Near-Infrared Spectroscopy and Its Potential for Point-Of-Care Testing

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Abstract: Point-of-care or ‘near-patient’ testing has received attention in recent years for its usefulness in rapid and reliable delivery of healthcare to a patient in a variety of clinical settings. Near-infrared spectroscopy (NIRS)-derived optical biomarkers (e.g., tissue oxygen saturation) have been utilized to monitor tissue vascularity and oxygenation status continuously in normal and patient populations. Despite its ease of use and modest cost, the NIRS modality is still not at point-of-care use in the healthcare sector as extensively as other physiological modalities such as Pulse Oximetry. This short communication examines the case for point-of-care testing with two examples of FDA-approved NIRS systems, and discusses the feasibility and implementation of the NIRS modality as a point-of-care technology.

Keywords: Point-of-Care (POC), Near-infrared Spectroscopy (NIRS), Food and Drug Administration (FDA), Optical Biomarkers, Sensitivity, Specificity.

1. Introduction

Applications of Near-infrared spectroscopy (NIRS) in understanding tissue metabolism in clinical, sports and ergonomics-related literature are rapidly growing (e.g., Bhambhani 2010 and 2012, Harrison et al., 2010, McGorry et al., 2010, Maikala 2012, Neary 2004, Perrey et al., 2010a and 2010b). Topical special issues on NIRS in different research domains are perfect examples of its popularity and utility (Maikala and Hargens 2010, Elwell and Cooper 2011, Ferrari et al., 2012). Lately, point-of-care or ‘near-patient’ testing has become a healthcare delivery issue of utmost importance, specifically in settings such as primary care, home healthcare, emergency medicine and in low resource or remote areas (Price and Kricka 2007). Point-of-care technologies (e.g., in vitro testing, noninvasive modalities, and low-cost imaging) facilitate effective and efficient care to a patient in a fast and safe manner. Besides eliminating the delay of processing at the central laboratory, and thereby decreasing turnaround time for a variety of diagnostic tests (Gibler and Blomkalns 2006), the suggested advantages of point-of-care testing are: quick identification of patients that are likely to have complications, decrease in time required for diagnosis, improved sample quality because of immediate ‘bed-side’ testing, and fast and accurate information transfer regarding diagnosis and treatment to patients and their insurers. However, in addition to cost and ease of operation, accurate and rapid diagnosis, and rugged performance under a variety of environments, the identification of appropriate and valid biological markers by a specific point-of-care modality is critical in delivering optimal healthcare by an end-user (e.g., emergency physician). Against this backdrop, this manuscript examines noninvasive NIRS as a point-of-care testing technology, and explores its feasibility.

It is well established that, in humans, blood flow is regulated at three levels of the circulatory system: (1) centrally by the cardiac output, (2) regionally by the distribution of blood flow between organs, and (3) microvascularly by distribution of blood flow within organs (Sibbald et al., 2000). In explaining the importance of tissue oxygenation and blood circulation, these authors stated that cardiac output and oxygen-related indices are poor substitutes for the quality of regional tissue oxygenation. Parameters derived from mixed venous blood provide a global estimation of tissue oxygenation, but do not represent the adequacy of tissue oxygenation in specific organs at risk. Subsequently, changes in mixed venous oxygen saturation reflect changes in the relationship between systemic oxygen delivery and consumption. To this effect, multi-channel noninvasive NIRS optical modalities (available as bench-top, portable and wireless) are being utilized in a variety of healthy and patient populations to assess tissue oxygenation continuously in terms of mixed venous oxygen saturation and hemodynamic status in real time. The mixed venous oxygen saturation, defined as the ratio of oxygenated hemoglobin to total tissue hemoglobin, reflects a continuous measure of the balance between oxygen delivery and oxygen consumption of the tissue region sampled.

NIRS is based on the principle that light energy in the near-infrared region (700-900 nm, also known as the ‘medical spectral window’) is differentially absorbed by the oxygenated and deoxygenated forms of chromophores in the tissue (e.g.,
hemoglobin). The propagation of light into a highly scattering medium (e.g., live tissue) follows the Modified Beer’s Law and results in an exponential light attenuation as it transmits through skin and bone into the tissue (Maikala 2010). In a typical investigation using a NIRS modality, a known amount of incident light (known as source) at specified wavelengths is impinged on the tissue to be studied and an unknown amount of light is recovered by a receiving optode (known as detector). Since the amount of light recovered during propagation through the tissue depends on optical properties (i.e., absorption and scattering of hemoglobin in the microvasculature), any change in absorbancy in the recovered light reflects a change in the physiologic state of hemoglobin in the illuminated region.

Interestingly, Pulse oximetry also uses similar optical spectroscopy principles, and is widely utilized in ‘near-patient’ clinical settings as a standard of care for noninvasively measuring arterial hemoglobin saturation. In contrast, the NIRS modality noninvasively monitors a venous-weighted oxyhemoglobin saturation (~75% venous, versus 20% arterial, versus 5% capillary blood, in the vascular compartment), but is still not as prominent as the pulse oximetry as a point-of-care healthcare delivery technology. Although known for its ease of use, modest cost, and continuous real time monitoring, a lack of presence of the NIRS modality at a near-patient setting is the focus of this communication. First, important attributes of a typical biological marker and regulatory compliance for a point-of-care technology are delineated. Second, selected examples of the NIRS modality used in point-of-care settings, its feasibility, and a strategy for implementing point-of-care technology in healthcare are described.

2. Making A Case for Point-of-Care Testing

As per Price and Kricka (2007), to be an effective noninvasive point-of-care modality, a monitoring device should adhere to four characteristics: 1) the variable that is measured should be strongly associated with morbidity or mortality, 2) the monitored variable must be one that can change relatively rapidly and warn of physiologic deterioration, 3) appropriate interventions must be available to modify a rapidly changing variable and reverse physiologic deterioration, and 4) the device must be simple for health care personnel to use with minimal instruction. The ‘variable’ in this context is simply a valid biological marker that is detectable by the system being used in diagnostic or research purposes. So what is a biological marker?

2.1. Biological Marker

A working group from the National Institute of Health, USA, standardized the following definition for a biological marker (also known as biomarker): a characteristic that is objectively measured and evaluated as an indicator of normal biological processes, pathogenic processes, or pharmacologic responses to a therapeutic intervention (Biomarkers Definitions Working Group 2001). According to Vasan (2006), a biomarker is a unique characteristic pertaining to either health or disease of a patient, and can be measured from a sample obtained through a clinical test (e.g., blood, urine, or tissue); directly in real time (e.g., hemodynamic measures such as blood pressure and heart rate); or from an imaging test (e.g., Computed Tomographic scan). Depending on its intent of application in a clinical or research setting, a biomarker is also classified as antecedent, screening, staging, prognostic, or a surrogate endpoint. A biomarker can also be treated as an investigative tool in terms of providing insights into a disease or injury mechanism (Vasan 2006).

In case of NIRS-derived measures, variables such as tissue oxygen saturation, total tissue blood volume, or tissue (de)oxygenation are often used as optical biomarkers. Since the derivation of tissue oxygen saturation eliminates the calculation of actual concentration of hemoglobin by ignoring the influence of optical path length in the tissue (Maikala 2010), this variable is the most exploited optical biomarker in NIRS-related literature. However, as per the four salient characteristics suggested by Price and Kricka (2007), it is not clear if this optical biomarker, and subsequently the NIRS modality can be used as a point-of-care technology in disease or injury diagnosis or prevention. Furthermore, in the United States, new technology is subject to regulatory compliance by the Food and Drug Administration (FDA), before it is routinely used by a healthcare professional.

2.1.1. Typical Approach of Regulatory Compliance for the NIRS Modality as the Point-of-Care Technology

One of the noble missions of the FDA is to protect public health through enforcement of law. Typically, a manufacturer of a NIRS modality supplies the FDA with a premarket notification for marketing clearance by addressing the intended use of the modality, including its safety and efficacy features. For the FDA approval of a point-of-care modality, three important evidence-based elements are typically reviewed: accuracy and reliability, labeling for healthcare professionals, and risk versus benefit (Biomarkers Definitions Working Group 2001).
2.1.2. Accuracy and Reliability

For a point-of-care modality to be recognized by the FDA as accurate and reliable, the following steps are assessed by the regulatory system: the stated environment for its application should be replicated in multiple settings during validation (e.g., in emergency care), study participants recruited should represent the proposed point-of-care users, and confirmation studies should be done at representative healthcare settings. Another important consideration is adequate and proper training for operators of the NIRS modality. Operators should be tested for their proficiency in execution of each technical step without any help and attain results that are similar to those obtained by laboratory professionals. The FDA also appraises the manufacturers’ hazard analysis to identify potential sources of error, illustrate ways to limit the likelihood of a potential error, and corroborate the usefulness of each improvement. By simulating an error scenario and monitoring performance of the modality (also termed as Stress test), the FDA validates the effectiveness of protective measures considered by the NIRS manufacturer, thereby fool proofing the utility of the modality by the end-user.

2.1.3. Labeling

The FDA reviews any written, printed or graphic material to make sure that step-by-step instructions are understandable, brief, and without any complexity for the intended user. Labeling should inform users of the NIRS modality not to tamper with safeguards, how to identify system errors, and explain the procedure for system restoration.

2.1.4. Risk versus Benefit

With the information provided by the manufacturer of the NIRS modality and relevant published literature, the FDA examines the possibility of medical benefits in utilizing the modality at point-of-care settings. They question the impact of the decrease in turnaround time by the modality at the point-of-care in facilitating earlier interventions by the clinicians and treatment to the patient. They estimate the risks associated with foreseeable misuse of the modality, failure (if any) during operation, performance accuracy and the consequence of a false-positive or false-negative result. Risk of superfluous hospital admissions and associated costs, consequences of delay in treatment, possibility of patients’ discharge from the hospital when they have a life-threatening condition are also considered during the FDA approval process.

Overall, when benefits of the NIRS modality as a point-of-care technology outweigh its known risks, then the FDA considers it is safe enough to approve for public use. Taking it further, the approval by the FDA for utilizing the NIRS modality can be translated into a health policy so that costs are covered by the health care provider. Although this translation process is beyond the scope of this manuscript, for the present argument, two healthcare scenarios that utilized specific NIRS units approved by the FDA are presented as cases for point-of-care testing.

3. Examples for the Case Study

**Inspectra™ Tissue Oxygen Saturation Monitor**

Beliman and Blondet (2009) used an oxygen saturation monitor (InspectraTM 325, Hutchinson Technology, Inc., Hutchinson, MN, USA approved by the FDA in 2006) to examine tissue perfusion in combat war patients suffering from battlefield injuries. For a four-month period, these authors monitored eight patients whose tissue oxygen saturation from the thenar muscle was less than 70%. Based on their previous finding, this specific cutoff value represented multiple organ failure and mortality. Before resuscitation, saturation values of seven patients ranged from 50% to 62%, after resuscitation those increased to 71% to 91%. Other physiological responses (e.g., blood pressure, heart rate, arterial hemoglobin saturation) were also simultaneously monitored. However, one patient did not survive during this study. Based on the authors’ findings, it was suggested that NIRS-derived biomarkers could be used as a significant point-of-care testing for early identification and treatment of hypoperfusion in the severely injured trauma patients.

**INVOS® Cerebral Oximetry**

A randomized prospective blinded study was designed to examine the influence of monitoring tissue oxygen saturation and intervention on clinical outcomes in coronary artery bypass surgery patients (Murkin et al., 2007). Two-hundred patients from a preoperative clinic were continuously monitored by a cerebral oxygen saturation monitor (INVOS 5100, Somanetics Corp., Troy, MI, USA approved by the FDA in 2008) with either active display of oxygen saturation combined with treatment modality (intervention group) or without display of cerebral oxygen saturation (control group). For the intervention group, a prioritized intraoperative treatment protocol (e.g., increase of pump flow, increase of mean arterial blood pressure, normalization of PaCO₂, deepen anesthesia, increase of FiO₂ and pulsatile perfusion) was utilized to maintain oxygen saturation values at or above an alarm threshold of 75% of the resting baseline. These results demonstrate that the treatment of increasing or maintaining tissue oxygen saturation, thereby returning to baseline values, in the intervention group resulted...
in a shorter length of stay in the intensive case unit, with a significant reduction in the incidence of major organ morbidity and mortality versus the control group. These authors concluded that without any crucial feedback from an optical biomarker such as cerebral oxygen saturation, it is difficult for a clinician to identify adverse complications in a patient in a proactive way.

4. Sensitivity and Specificity of NIRS

From the preceding two examples, it might be sufficient to argue that the NIRS modality is a useful clinical device at the ‘near-patient’ setting. However, to be a clinically valid measure, a biomarker should also possess high sensitivity and high specificity so that an end-user can utilize the performance measure confidently in clinical decision-making (Vasan 2006). In other words, sensitivity and specificity determine the probability that the specific NIRS modality-derived physiological measurement will correctly identify a patient having the specific disease or not (i.e., true positives or true negatives).

To this effect, Comerota et al. (2003) assessed the sensitivity and specificity associated with cutoff points in tissue oxygen saturation of the gastrocnemius muscle in 49 individuals with and without peripheral arterial disease. Receiver-operator characteristic curves were utilized in evaluation of the performance of the Inspectra™ tissue oxygenation monitor. Sensitivity was defined as the portion of patients testing positive for peripheral arterial disease when a saturation endpoint was used for the patients known to have peripheral arterial disease. Specificity was defined as the portion of patients testing negative for peripheral arterial disease status when a saturation endpoint was used for participants known to be normal. In patients with peripheral arterial disease, the time elapsed from peak exercise to 50% tissue oxygen saturation recovery was >70 seconds, with a sensitivity of 89% and a specificity of 85%. When time elapsed from peak exercise to 100% tissue oxygen saturation recovery was evaluated, a value of >165 seconds resulted in a sensitivity of 88% and a specificity of 81%. These authors suggested that the optical biomarker ‘tissue oxygen saturation’ is a valid endpoint for diagnosis and monitoring patients with peripheral arterial disease.

Responses derived from INVOS® cerebral oximeter were compared with transcranial Doppler during neurological monitoring of patients undergoing carotid endarterectomy (Pugliese et al. 2009). Sensitivity and specificity in predicting the occurrence of cerebral ischemia were performed according to Bayes theorem. For Doppler-derived responses, the performance measure was a reduction in the mean blood flow velocity in the middle cerebral artery over 50% from baseline (or pre-clamping value) or an absolute mean blood flow velocity in the middle cerebral artery under 10 cm/sec. For cerebral oximeter-derived responses, a reduction in a tissue oxygen saturation value of more than 20% from baseline or an absolute value under 45% was considered a significant performance measure. Results demonstrated that Doppler-derived responses had a sensitivity of 100% and a specificity of 80%, suggesting the transcranial Doppler system’s inadequacy in identifying the need for shunting during clamping. In contrast, tissue oxygen saturation had sensitivity and specificity of 100% in detecting early neurological deficit during clamping, suggesting the usefulness of the NIRS modality in identifying cerebral ischemia objectively. But could these examples of sensitivity and specificity be good enough to consider the NIRS modality at the point-of-care application?

5. Discussion

As evident from the two FDA-approved NIRS systems as a case study (Inspectra™ tissue oxygenation monitor, INVOS® cerebral oximeter), and in particular, based on their accuracy in performance (in terms of sensitivity and specificity), the NIRS modality seems to encompass four characteristics suggested by Price and Kricka (2007). For example, the variable, tissue oxygen saturation, could be used as a diagnostic biomarker in reducing the incidence of morbidity and mortality [characteristic 1]. Continuous monitoring of the saturation values with respect to a cutoff point or threshold could inform the clinician about the patient status [characteristic 2]. More importantly, if there is a drastic change in the saturation values of patients under observation, interventions could be facilitated immediately to achieve a clinical goal [characteristic 3]. At the most basic level, a typical system’s attributes are: relative ease of use with nominal instructions, real time continuous monitoring, portability, speed of delivery of results, minimal invasiveness, increased safety of administering to the patient (non-ionizing radiation), and relatively low cost as compared to other modalities such as functional magnetic resonance imaging using blood oxygenation level differences(MRI BOLD), and also lower costs associated with average length of stay in the hospital or hospital costs due to routine monitoring [characteristic 4] (Price and Kricka 2007). These above justifications seem to be a strong sign for a point-of-care technology. Surprisingly, in spite of these characteristics, usage of the FDA-approved NIRS modality at ‘near-patient’ testing is minimal. So what are the NIRS-related concerns that are still not being resolved?
5.1 Conflicting Issues

A few important questions however remain unanswered: What do these tissue oxygen saturation values mean to a clinician? What do (ab)normal tissue saturation values suggest at the point-of-care? Does the NIRS modality provide new critical information not available by other current resources? Does the NIRS modality have ‘universally’ acceptable threshold limits or reference values one should look for at the point-of-care? According to Vasan (2006), defining abnormal threshold values is a critical step before its clinical use as a biomarker. The effect of age, gender, ethnicity and other demographics in normal and patient populations is also important before it can be accepted as a valid marker for diagnosis. What are the reference values specific for each patient population and for each NIRS modality? Al-Rawi et al. (2006) identified tissue oxygen saturation thresholds (using NIRO 300, Hamamatsu Photonics, Hamamatsu, Japan) in adult patients with cerebral ischemia as a drop of 13% in oxygen saturation levels (in contrast to different cutoff points chosen by Murkin et al. 8 using INVOS® Cerebral Oximetry). This threshold by Al-Rawi et al. (2006) was obtained with a sensitivity of 100% and a specificity of 93.2%. Above this threshold, their patients failed to show any evidence of ischemia on clamping. But, similar to Smith and Elwell (2009), Al-Rawi et al. (2006) voiced their concern for the presence of a large biological variability and lack of consensus even for the ‘normal range’ baseline cerebral oxygen saturation values (~60-85%) in NIRS-related literature. Interestingly, a difference in saturation values obtained from the NIRS modalities such as INVOS® Cerebral Oximetry and NIRO 300 (not yet approved by FDA) was also reported previously by Gagnon et al. (2002), suggesting the fact that there is an urgent need for a gold standard in NIRS technology before there can be a global clinical acceptance of thresholds. The same dilemma of identifying the “normal” range in muscle oxygen saturation is also evident for both healthy and patient populations. Indeed, demographic-relevant thresholds for defining risk stratification or identifying normal limits pertaining to such classification and validity of these thresholds is greatly lacking for the NIRS modality. These concerns notwithstanding, noninvasive monitoring of NIRS-derived optical biomarkers in patient populations with diabetes, liver cirrhosis, renal disorders, heart failure, chronic obstructive pulmonary disease, peripheral vascular disease is still growing rapidly (Kraveri et al. 2010), but not yet at point-of-care.

A compelling issue still persists. Can the NIRS modality be used as a stand-alone system for diagnostics, given its utility in various patient populations? Hirsch et al. (2010) challenged that NIRS cannot be used as a standard of care in intensive care settings. A lack of strong evidence for NIRS modality in terms of methodological limitations, lack of randomized trials, lack of correlation with neurological abnormalities and clinical outcomes, presence of large inter- and intra-individual temporal variability was emphasized in their criticism. Since this biomarker assists surgeons and physicians in interventions to maintain safe cerebral oxygenation levels of patients, these authors advocated the usage of NIRS only as an adjunct to other modalities in patient monitoring. A similar apprehension was also articulated by others (e.g. Pattinson et al. 2004).

In their rebuttal to Hirsch et al. (2010), Tweddell and colleagues (2010) argued that NIRS should be used as a standard of care in the postoperative setting. Relevant studies were summarized by these authors to emphasize that the NIRS modality does provide a target for goal-directed therapy (e.g., treatment of low oxygen delivery), as tissue oxygen saturation values can be represented as a noninvasive surrogate for oxygen saturation of the mixed venous blood. To justify the level of evidence and treatment effect with respect to the NIRS modality, Tweddell and colleagues utilized a classification structure “A, B and C” (from the American Heart Association and the American College of Cardiology Task Force on Practice Guidelines), where Level A is the highest evidence supported by multiple randomized controlled trials. Admittedly, Tweddell et al. (2010) reiterated lack of strong evidence-based clinical outcomes for the NIRS modality in terms of multiple randomized trials or meta analyses. However, with evidence from selected prospective observational NIRS studies, these authors felt the justification as Level B evidence (assigned to studies with data derived from a single randomized trial, or non-randomized studies). To stress their support for the NIRS modality, the following statement from the Task Force on Practice Guidelines was emphasized by Tweddell et al. (2010): “A recommendation with level of evidence B or C (Consensus opinion of experts, case studies, or standard of care) does not imply that the recommendation is weak. Many important clinical questions addressed in the guidelines do not lend themselves to clinical trials. Even though randomized trials are not available, there may be a very clear clinical consensus that a particular test or therapy is useful or effective”. However, in the case of diagnostic testing in these highly specific and controlled health care circumstances, there is no reason that level A evidence cannot be obtained in future, if in fact the specific test represents a major step forward in efficient patient treatment. More importantly, Tweddell et al. (2010) reiterated the importance of the FDA approval for selected NIRS systems, justifying that such an approval from a regulatory agency further signifies the importance of utilizing the NIRS modality at the point-of-care testing.
5.2 Implementing Point-of-Care Testing for the NIRS Modality

Developing a blueprint for executing point-of-care testing for the NIRS modality at the near-patient setting is a challenging undertaking. To this effect, an excellent approach suggested by Gibler and Blomkalns (2006) to implement cardiac biomarkers at the point-of-care testing for an emergency care unit can also be utilized for the NIRS modality as well. Following their methodology on cardiac biomarkers, for a successful implementation of optical biomarkers (for example in the emergency department), it is critical to have a strong collaboration among clinicians, laboratorians, and hospital administrators.

The role of clinicians is critical in improving the turnaround time for diagnosis, thereby reducing time for clinical decisions in terms of admission and discharge of patients. Additionally, based on their expertise and experience, clinicians can document (ab)normal thresholds of optical biomarkers for patients which is still sparse in the NIRS-related literature.

Involvement of laboratorians (consisting of clinical chemists and pathologists) in the evaluation and implementation of the NIRS modality as a point-of-care test is important as well. This particular group could facilitate pilot trials for a baseline evaluation of the point-of-care testing to be used. They could investigate if the utility of NIRS would have a positive impact in a point-of-care setting. Typical outcomes from a pilot trial can include details of turnaround time (pre- versus post-testing turnaround times) and performance accuracy of the NIRS-derived optical biomarkers. However, such testing for turnaround times should be in compliance with the Clinical Laboratory Improvement Amendments that provide standards of quality for laboratory testing, thus assuring the clinical accuracy and reliability of the point-of-care testing. It is also important to note that these laboratory professionals should evaluate trials for the point-of-care testing of the NIRS modality to distinguish if they measure up to the central laboratory version of the same biomarkers (e.g., venipuncture blood collection), thereby confirming the accuracy of the NIRS modality as an effective clinical decision maker. By facilitating an online link between the NIRS modality at the near-patient setting and the laboratory information systems, point-of-care test results performed in the healthcare setting can be stored as part of the patient medical and billing records. Similar to the ease of obtaining other central laboratory analyzer results (Gibler and Blomkalns 2006), the rapid retrieval of electronic records of point-of-care test results from the NIRS modality should improve the clinicians’ effectiveness.

Gibler and Blomkalns (2006) also stressed the involvement of hospital administrators from the beginning of the implementation process so that the cost-benefit analysis of the point-of-care testing can be performed and validated. Industrial engineers who are part of hospital administration should utilize the six sigma tools and methods so that quality and reliability of the optical biomarkers can be examined, with the ultimate goal of meeting or exceeding the patient requirements in terms of minimizing the costs for care and maximizing the efficiency of the process of point-of-care testing. However, evaluating the demonstrable cost effectiveness of the point-of-care testing in terms of quality assurance and quality improvement requires a thorough evaluation of process indicators such as length of stay, speed of delivery of guideline-based therapies to patients, discharge disposition, and hospital charges. This collaboration between various stakeholders ultimately results in satisfaction among patients, their insurers, and health care providers. However, as emphasized by Gibler and Blomkalns (2006), the point-of-care testing should ‘complement’ rather than ‘shift’ from the central laboratory procedures.

Overall, it is important to note that the present manuscript dealt with only two FDA-approved NIRS devices that are being widely used in clinical settings in USA. Although there are numerous publications that have utilized Inspectra™ tissue oxygenation monitor and INVOS® cerebral oximeter, only a few clinical studies were selected for the present review to simply demonstrate the NIRS feasibility (or lack of it) within the realm of characteristics suggested by Price and Kricka (2007) and Vasan (2006). Similarly, there are FDA-approved NIRS units that are available in the market, but the publications for this communication were not relevant. Furthermore, there are other NIRS devices in the market that are not approved by the FDA (e.g., NIRO 300 of Hamamatsu Photonics, Japan, Oxymon Mk III of Artinis Medical Systems, The Netherlands, OxiplexTS™ of ISS, Inc., USA) but are extensively used in clinical research and human performance monitoring studies (Elwell and Cooper 2011, Maikala and Hargens 2010, Ferrari et al. 2012). As suggested by a few authors (e.g., Smith and Elwell 2009, Villringer et al. 2004, Taillefer and Denault 2005), more research relevant to optical biomarkers is still needed from a variety of populations before the NIRS modality could routinely be used as a ‘near-patient’ or point-of-care testing device.

6. Conclusions

Based on the present communication, evidence for the applicability of NIRS-derived optical biomarkers at the point-of-care setting is still inconclusive. However, its extreme usefulness as an adjunct to other diagnostic and treatment modalities for patient monitoring (simultaneously from multiple tissue regions) cannot be ruled out. The arrival of nascent wireless noninvasive wearable systems (e.g., PortaMon, Artinis Medical Systems, BV, The Netherlands) should provide...
much needed impetus to biophotonics researchers and clinicians to further develop the NIRS modality towards an effective and efficient point-of-care technology.

7. References