Room Air Readings of Brain Tissue Oxygenation Probes

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Abstract *Objective*: Brain tissue oxygenation ($p_{bt}O_2$) monitoring with microprobes is increasingly used as an important parameter in addition to intracranial pressure in acutely brain-injured patients. Data on accuracy and long-term drift after use are scarce. We investigated room air readings of used $p_{bt}O_2$ probes for their relationship with the duration of monitoring, geographic location of the center, and manufacturer type.

Methods: After finishing clinically indicated monitoring in patients, $p_{bt}O_2$ probes used in two centers in Berlin and Munich were explanted and cleaned to avoid blood contamination. Immediately afterward, room air readings of partial oxygen pressure ($p_{air}O_2$) from 44 Licox® and 10 Raumedic® $p_{bt}O_2$ probes were recorded. Assumed height above sea level was 42 m for Berlin and 485 m for Munich; this resulted in assumed theoretical $p_{air}O_2$ readings of 157.8 mmHg in Berlin and 149.9 mmHg in Munich.

Results: Licox® probes in Berlin showed a mean $p_{air}O_2$ of 160.5 (SD 14.4) mmHg and of 147.8 (11.9) mmHg in Munich. Raumedic® probes in Berlin showed a mean $p_{air}O_2$ of 170.5 (12.2) mmHg and the single Raumedic® probe used in Munich 155 mmHg. No significant drift was found over time for probes with up to 14 days of monitoring. Prolonged use of up to 20 days showed a clinically negligible drift of 1.2 mmHg per day of use for Licox® probes.

Mean absolute deviation for $p_{air}O_2$ from expected values was 6.4% for Licox® and 9.7% for Raumedic® probes.

Conclusion: Room air partial oxygen pressure $p_{air}O_2$ may be utilized to assess the proper function of a $p_{bt}O_2$ probe. It provides a tool for quality control which is easy to implement. Probe readings are stable in the clinically relevant range, even after prolonged use.

Keywords Brain tissue oxygenation · Atmospheric pressure · Monitoring · Room air reading · Long-term assessment

Introduction

Monitoring brain tissue oxygenation ($p_{bt}O_2$) with intraparenchymal microprobes is an emerging tool and recommended in guidelines after traumatic brain injury and aneurysmal subarachnoid hemorrhage [1, 2]. A commonly proposed threshold is 20 mmHg: values below this margin are associated with a worse outcome [3]. As monitoring of critically injured patients may be required for days or even 1 or 2 weeks, it is crucial to know how accurate the readings of $p_{bt}O_2$ probes are over time and whether long-term drift is present. Currently, bench testing is available only for probes in mint condition and an assessment of $p_{bt}O_2$ devices after in vivo use is lacking [4, 5].

On earth, ambient dry air provides a stable environment with an oxygen fraction of 20.95% and a partial pressure of 159.21 mmHg at sea level. Therefore, a simple and ubiquitously available method of assessing the accuracy of a $p_{bt}O_2$ probe may be to use plain room air as a reference. Therefore, we investigated room air readings of used $p_{bt}O_2$ probes for their relationship with duration of monitoring, geographic location of the center, and manufacturer type.

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Methods

Indications for $p_{bt}O_2$ monitoring were based on clinical considerations and were not part of the study. We investigated equipment from both vendors currently on the market; in particular, Licox CC1.SB probes (Integra Neuroscience, Saint Priest, France) and Neurovent PTO probes (Raumedic AG, Münchberg, Germany). We gathered data from probes used in two centers, located in Berlin and Munich, Germany. After finishing clinically indicated monitoring, $p_{bt}O_2$ probes were removed, superficially cleaned with a pad to prevent blood contamination and inspected for obvious mechanical damage. Immediately afterward, room air readings of partial oxygen pressure ($p_{air}O_2$) were recorded until a stable reading was achieved. As no patient data were used in this setup, the need for informed consent was waived.

Physical Laws and Considerations

Average standard atmospheric pressure at sea level is 1,013.25 kPa, equivalent to 760 mmHg (29.92 in), with a typical range between 670 mmHg (26.5 in) and 800 mmHg (31.5 in) on a mercury column barometer. Introduced by daily temperature fluctuations, atmospheric pressure shows a semicircadian rhythm. The amplitude of these fluctuations is dependent on latitude, with about 5 kPa (3.75 mmHg) at the equator, and 0.5–1 kPa (0.38–0.75 mmHg) at continental climate zones.

Simplified, atmospheric pressure decreases with altitude by: $p_{height} \sim p_0^* \exp(-\text{height}/h_0)$,

with h_0 = 8435m. For low altitudes, this equals approximately about 1.2 kPa (0.9 mmHg) for every 100 m.

Assumed elevation above sea level was 42 m for Berlin, Germany, and 485 m for Munich, Germany. Using the stable oxygen fraction of 20.95%, this resulted in assumed theoretical $p_{air}O_2$ readings of 157.8 mmHg in Berlin and 149.9 mmHg in Munich [6].

Statistical Analysis

Data analysis was performed using R 3.3.1, R foundation for Statistical Computing, Vienna, Austria. The duration of previous use was plotted against the room air reading. Multivariate analysis was performed with linear regression using room air reading as a dependent variable, duration of use as an independent linear predictor, and probe type and center location as cofactors.

Results

Room air readings of $p_{air}O_2$ from 44 Licox® and 10 Raumedic® $p_{bt}O_2$ probes were available for analysis. One probe from the Munich center showed a $p_{air}O_2$ reading of 334 mmHg, more than 10 standard deviations off from the mean of all other probes. Although no mechanical damage was noted, this single probe was considered defective and excluded from analysis.

Licox® probes in Berlin showed a mean $p_{air}O_2$ of 160.5 (SD 14.4) mmHg and of 147.8 (11.9) mmHg in Munich. Raumedic® probes in Berlin showed a mean $p_{air}O_2$ of 170.5 (12.2) mmHg and a single Raumedic® probe used in Munich displayed 155 mmHg.

Licox® probes showed an increase of 1.28 mmHg ($p < 0.001$) per day of use when all data with up to 20 days of forgone monitoring time were considered. No significant trend was found if readings from probes with up to 14 days of previous use were examined. We found no significant increase per day of previous use for Raumedic® probes. Mean absolute deviation for $p_{air}O_2$ from expected values was 6.4% for Licox® and 9.7% for Raumedic® probes. Figure 1 shows the relationship among time, location of use, and type of probe with the acquired room air readings.

Discussion

Our findings show that room air may be utilized as a verification tool of proper function of a $p_{bt}O_2$ probe. Differences in geographic location and altitude are reflected accurately by room air readings of $p_{bt}O_2$ probes. For use of up to 14 days, readings of used probes remained stable. Even with prolonged utilization beyond that time period, the average drift of 1.2% per day of use translates to lower values than differences in measurement to be expected in vital brain tissue [7, 8]. Therefore, we consider probe drift per day of use to be clinically negligible.

The knowledge derived may help a clinician to decide whether previous readings obtained during clinical monitoring had been accurate. In the case of challenged low (or high) readings during previous clinical use, a finding compliant with proper probe function may trigger implantation of a new probe. Unfortunately, our findings do not represent an online function test for probes under consideration. The fragile nature of Licox® probes prohibits reinsertion after room air testing. In theory, this may be possible for the more rigid Raumedic® probes, but is strongly disadvised owing to potential breaches of sterility.

The main limitation of our study is that we did not the measure actual $p_{air}O_2$ with a dedicated and calibrated device. Rather, we relied on the theoretical calculated $p_{air}O_2$ value for

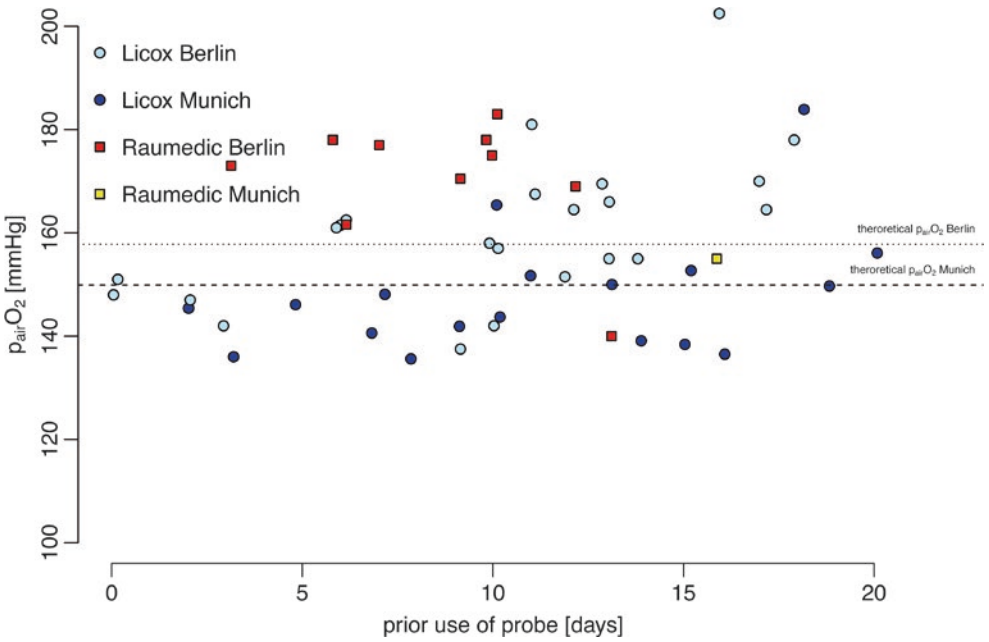

Fig. 1 Room air readings ($p_{air}O_2$) of brain tissue oxygenation probes from two manufacturers plotted versus days of previous use. Licox® probes are indicated by *circles*, Raumedic® probes by *squares*. *Dotted* and *dashed lines* indicate the theoretical readings in two centers, located in Berlin and Munich, Germany, respectively

the environment of the respective location. Daily fluctuations, in addition to high or low barometric pressures may subtly alter theoretical values of $p_{air}O_2$. Furthermore, it was assumed that it remained stable when measured indoors in the ICU with active air conditioning. Although both manufacturers perform adjustment of displayed pO_2 readings according to surrounding tissue temperature, the use of probes at room temperature is not at a level occurring in the living human body and outside of the manufacturers' specifications. Additionally, the cleansing process of the probes was not standardized and remnants of blood and tissue after clinical use may have contributed to unaccounted confounding. However, despite these limitations, the robustness of findings serve as important proof-of-principle of the validity of our analysis.

Conclusion

Room air partial oxygen pressure $p_{air}O_2$ may be utilized to assess the proper function of a $p_{bt}O_2$ probe. When the local altitude above sea level is considered, it provides a tool for quality control which is easy to implement. Probe readings are stable within the clinically relevant range, even after prolonged use.

Conflicts of interest statement We declare that we have no conflicts of interest.

References

1. Bratton SL, Chestnut RM, Ghajar J, et al. Guidelines for the management of severe traumatic brain injury. X. Brain oxygen monitoring and thresholds. J Neurotrauma. 2007;24(Suppl 1): S65–70.
2. Diringer MN, Bleck TP, Claude Hemphill J 3rd, et al. Critical care management of patients following aneurysmal subarachnoid hemorrhage: recommendations from the Neurocritical care society's multidisciplinary consensus conference. Neurocrit Care. 2011;15:211–40.
3. Ngwenya LB, Burke JF, Manley GT. Brain tissue oxygen monitoring and the intersection of brain and lung: a comprehensive review. Respir Care. 2016;61:1232–44.
4. Purins K, Enblad P, Sandhagen B, Lewén A. Brain tissue oxygen monitoring: a study of in vitro accuracy and stability of Neurovent-PTO and Licox sensors. Acta Neurochir. 2010;152:681–8.
5. Stewart C, Haitsma I, Zador Z, Hemphill JC, Morabito D, Manley G, Rosenthal G. The new Licox combined brain tissue oxygen and brain temperature monitor: assessment of in vitro accuracy and clinical experience in severe traumatic brain injury. Neurosurgery. 2008;63:1159–1164; discussion 1164–1165.
6. Atmospheric pressure. Wikipedia. https://en.wikipedia.org/wiki/Atmospheric_pressure. Accessed 15 November 2016.
7. Ponce LL, Pillai S, Cruz J, Li X, Julia H, Gopinath S, Robertson CS. Position of probe determines prognostic information of brain tissue PO2 in severe traumatic brain injury. Neurosurgery. 2012;70:1492–1502; discussion 1502–1503.
8. Hawryluk GWJ, Phan N, Ferguson AR, Morabito D, Derugin N, Stewart CL, Knudson MM, Manley G, Rosenthal G. Brain tissue oxygen tension and its response to physiological manipulations: influence of distance from injury site in a swine model of traumatic brain injury. J Neurosurg. 2016;125:1217–28.