**A complex system’s approach to study Hemodynamics with Optical Techniques**

S. L. Novi1, R. M. Forti1, W. A. A. Rocha2, R. C. Mesquita1

1Neurophysics Group, IFGW, UNICAMP,

2Institute of Mathematics, Statistics and Computing Science, IMECC, UNICAMP

**Introduction:** Network science is an interdisciplinary approach used to characterize network structure and function. It has been widely explored in the last two decades mainly due to the increasing acceptance that macroscopic behavior of complex systems emerges from the interaction of their constituent particles [1]. In fact, different complex networks have similar properties in terms of global organization, information transference and connectivity despite their differences in microscopic structure. Therefore, it is often possible to characterize most of the system features with network parameters. In this work, we aimed to illustrate our novel applications of complex systems, and of network science in particular, to optical data acquired from biological tissue.

**Materials and Methods:** We investigated the potential of complex systems approaches to 3 different experimental protocols: (1) the resting state properties measured with Near-Infrared Spectroscopy (NIRS) in both healthy adults and patients with carotid stenosis; (2) the connectivity of cerebral blood flow measured by Laser Speckle Imaging in a rat model of ischemic stroke, and; (3) the tumor hemodynamics microenvironment in mice, both during the steady state and during Photodynamic Therapy (PDT). In all 3 cases, the spatial information from the light detector assumes the role of nodes of the network, while the links between two nodes were computed based on the Pearson correlation coefficient across the node’s time series. In order to build undirected and binary graphs, we varied the threshold, *p*, so that we could analyze the network parameters as a function of the threshold. We estimated standard global networks parameters [2], such as the average degree, degree standard deviation, clustering coefficient, characteristic pathlength and diameter. The connectivity patterns among each cohort was established by projecting all networks in the same plane and then extracting the most frequent patterns.

**Results and Discussion:** Our methodology suggests that the human brain seems to behave as a classical complex system at rest, in which there is only few allowed states that share similar network features. For the healthy volunteers, we observed a dominance of the left hemisphere in terms of connectivity and centrality. For the stenosis patients, we found that the resultant networks correlate with the level of occlusion in the carotid. The latter is similar to what we have found in the rat model of ischemia, in which the connections and clusters become denser and the average distance between two nodes tends to decrease as the level of ischemia increases. This result is coherent with the fact that ischemia can influence the system and force all its constituent particles to behave in such a way that it generates a more synchronized macroscopic behavior (lack of cerebral autoregulation). As a negative control, the tumor hemodynamics in mice does not appear to have complex system properties, and we could not find an indicator of the efficacy of the PDT treatment on cancer cells based on network parameters.

**Conclusion:** In this work, we illustrate a procedure to combine complex networks and optical techniques, which appears to be promising and efficient to investigate a variety of physiological phenomena. In humans, our results contribute to the understanding of how the brain works and is organized, both in diseased and in healthy situations. Results from animal models strengthen the hypothesis that cerebral correlates with severity of ischemia. With further investigation, these results could be helpful to diagnose human stenosis patients. Finally, our results in tumor hemodynamics reinforce that the brain is unique as a complex system.

**References:** [1] Bullmore, E. & Spors, O., 2009*,* Volume 10, pp. 186-198. [2] Rubinov, M. & Sporns, O., 2010, *NeuroImage,* Volume 52, pp. 1059-1069.