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LUCA Device: a Multi-Wavelength Time-Resolved Spectroscopy and Diffuse Correlation Spectroscopy Device with an Integrated Clinical Ultrasound Module/Probe

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Abstract: We present the LUCA-device combining two diffuse optical techniques, time-resolved and diffuse correlation spectroscopies, with simultaneous ultrasound imaging for improved cancer screening. In particular for thyroid cancer.

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1. Introduction

An international, multi-disciplinary project (LUCA[1] - Laser and Ultrasound Co-Analyzer for thyroid nodules) has developed a versatile device combining sixteen channel diffuse correlation spectroscopy (DCS) with eight wavelength time-resolved spectroscopy (TRS) with medical ultrasound. Its primary aim is to increase the sensitivity and specificity of thyroid cancer diagnosis by adding direct physiological and hemodynamic information to the screening process. It allows for the measurement of tissue hemodynamics (blood oxygenation, blood volume microvascular blood flow), chemical constitution (scattering spectrum, collagen, water and lipid concentrations) as well as anatomy. The measurements are done with an integrated probe combining optical fibers and a clinical ultrasound sensor. This combination enables rapid integration into the clinical flow as well as ultrasound guidance for the optical data acquisition and analysis.

We have targeted thyroid cancer since it is a major health challenge (around five hundred thousand new cases diagnosed annually worldwide), and thyroid nodules have a high prevalence (up to 76% of the population screened with ultrasound) [1], the current diagnosis techniques (US screening followed by ultrasound-guided fine needle aspiration biopsy) lack of specificity and sensitivity, leading often to non-diagnostic or false positive results, and consequent unnecessary surgeries. In this framework, even a modest improvement in the diagnosis could have a great impact, in term of better therapeutic outcomes and of a more efficient use of health resources.

We will present the basics of the device and its characterization as well as current *in vivo* results from the ongoing studies on thyroid screening.

2. The LUCA device

The LUCA device includes a diffuse correlation spectroscopy module (DCSM), a time resolved spectroscopy module (TRSM), an ultrasound module (USM), a multi-modal probe, and a post-processing data analysis module (NEM). All the different modules are integrated in a single device by the main control module (MM), that handles

[1] http://www.luca-project.eu. Acknowledgments: This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N. 688303.

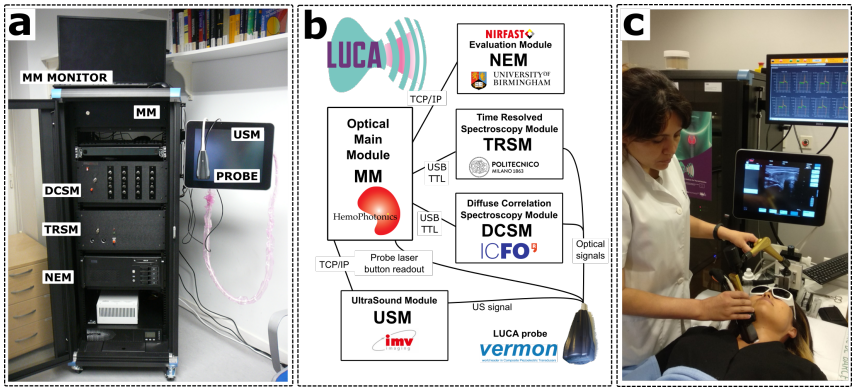

Fig. 1. (a) Photo of the LUCA device. (b) Block diagram of the LUCA device and connections. (c) Clinical use of the LUCA device.

the communications with all the other modules of LUCA through USB and network (TCP/IP) connections, and TTL signals. A photo and a block diagram of the LUCA device and modules are reported in figure 1 (a) and (b), while in (c) we show the clinical operation of the device.

DCS and TRS nowadays have reached commercial-level maturity as independent solutions and allow to retrieve biomarkers as microvascular blood flow (DCS), and tissue chromophore concentration as oxy/deoxy-hemoglobin, water lipid and collagen concentration (TRS). The LUCA DCSM (ICFO, Spain) is characterized by a custom fiber coupled laser system and a 16-channel detection system, based on custom developed autocorrelators (HemoPhotonics, Spain). The 8-wavelength LUCA TRSM (Politecnico di Milano, Italy) is based on eight fiber coupled edge emitting diodes, Silicon Photon-multipliers (SiPM) detectors, and a time-correlated single photon counting system based on a Time-to-Digital Converter. The cost of the manufacturing for all the custom TRS and DCS sub-systems and components is about five times lower than typical equivalent systems in the literature and in the market.

The LUCA USM is based on EXAPad, a commercial ultrasound system by IMV Imaging, France. The software and graphical interface have been modified from the commercial versions in order to deal with the communication with the other LUCA modules and run the combined optical-ultrasound LUCA measurements.

The LUCA probe (Vermon, France) combines a standard US transducer, commonly used for thyroid ultrasound, and case allowing the insertion of the optical fibers necessary for the DCS and TRS modules. The optical fiber tips are placed on two replaceable fiber holders attached to the nose of the probe at the two opposite side of the transducer, one with the source fibers, one with the detection fibers.

The LUCA device includes furthermore a post-processing unit (University of Birmingham, UK), consisting of a custom assembled computer with a NIRFAST based data analysis software.

3. Pre-clinical tests and clinical study

Each module of the LUCA device and the whole device have been thoroughly and successfully tested before the starting of the clinical campaign, on tissue simulating phantom and *in vivo*, to demonstrate their functionalities, and verify the stability of the instrument. Particular care have been dedicated to test the possible crosstalk between all the technologies involved in LUCA, such as US, DCS and TRS, since they operates simultaneous acquisitions in the LUCA work-flow.

The *in vivo* tests consisted in variability measurements on the same thyroid of the same voluntary subject. This allowed us to determine the precision of the single LUCA acquisition, of measurements in the same region by replacing the probe several times, and of measurements repeated in different days. Moreover, we checked the capability of LUCA to detect hemodynamic changes by measuring the arm muscle during an arm cuff occlusion.

The LUCA project clinical campaign on thyroid patients started in July 2019 at IDIBAPS/Hospital Clínic Barcelona and it is supposed to finish in July 2020. It consists in measurements of 70 subjects in total, divided in 15 healthy controls, 25 patients affected by thyroid single benignant nodule, 15 patients affected by single malignant nodule, 15 with multi-nodular goiter.

We will present the preliminary results of the clinical campaign, together with the pre-clinical tests and a description of the full working LUCA device.

References

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