Ice ball formation monitoring during tissue cryoablation using sapphire shaped crystals

Zotov A.K. [1*], Dolganova I.N. [1,2], Shikunova I.A. [1], Alekseeva A.I.[3] and Kurlov V.N. [1]

[1] *Osipyan Institute of Solid State Physics of the Russian Academy of Sciences,*
[2] *Bauman Moscow State Technical University*
[3]Research institute of human morphology
**E-mail: akzotov@hotmail.com*

The application of cryogenic temperatures to biological tissues has a therapeutic and ablative effect and underlies cryotherapy and cryosurgery. Cryoablation of tissues is currently used for minimally invasive removal of neoplasms of various nosologies. Such a widespread use of cryoablation in clinical practice can be explained by the advantages of this approach, namely, minimal invasiveness, relative painlessness, hemostatic effect, short recovery period for patients, and immunostimulatory effect [1].

Cryoprobes serve as tools for implementing cryosurgery methods, which must meet a number of requirements, such as biocompatibility and chemical inertness of the tip, the ability to provide a high rate of tissue cooling, which ensures ablation, and the ability to achieve temperatures sufficient for tissue ablation. Mostly cryoprobes are made of materials with high thermal conductivity at cryogenic temperatures, usually metals such as copper, brass, stainless steel, etc. However, as a rule, existing metal probes and tips are often disposable, as they do not withstand strong sterilization methods.

In addition, the process of criablation is associated with significant risks of damage to healthy tissues surrounding the pathology with the possibility of incomplete cell death. In this regard, the process of tissue cryoablation requires constant control of the volume of the ice ball during freezing of the area of interest to prevent damage to healthy adjacent tissues [1-3].

To solve this problem, it is proposed to use optical diagnostic methods, in particular, diffuse reflection spectroscopy and terahertz pulsed spectroscopy, since low temperatures lead to dielectric contrast in tissues that are in different frozen and non-frozen states. To implement these methods, it is proposed to use cryoprobes based on profiled sapphire crystals. Sapphire is an advantageous material for biomedical applications [4-10] due to a combination of its properties: high hardness, mechanical strength, biocompatibility, chemical inertness, thermal stability, high thermal conductivity at cryogenic temperatures. In addition, it has a high optical transparency, which allows light to be delivered to tissues through the sapphire glass.

In this work, we demonstrate the developed sapphire cryoprobe and experimentally confirm the possibility of monitoring of the ice ball formation in tissues. In addition, we compare the performance of the most commonly used metal probes with the sapphire one. The results reveal the benefits of sapphire for cryosurgical applications.

The work was supported by the Russian Science Foundation Project No. 19-79-10212.

References

[1] Tumor ablation. Principles and practice. Ed. by E. van Sonnenberg et al. Springer-Verlag New York; (2005).
[2] J. Bischof, K. Christov, B. Rubinsky, “A morphological study of cooling rate response in normal and neoplastic human liver tissue: Cryosurgical implications,” Cryobiology 30, 482–492 (1993).
[3] W.B. Bald and J. Fraser, “Cryogenic Surgery,” Reports on Progress in Physics, 45, 1381 (1982).
[4]. I. Shikunova et al., “Sapphire capillary interstitial irradiators for laser medicine,” Proc. SPIE 10716, 1071605 (2018).

[5] G. Katyba et al., “Sapphire shaped crystals for waveguiding, sensing andexposure applications,” Prog. Cryst. Growth Charact. Mater. 64(4), 133–151 (2018).
[6] V.N. Kurlov et al., Crystal Growth Processes Based on Capillarity: Czochralski, Floating Zone, Shaping and Crucible Techniques. Chapter 5. Shaped Crystal Growth (pages 277-354), John Wiley & Sons, United Kingdom (2010).
[7] E.N. Dubyanskaya, et al. “A concept of cryoapplicator based on sapphire shaped crystal enabling control of the ice ball formation using spatially resolved elastic backscattering of light,” Proc. SPIE, 10685, 1068529 (2018)
[8] Arsen K. Zotov, Arsenii A. Gavdush, Gleb M. Katyba, Larisa P. Safonova, Nikita V. Chernomyrdin, Irina N. Dolganova, "In situ terahertz monitoring of an ice ball formation during tissue cryosurgery: a feasibility test," J. Biomed. Opt. 26(4) 043003 (2021)
[9] A. V. Pushkarev et al. Comparison of Probe Materials for Tissue Cryoablation: Operational Properties of Metal and Sapphire Cryoprobes. Journal of Biomedical Photonics & Engineering, [S.l.], v. 8, n. 4, p. 040501, nov. 2022. ISSN 2411-2844
[10] I. N. Dolganova et al. Feasibility test of a sapphire cryoprobe with optical monitoring of tissue freezing. *J. Biophotonics* ,16(3) (2023)