Shedding computational light on early invasive skin melanoma

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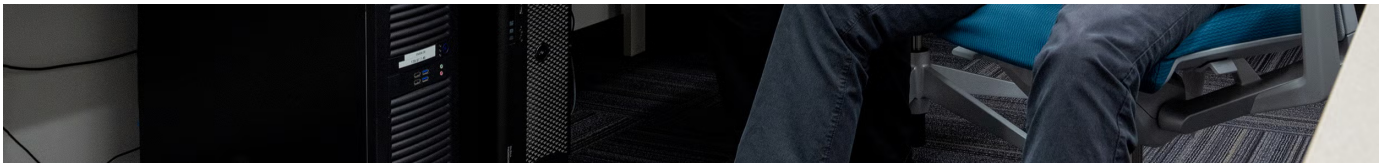
Researchers at the Cheriton School of Computer Science have elucidated a key piece in the puzzle to detect early invasive skin melanoma. Using computational models of the skin to simulate the complex biophysical changes during early stages of tumour progression, the research holds the potential to improve non-invasive diagnostic methods, particularly in resource-limited regions.

Melanoma, the deadliest form of skin cancer, poses a high risk of spreading once the tumour advances to the vertical-growth phase in the dermis. According to the Canadian Cancer Society, an estimated 11,300 Canadians were diagnosed with melanoma and 1,300 died from the disease <https://cancer.ca/en/cancer-information/cancer-types/melanoma-skin/statistics> in 2024 alone. Despite advancements in medicine, treating melanoma remains a challenge, particularly in its later stages. Early detection is critical to improve patient outcomes.

“Detecting melanoma early is considered the Holy Grail in this field,” explains Professor Gladimir Baranoski. “Many researchers are looking for a solution, a way to detect the cancer early, but it is a complex problem. We’re still years away from detecting melanoma at an early stage when treatment is most effective, but our research is an important step in the quest for early cancer detection.”



L to R: Petri Matthew Varsa and Professor Gladimir V. G. Baranoski

Petri Varsa <https://cs.uwaterloo.ca/~pmvarsa/> is a PhD candidate at the Cheriton School of Computer Science. He has an MSc in Computer Science from the University of Calgary and a BMath in Computer Science from the University of Waterloo. His research focuses on the simulation of natural phenomena, with applications spanning remote sensing and computer graphics. He will defend his doctoral thesis in February 2025 </events/phd-defence-computer-graphics-first-principles-framework-for-simulating-light-and-snow-interactions>.

Gladimir V. G. Baranoski <http://www.npsg.uwaterloo.ca/people/gladimir/> is a Professor at the Cheriton School of Computer Science. His research interests include the predictive simulation of light interactions with organic materials and biophysically based rendering of natural phenomena. He also explores computational biology, using simulations to deepen understanding of biological systems, with a focus on biomedical and biophotonics applications. He leads the Natural Phenomena Simulation Group <http://www.npsg.uwaterloo.ca/members.php>.

Non-invasive optical technologies that measure the spectral characteristics of lesions are a vital tool in melanoma diagnosis. These methods reduce the need for biopsies, offering safer and more accessible options. But detecting melanomas at a stage when they produce the characteristic uneven pigmentation and irregular borders often means the cancer has already invaded deeper skin layers and possibly spread.

Detecting subtle changes during early tumour invasion into the skin's papillary dermis, a key stage before metastasis, is critically important, explains Petri Varsa, who conducted the research as part of his doctoral studies on simulating natural phenomena.

"The first layer of the dermis — the papillary dermis — is very thin," Professor Baranoski said. "Few studies have simulated the early stage of melanoma when it's confined to the papillary dermis, but we have simulated what this layer looks like. We first thought we might be able to identify a lesion at this stage by its colour. But as we discovered, using colour alone we cannot distinguish between healthy skin and skin with early invasive melanoma. So what other characteristics could we use?"

Using their Hyperspectral Light Impingement on Skin, or HyLIoS, model, the researchers conducted *in silico* experiments to simulate the effects of angiogenesis on the spectral characteristics of early melanoma. These simulations examined baseline conditions, the onset of angiogenesis, and collagen fibre displacement in the dermis — key stages of tumour progression — to calculate reflectance curves for both healthy skin and skin with early invasive melanoma.

"By combining reflectance changes from the melanoma and from angiogenesis in the papillary dermis, we saw characteristic steps in the 550 nm to 600 nm region of the spectra," Professor

dermis we saw a characteristic step in the 550 nm to 600 nm region of the spectra," Professor Baranoski notes. "This was our eureka moment. As the tumour grows it needs nutrients and oxygen, which are supplied by the blood. Blood vessels are forming and the blood content of that layer is increasing. It's important to note that we never adjust the model's parameters outside the range of values that are physiologically valid."

One of the key outcomes of the study is the proposal of a low-cost spectral index, which the researchers termed the Degree of Curve Concavity or DCC. This index could be used to monitor changes in spectral responses caused by angiogenesis for early melanoma detection.

Professor Baranoski emphasizes that the *in silico* models could not have been created and validated without months of meticulous effort of students he has advised over the years — undergrads and grads alike who searched the scientific literature on melanoma progression and painstakingly gathered data on spectral changes associated with it in human skin samples.

"It's tedious, laborious and mechanically intensive work, but good research requires this level of commitment and diligence," he said. "We have to be certain that we've accurately and precisely obtained data from published research that we used to evaluate our *in silico* models."

By making their HyLIoS model <http://www.npsg.uwaterloo.ca/models/hyliosex.php> and datasets <http://www.npsg.uwaterloo.ca/data.php> openly accessible, the researchers hope to support further investigations into melanoma progression and other medical conditions.

"Our research is a small part of the vast foundation necessary to detect early invasive skin melanoma," Petri said. "But it's clear that accounting for the stepped spectral change we see because of angiogenesis in melanoma is important. We hope our study adds to the knowledge base and motivates people to take more measurements that perhaps one day lead to better diagnostic tools."

To learn more about the research on which this feature article is based, please see Gladimir V.G. Baranoski, Petri M. Varsa. Angiogenesis-elicited spectral responses of early invasive skin melanoma: Implications for the evaluation of lesion progression <https://onlinelibrary.wiley.com/doi/full/10.1002/jbio.202400208>, *Journal of Biophotonics*, volume 17, issue 10, pp. 2024002081:1–13, October, 2024.