Evaluation of Spatially Resolved Spectroscopy (SRS) in Traumatic Brain Injury (TBI)

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Aims
To evaluate current SRS method on realistic 5 layered head models.
To adapt SRS to work with model based numerical reconstruction.

Introduction

Traumatic brain injury (TBI) patients require constant monitoring to guide therapy and preserve neurological tissue. Functional near infrared spectroscopy (fNIRS) has potential to provide real time cerebral oxygenation assessment. However, accurate brain measurements are limited by signals originating in superficial skin and bone regions [1].

Equation 1 – Equation to calculate absorption coefficient, μa, at a given wavelength, λ, using the change in light attenuation, A, with detector separation, p, where, k, is an unknown constant.

\[ k_{a}(λ) = \frac{1}{2} \left( \frac{\Delta A(λ)}{p^2} \right) \]  

Equation 2 – Equation to calculate chroanophore concentration from absorption coefficient, μa, using extinction coefficients, ε, for each chroanophore at each wavelength.

Spatially resolved spectroscopy (SRS) is an algorithm (Eqs. 1 & 2) designed to measure tissue oxygenation index (TOI) and tissue haemoglobin index (THI) in deep tissues (~2 cm depth), without contamination from superficial layers [2]. This is achieved by measuring ∆A/∆p; the change (gradient) in detected light over a series of multi-distance detectors (Fig. 1A & B).

The ability to differentiate deep and superficial signals is paramount for TBI monitoring; after trauma, oxygenation changes in the brain no longer mirror those of somatic tissues.

Method

Table 1 – Probe Specifications

<table>
<thead>
<tr>
<th>Source</th>
<th>Detector</th>
<th>No. of Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>735, 810, 850</td>
<td></td>
<td>37 &amp; 43</td>
</tr>
</tbody>
</table>

Table 2 – Optical Properties

<table>
<thead>
<tr>
<th>Region</th>
<th>HbO</th>
<th>HbR</th>
<th>HbT</th>
<th>HbD</th>
<th>S1</th>
<th>S2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin</td>
<td>0.550</td>
<td>0.040</td>
<td>0.070</td>
<td>0.14</td>
<td>2.82</td>
<td></td>
</tr>
<tr>
<td>Bone</td>
<td>0.392</td>
<td>0.008</td>
<td>0.049</td>
<td>15.4</td>
<td>1.47</td>
<td></td>
</tr>
</tbody>
</table>

Finite element model (FEM) simulations were used to model the Niro-200NX (Hamamatsu) probe geometry and source wavelengths (Table 1) on a realistic, 5 layered head model (Fig. 2) with the optical properties shown in Table 2. Data were simulated for saturation changes in the brain, between 80-100%, while superficial absorption remained constant. The SRS algorithm was then used to calculate TOI values for the simulated datasets.

Simulation findings confirmed the validity of SRS for homogeneous models. However when scattering and absorption were heterogeneous both the TOI range and the quantitative accuracy decreased. Modelling scatter to be homogeneous showed reduced TOI and accuracy improvements indicating inadequacies in the current SRS model concerning scattering assumptions.

In vivo data collected using the Niro-200NX (Hamamatsu) during valsals manoeuvers confirmed the validity of the simulation findings for a fully heterogeneous mesh. A valsals causes intracranial pressure changes of ~30% with similar changes depicted in the TOI [4]. However the average brain TOI (Fig 5) only changed by ~10%. The quantitative accuracy of the TOI was also lower than expected at ~50%, with baseline oxygen saturation in the brain expected to be ~75%.

The simulated data highlights limitations of the current SRS algorithm and suggests that a more complex model, incorporating heterogeneous scatter and regional reconstruction, is required to improve the validity of SRS.

Conclusion

SRS provides increased sensitivity to changes in brain haemodynamics compared to standard NIRS measurements. Current TOI calulations are capable of identifying changes in brain saturation however the range and quantitative accuracy of the values are still susceptible to influences from superficial layers and heterogeneous scatter. Adaptation of SRS to work with a FEM reconstruction showed substantial improvements in quantitative accuracy of TOI. However FEM tomographic reconstruction methods provided the best overall TOI range and quantitative accuracy; this was due to 168 overlapping measurements from the DOT style probe (Fig. 7).