to extra cerebral contamination of NIRS values, could also have influenced the measurement. Young et al. in their study to examine behavior of near-infrared light in the adult human head, found that removal of bone and dura from the the light path caused a significant reduction in detected intensity. They postulated that there is optical channelling of NIRS light when all extracerebral layers are intact. The clinical implications of their study was that if NIRS is sensitive to boundary conditions, it will be unreliable in neurosurgical scenarios which alter the same [5].

NIRS probes have constant source-to-detector distance making the optical penetration depth constant. Thus in patients suffering from head trauma, undergoing neurosurgery or recovering after decompressive craniectomy, the boundary conditions do not remain constant resulting in altered OPL which results in erroneous readings that might not reflect the true cerebral oxygenation status [4–6].

## 4 Conclusion

In neurosurgical setting, after craniotomy, tissue boundary conditions change and the probes' spatial sensitivity profile becomes inadequate to monitor cerebral oxygenation. This results in erroneous values of $rSO_2$ thereby hindering the intraoperative monitoring of cerebral oxygenation.

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### Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Informed consent** Informed consent was obtained from the individual participants included in the study. None of individual participants identifying information is included in this article.

**Research involving human participants** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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