Intraoperative functional brain imaging - hemodynamic response visualization using Laser Doppler.

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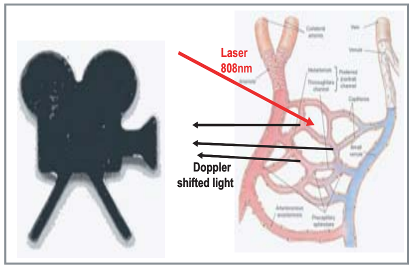
Optics - Laser Doppler Imaging.

As the name suggests, LDI, Laser Doppler Imaging exploits the Doppler effect to generate images, in this case of red blood cells moving within the microcirculatory system.



By using an 808nm laser as illumination, oxy- and deoxy-hemoglobin are sampled equally and so, by collecting the Doppler shifted light we obtain information on all the red cells moving in the illuminated tissue, hence we can visualize: Perfusion, Concentration of moving cells and their Speed distribution.
At 808nm the light penetration depth is in the millimetre range and so is highly appropriate for imaging the active cortical surface.

The LDI has been designed to fit beneath a standard surgical microscope and is non-invasive as it does not come into contact with the patient and is classified as laser class I.

$$\text{Perfusion} = \langle C \rangle V_{rms} \propto M_1 = \int_0^\infty \nu S(\nu)\,d\nu,$$

$$\text{Concentration} = \langle C \rangle \propto M_0 = \int_0^\infty S(\nu)\,d\nu,$$

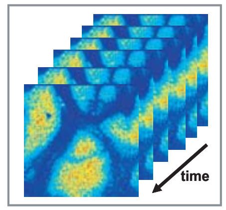
$$\text{Speed} \propto \frac{M_1}{M_0},$$

$$S(\nu) = \left| \int_0^\infty I(t) \exp(-i2\pi\nu t)\,dt \right|^2.$$

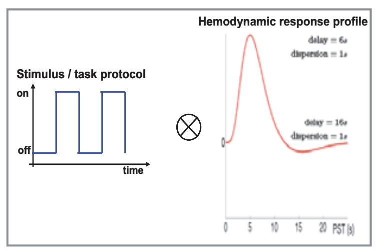
Image Analysis - Isolation of function related data.

Laser Doppler images contain information from all moving red blood cells whatever the origin of their movement. To form a 'functional' image, the data pertaining only to the function of interest needs to be isolated. We have achieved this by acquiring a sequence of images whilst the subject followed a predetermined task protocol.

Take image sequence during stimulation



The data was then analysed, after reallignment and denoising, by a wavelet based regressor analysis. The information of interest was modelled by convolving the stimulation protocol with the expected hemodynamic response profile and then separated from all the other periodic contributions to the image (breathing, heart beat, vasomotion, etc).

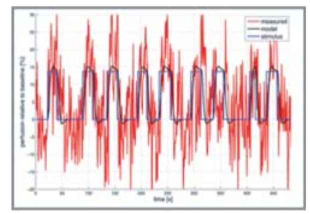


Activation regressor.

A parameter map was then formed for that specific task and its statistical significance tested. This generates the map of the cortical area active whilst the task is being performed (see image to the right).

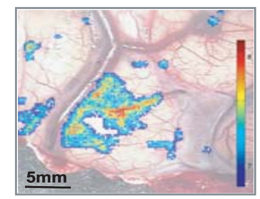
Intraoperative Functional Brain Imaging.

Prior to tumor removal surgery, both tumor and specific functional areas are located using MRI techniques. Once open however, the brain shifts necessitating a re-navigation during surgery i.e. cortical electro-stimulation (risking epileptic seizure, false positives and consuming time).
Here we show results obtained during an awake open brain surgery of a tumor patient performing a finger tapping task. The areas showing high statisical significance correlate well with those identified by the preoperative functional MRI and the intraoperative cortical electrostimulation.

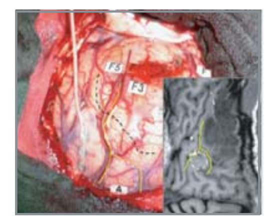


Time course.
The average time-course of the activated region after subtracting unrelated regressors shown with the stimulation protocol.

Active area map.
Statistical parameter map showing the active region superposed on a conventional optical image of the brain area.



Operation site.
Surgeons view of the operation site. Labels denote areas identified as active by electrostimulation. The inset shows the corresponding Mercator MRI view of activity in the hand knob area as well as the tumor.



Outlook: Thanks to its high spatio-temporal resolution and the very strong signal achieved, LDI can be readily applied in:
Surgery - for rapid non-invasive identification of specific areas, repeated use could map many different functions during surgery.
Research - for hemodynamics, LDI is suited to awake experimentation so that the confounding issues associated with anesthesia, can be avoided.
Further - Larger areas and working distance. Higher spatio-temporal resolution. Multi-wavelength, oxy, deoxyhemoglobin imaging hence metabolic imaging.