

MUELLER POLARIMETRIC IMAGING FOR IMPROVED DIAGNOSIS AND TREATMENT OF HEAD AND NECK SQUAMOUS CELL CARCINOMA (HNSCC)

Institution. École polytechnique

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Research Unit. Laboratoire de Physique des Interfaces et des Couches Minces (LPICM)

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Head and neck squamous cell carcinoma (HNSCC) develops from the epithelium lining the oral cavity, pharynx, larynx, and cervical esophagus. It accounts for approximately 5% of newly diagnosed cancers in developed countries, and its incidence is increasing. Nearly 900,000 new cases and 500,000 deaths are reported worldwide each year. Despite recent advances in diagnosis and treatment, the prognosis of HNSCC remains poor.

HNSCC is primarily associated with tobacco and alcohol consumption. Despite recent advances in diagnosis and treatment, its prognosis remains poor. Local recurrence represents the main oncological challenge. Even after complete surgical resection of the primary tumor with histologically clear margins, local recurrence occurs in 10–30% of cases. This is partly due to the difficulty in detecting minimal residual disease and to the presence of fields of cancerization, areas of mucosa exhibiting tumor-associated genetic alterations and/or dysplasia.

These fields often correspond to precancerous lesions, generally located adjacent to the primary tumor, but they can also be present elsewhere in the mucosa as precursors of tumor development. Some lesions are directly visible, such as leukoplakia, which can progress to invasive carcinoma. For these lesions, the standard diagnostic and therapeutic approach relies on biopsy to assess the presence and grade of dysplasia, a key predictor of malignant transformation. However, most precancerous lesions are not macroscopically visible and often remain undetected, potentially leading to local recurrence or second primary tumors.

Early detection of malignant lesions is therefore crucial for achieving favorable oncological outcomes, as local recurrence remains the main cause of treatment failure. White-light examination, palpation, and conventional radiological imaging often fail to distinguish malignant from premalignant lesions or to differentiate tumor tissue from surrounding healthy tissue. Biopsy and histopathological examination remain the gold standard, but they are invasive, time-consuming, and prone to underestimation or misdiagnosis due to sampling bias.

There is thus a strong need for non-invasive alternatives to avoid repeated biopsies, which are associated with cost and morbidity, in order to enable long-term monitoring of potentially precancerous lesions. Recently, new optical tools, such as confocal microscopy, narrow-band imaging, and diagnostic adjuncts—have been evaluated for detecting premalignant and malignant lesions in the oral cavity, but no clear clinical benefit has yet been demonstrated.

Mueller polarimetric imaging has shown strong potential for detecting precancerous and cancerous lesions in biological tissues and for improving the delineation of surgical margins. The LPICM is a pioneer in the field of Mueller polarimetric imaging for biomedical applications and one of the first groups worldwide to implement this technique *in vivo* in a clinical setting.

Advanced research at LPICM focuses on using Mueller polarimetric imaging to probe the microstructure of the cervix for two main applications: *i)* improving the detection and surgical excision of precancerous lesions; *ii)* reliably diagnosing prematurity.

Despite significant technical challenges associated with implementing Mueller polarimetric imaging *in vivo*, the LPICM biomedical team has successfully developed a Mueller Polarimetric Colposcope (MPC). This system is currently being tested to analyse the cervix of several hundred pregnant women in a clinical study at the University Hospital of Kremlin-Bicêtre in France (a world first). This study aims to statistically evaluate the ability of the MPC to monitor normal pregnancy progression and improve the diagnosis of prematurity. In addition, a new clinical trial is being prepared at Foch Hospital in France to assess the statistical performance of the MPC in detecting precancerous cervical lesions. The LPICM biomedical team is also actively working on integrating Mueller polarimetric imaging into endoscopic systems for the exploration of internal organs and body cavities.

The aim of this thesis is to evaluate Mueller polarimetric imaging as a novel tool for improving the detection and management of HNSCC, with three main objectives:

- Early detection and diagnosis of patients at risk for HNSCC, enabling improved oncological outcomes while minimizing the morbidity associated with unnecessary repeated biopsies;
- Improved histological mapping and delineation of tumor margins to support more precise surgical resections;
- Enhanced postoperative monitoring for the early identification of local recurrence or second primary tumors.

The PhD student's work will focus on *ex vivo* and *in vivo* analysis of biological tissues, data post-processing, and modeling of the polarimetric properties of healthy and cancerous regions, contributing to the development of machine learning and deep learning algorithms for automated diagnosis.

The thesis will be conducted in close collaboration between LPICM and the Institut Gustave Roussy (IGR). It will be supervised by Prof. Angelo Pierangelo (École Polytechnique) and co-supervised by Prof. Antoine Moya-Plana (IGR). On a daily basis, the PhD student will interact with PhD candidates, postdoctoral researchers, and permanent staff of the LPICM Biomedical Polarimetric Imaging Team, as well as with clinicians and researchers from the Head and Neck Surgery Team at IGR. This continuous interaction will enable the student to benefit from LPICM's experimental and theoretical expertise in Mueller polarimetric imaging, while also acquiring biomedical knowledge and gaining insight into the practical constraints of the hospital environment.

This thesis work will result in high-impact scientific publications in international peer-reviewed journals covering physics and optics, as well as optical instrumentation and biomedical imaging. Journals in biology and medicine may also be targeted. The candidate will have the opportunity to participate in major national and international conferences in these fields.

Patent applications will also be filed for both the instrumental developments and the image-processing methods developed during the project.

Profile and Skills Required

- Optics and optical instrumentation
- Optical measurements and signal processing
- Solid knowledge of physics and linear algebra
- Proficiency in Matlab and other programming languages
- Willingness to work in a multidisciplinary environment

- Strong motivation for continuous interaction with the medical field
- Good command of English

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