NeuroSENSE, an electroencephalogram based cerebral monitor, in additionnal to cerebral oxymetry in pediatric cardiac surgery.

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Introduction.

Considering the improvements in cardiac surgery over the last few decades, we are now able to care most of the congenital cardiac diseases. However, the occurrence of neurological disabilities in the postoperative period remains high[1,2]. Even if improvements have been made for the prevention of such complications at the short term, the long term neurological outcome remains a challenge for the next few years[1,2,3].

Then, one of the key issues at this very moment is to clearly identify the risk factors, to find a way to prevent them and as such decrease morbidity associated with congenital cardiac surgery. In this context, cerebral Near Infrared Spectroscopy (NIRS) has gained much interest over the last years[1,3]. However, it should be noted that we still do not have any data clearly showing that the use of NIRS decreases the rate of neurological complication in the postoperative period[1,3,4,5]. The absence of validated thresholds is one of the pitfalls of this device and explains why the clinical interpretation of abnormal data is sometimes baffling[1,3,4]. Therefore, the question of the integration of other monitors remains open to adapt therapeutic target when abnormal NIRS data occur.

In that view, we will describe here two cases where the NIRS was used together with an electroencephalogram (EEG) based monitor (NeuroSENSE NS-701). We will see that when NIRS shows abnormal values in the absence of any explanation and when other parameters are strictly normal, the NeuroSENSE association can be saving. Indeed, in these two cases, NeuroSENSE had showed normal cerebral activity and aggressive therapeutic actions have been avoided.

Finally, we will discuss the available literature regarding an EEG based cerebral monitoring during congenital cardiac surgery.

Case report.

Patient 1

A 4-year-old boy with ventricular septal defect was referred to our hospital. The child was monitored with both NIRS and NeuroSENSE in add to usual monitoring. NeuroSENSE is an EEG based monitor initially commercialized as an anesthesia-depth analyser. It is applied on the forehead and provides a raw EEG signal bilaterally. Amoung others, Wavelet Analysis Value for Central Nervous System (WAVcns) are calculated from both sides and reflect the depth of anesthesia as well as the cortical activity.
As soon as the cardiopulmonary bypass (CBP) was initiated, the NIRS values dropped under 30%. Even after administration of a red blood cell concentrate, normalization of the hemoglobin rate (6,3 g/dL to 9,6 g/dL) and values of $PaCO_2$ and pH, the NIRS remained very low for more than 15 minutes and re-increased very slowly (see figure 1). This drop in the NIRS values was accompanied by a simultaneous decrease of WAVcns values, around 20 at both sides, and was associated with a change in the raw EEG. However, these changes disappeared very quickly, as soon as the full CPB flow was reached some 50 secondes later. The child could be extubated 3 hours after surgery and was neurologically perfect.
This case report demonstrates the limits of the NIRS monitor. While the NIRS values were alarming for more than 15 minutes without any obvious explanation (flow, Hb, pH, $PaCO_2$), the

NeuroSENSE values comforted the clinician, showing an almost persistence of normal electrical brain activity.

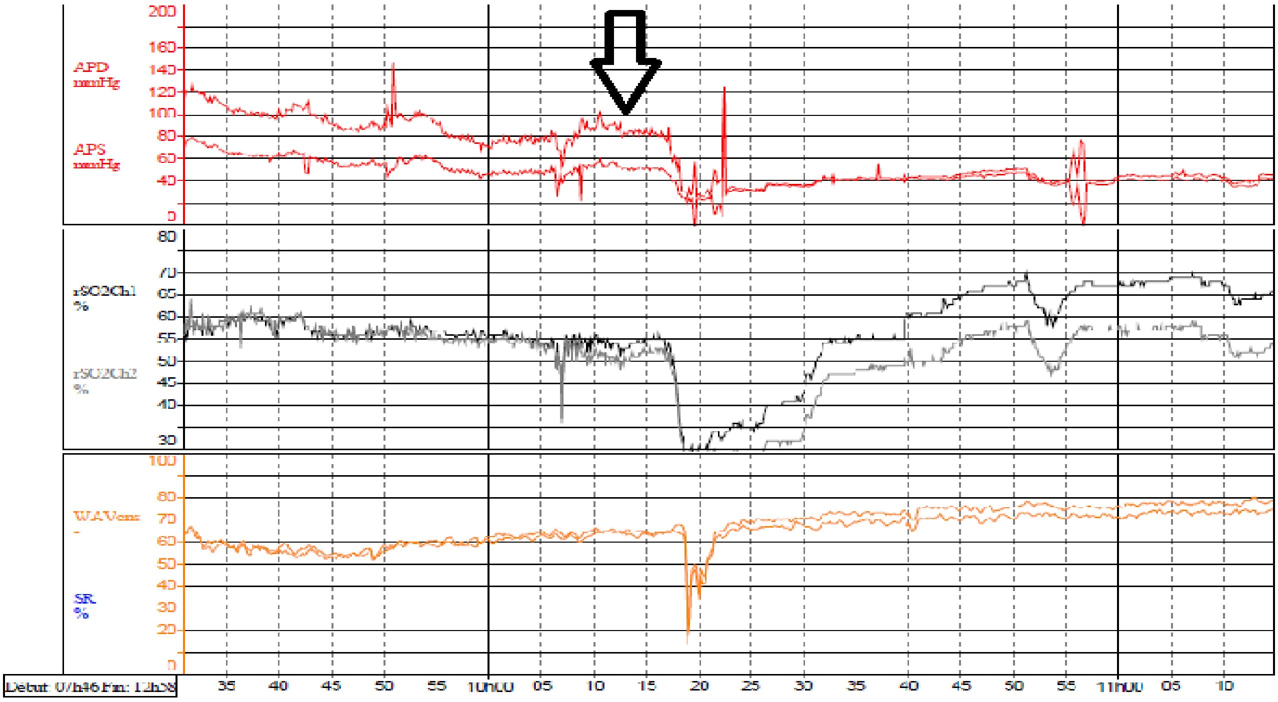

Figure 1 : Brutal drop of the NIRS data (second box) and WAVcns values (third box) at the initiation of the CPB (arrow) with quick restoration of the WAVcns but not NIRS values.

Patient 2

A 6-year-old girl was transferred to our institution for surgical cure of tetralogy of Fallot via a humanitarian organization. The girl was monitored as our previous patient. The functioning of the NIRS device was confirmed before starting the surgery but, from the beginning, despite a proper placement, no values could be obtained. This is probably due to the high degree of hematocrit and the darkness of the skin. It is only when the full CPB flow was reached and as such some hemodilution was achieved that cerebral oximetry values were obtained. In the meantime, the NeuroSENSE was available before the start of anesthesia, allowing cerebral monitoring in the absence of NIRS (see figure 2)

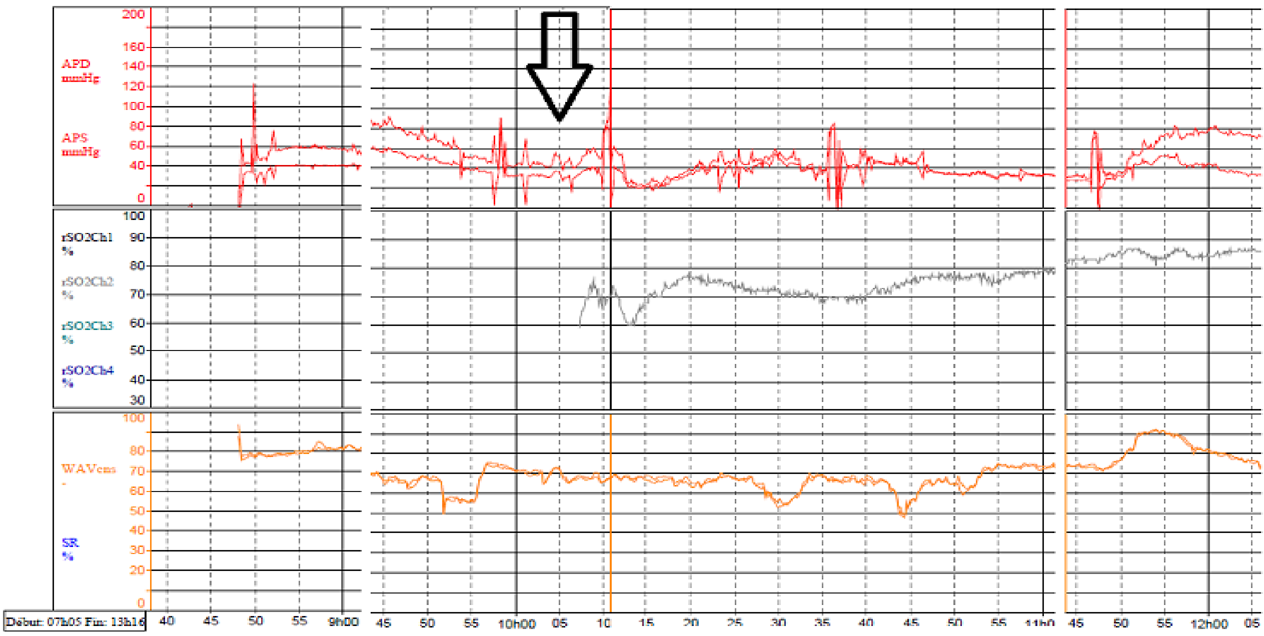

Figure 2 : Apparition of NIRS (second box) values at the initiation of the CPB (?) while WAVcns data were available from the beginnig of the procedure (third box)

This case highlights the limits of the NIRS at the beginning of a procedure in patients with very high hematocrit concentrations. Once again, the NeuroSENSE seems to be very helpful and can be considered as a valid alternative cerebral monitor in the absence of NIRS data during congenital cardiac surgery.

Discussion.

As we know, NIRS devices are based on the principle of relative absorption of well defined luminous wavelenght by certain chromofor. It allows us to quantify in a close tissue space and in real time Hb concentration and saturation[4,5,6]. Several devices are available, with different levels of sophistication. In these two cases, we have opted for INVOS 5100c which allows the use of four channels and uses a light-emitting diode even if all the NIRS devices are based on the same principles[5,6].

Therefore, NIRS is an interesting tool to assess the perfusion of a define structure, cerebral in this case. Over the past decades, NIRS monitors have been widespread used in pediatric cardiac surgery to become almost a gold standard nowadays. However, important limitations remain and the clinician should interpret all the results very carefully. For instance, the exact and relative participation of the different vascular beds in the measured volume is impossible to determine. As well as the eventual participation of others structures present in the sample and of which the proportions can vary largely[1,3,4,5,6]. The size of the sample is necessarily limited and doesn't bound to represent all the organs behind. Last but not least, the absence of validated thresholds is one of the major pitfalls of this technique and explains why the clinical interpretation can sometimes be baffling. NIRS is certainly an attractive tool but trends more than absolutes values have to be interpreted with the integration of other valuable data in order to avoid unnecessary and harmful decisions during pediatric cardiac surgery[3,4,5,6].

We know for many years that raw EEG analysis can provide valuable information during general anesthesia, including in pediatric cardiac procedures[7]. Unfortunately, EEG analysis requires specialist contribution and is space consuming to the detriment of other monitors. Moreover, it is easily interfered during surgical procedure. EEG analysis is then nor cost effective nor applicable in every day practice[7].

Therefore, more simple and practical devices, also based on the EEG analysis, have been created. In that sight, the Bispectral index technology (BIS) was one of the first which has been commercialized and is still the most widespread EEG based device used worldwide[7,8]. BIS assesses the depth of anesthesia and as such reduces the risk of awareness during surgery[2,7]. It also confirms the absence of a burst suppression which is mandatory before a deep hypothermic circulatory arrest[2,7,8].
This monitor compares the EEG signal from a single patient with thousands of others which were previously collected in a database. These were collected from adult patients at different stages of anesthesia, induced by different kinds of hypnotic drugs[8]. An algorithm then calculates an arbitrary value from the comparison, using a mathematical process based on the Fourier transformation and bispectral analysis[7,8].
It gives a value from 0 to 100, 0 corresponding to the absence of cerebral activity, or burst suppression, and 100 to a fully awake status. The limits, still arbitrary, when a patient is considering ideally fit for surgery are fixed between 40 and 60[7,8]. If the exact formula used by the algorithm is preserved by a trade secret, we know what are the factors which are included in the calculation. The EEG waves frequency (the ratio of rapid wave to slow ones decreasing in an asleep patient), the

synchronize wave degree (asynchronize increasing in a awake patient) and the percentage of burst suppressions are different factors included in the calculation[8].

Knowing that, we can easily imagine some limits of such a monitor. Moreover, the database which is described above is issued from an adult population and we know that EEG profile changes throughout the years, its amplitude and the ratio of slow waves decreasing[8].
Therefore, we have to note some pediatric distinctiveness. Variations of the BIS during an inhaled induction of anethesia is typical (rapid drop with paradoxal reincreasing). Later, during the awekening, reincreasing of BIS values are more likely to be abrupt with an ON-OFF profile[8]. Moreover, we know that paradoxal high values of BIS can be observed during sevoflurane anesthesia, reflecting seizure activity[8].
Despite all these differences, considering that the effect of the anesthetic agents on the BIS values are equivalent from adult to child population, the BIS monitor remains valid and, to date, is the only used EEG-based cerebral monitor in children[8].

Here, we describe the usefulness of the NeuroSENSE, another EEG-based cerebral monitor. WAVcns values, which are in the same arbitrary limits between 0 and 100, are a delay-free, linear and time invariant quantifier of the cortical activity[9]. Moreover, in comparison to the BIS, the algorithm is fully known[9]. NeuroSENSE also assesses the Supression Ratio, which is the amount of time without EEG detection and an Electromyographic activity indicator[9]. WAVcns has also been used in closed loop anesthesia in children[10]. Its use in pediatric population seems useful as the raw EEG is very clear.

Although very helpful, the cerebral oximetry shows important limitations[1,3,4,5,6]. If not interpreted properly it can mislead the clinician in taking aggressive and useless decisions (transfusion, increasing of the mean arterial pressure and cerebral perfusion pressure, hyperoxygenation, hypercapnia,...).
We describe two cases where the use of NeuroSENSE was very helpful. Although almost all data regarding EEG based monitoring in children are based on BIS, we show the importance of another EEG-based monitor with a well known algorithm[10]. Moreover, raw bilateral EEG is very clear with the use of NeuroSENSE.
The use of this monitor in assessing the cerebral perfusion during pediatric cardiac surgery is not described and validated previously, but our two cases show the extension that we could get from it.

Conclusion

If survival rate has increased over the last few decades in pediatric cardiac surgery, the prevention of neurological complications remains one of the major challenges nowadays. In this regard, perioperative brain protection has become one of the major issues. Although the NIRS gives valuable information, the clinicians should be aware of the drawbacks with its use. Here we demonstrate that its association with an EEG-based cerebral monitor, the NeuroSENSE, could lead to a better management. Future studies are needed to show whether this can improve the outcome of children undergoing congenital cardiac surgery.

Bibliography :

1. Barry D. Kussman, David Wypij et all., Relationship of Intraoperative Cerebral Oxygenetaion Saturation to Neurodevelopmental Outcome and Brain Magnetic Resonance Imaging at 1 Year of Age in Infants Undergoing Biventricular Repair, *Circulation*, pg 245-254, July 2010.
2. Tain-Yen Hsai, Peter J. Gruber, Factors Influencing Neurologic Outcome After Neonatal Cardiopulmonary Bypass : What We Can and Cannot Control, *Ann Thorac Surg*, pg S2382-S2388, 2006.
3. Y Durandy, M Rubatti, R Couturier, Near Infrared Spectroscopy during pediatric cardiac surgery : errors and pitfalls, *Perfusion* 26(5) 441-446, 2011.

4. Beth A. Johnson, Anthony C. Chang, Near infrared spectroscopy and tissue oxygenation : The unremitting quest for the holy grail, *Pediatric critical care med*, vol 9, No 1, pg 123-124, 2008.
5. Alexander J. C. Mittnacht, Near infrared Spectroscopy in children at risk of low perfusion, *Curr Opln Anaestheslol* 23:342-347, 2010.
6. Martin Wolf, Gorm Greisen, Advances in Near-Infrared Spectroscopy to Study the Brain of the Preterm and Term Neonate, *Clin Perinatol* 36 pg 807-834, 2009.
7. Dean B. Andopoulos, Stephen A. Stayer et all, Neurological Monitoring for Congenital Heart Surgery, *Anesth Analg* 99:1365-75, 2004.
8. Isabelle Murat, Isabelle Constant, Bispectral index in pediatrics : fashion or a new tool, *Pediatric Anesthesia*, 15:177-180, 2005.
9. Momeni M, Baele P, Jacquet L-M, Peeters A, Noirhomme P, Rubay J, Detection by NeuroSENSE Cerebral Monitor of Two Major Neurologic Events During Cardiac Surgery, Journal of Cardiothoracic and Vascular Anesthesia 2013.
10. West N, Dumont GA, van Heusden K, et all, Robust closed-loop control of induction and maintenance of propofol anesthesia in children, Peadiatric Anaesth, 23(8):712-9, 2013.