Advances and Perspectives in Near-Infrared Fluorescent Organic Probes for Surgical Oncology

And Elshani[α]
Anda Sylqa[α],Erblina Muji[β]
[α] *University of Prishtina, Str. "George Bush", No.31, 10 000 Prishtinë, Republic of Kosovo , Prishtina, Kosovo*
[β] *University of Tetovo,Rruga e Llindenit pa nr.,1200,Tetovë, Republic of North Macedonia*
andielshani20@gmail.com

Background: Surgical oncology relies on precise imaging to detect and remove tumors. Near-Infrared (NIR) fluorescence imaging has become essential for this, offering high-resolution, real-time visualization during surgery. The light in NIR range of 700–1,700 nm is safe and does not harm patients as it penetrates deep tissues and has less autofluorescence readying the image for better clarity than the normal techniques. The use of NIR molecular probes in particular tumor-specific probes have led to advancement in cancer imaging due to the enhanced sensitivity and specificity. Many of the recently developed multifunctional NIR dyes target the tumour and also have other therapeutics design, which is aimed at amelioration of the surgical methodology and the way cancer is managed.

Aims: This review highlights recent advancements in NIR probes for surgical oncology, focusing on their design, applications, and future potential.

Methods: Probe Design: NIR organic probes were synthesized for tumor imaging using the NIR-II window, ensuring deep tissue penetration and high-resolution imaging. Nanoparticles and small-molecule dyes were conjugated with tumor-targeting ligands (e.g., peptides, antibodies) for specificity.Technological Innovations**:** Innovations included photostable, biocompatible NIR-II dyes with enhanced surface modifications to improve circulation and reduce toxicity. Pre-Clinical and Clinical Studies: Probes were tested in murine tumor models and clinical settings, demonstrating success in real-time tumor visualization, enhancing precision in tumor resection during surgery.

Results: NIR-II Probe Innovations: Recent advancements have led to the creation of probes with remarkable tissue penetration (over 5 mm depth) and high-resolution imaging. Novel organic molecules with optimized structures exhibit fluorescence in the NIR-II range (1000-1700 nm), allowing clear differentiation between cancerous and normal tissues . Comparative Performance: NIR-II probes, particularly the novel p-FE derivative, demonstrated a 3x higher signal-to-noise ratio (SNR) compared to traditional NIR-I dyes, enabling accurate tumor margins in surgical settings. In contrast to conventional fluorescence techniques, the enhanced contrast in deep tissues reduced the false positive rates in preclinical models by 20%. Imaging Results: In murine models, NIR-II probes significantly improved tumor resection accuracy, with a 95% detection rate of micro-tumors (<0.5 mm). Imaging results from clinical trials further supported the potential of these probes, highlighting a 40% improvement in visual clarity during cancer surgeries .

Conclusion: NIR fluorescent organic probes, through advanced bioengineering and photostable design, are reshaping tumor resection practices, allowing for more precise and complete removal of cancerous tissues. As research progresses, integrating this technology into routine clinical practice seems promising, offering improved patient outcomes. Further clinical trials and technological advancements will be critical to fully realizing the routine use of NIR probes in cancer surgery.

Acknowledgments:We express our sincere gratitude for the funding provided by the European Commission under the project titled “Nanoparticles in Environment and Medical Research” (NanoKos - 438247)

References

[1] Hong, G., Antaris, A. L., & Dai, H. (2017). *Nature Biomedical Engineering,* Near-infrared fluorophores for biomedical imaging.

[2] Zhu, S., & Tian, R. (2018). *Advanced Materials,* Near-infrared-II molecular dyes for cancer imaging and surgery.

[3] Owens, E. A., et al. (2016). Near-infrared fluorescent small molecules for image-guided surgery and tissue imaging. *Chemical Society Review*