Laser Perforation of Bones. Photothermal Effects and Clinical Applications.

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Abstract— The mechanism and clinical effectiveness of laser bone perforation with wavelengths of 0.97 and 1.9 μm are being studied. The crucial role of intermittent contact of the optical fiber tip with the bone and the appropriate radiation power for its advancement has been demonstrated. The clinical efficacy of laser osteoperforation to treat bone and joint pathology has been confirmed.

Keywords — laser osteoperforation, laser surgery, bone pathologies

I. Introduction

The use of laser radiation for bone perforation has been in practice since the late 20th century. Laser osteoperforation (LOP) is performed using near-infrared radiation [1,2]. In recent years, short-wave infrared radiation and blue (445 nm) lasers [3] have also been used. However, the physical processes of laser radiation interaction with bone are not yet fully understood, which hinders the development of effective medical technologies. Therefore, the objective of this study is to investigate the mechanisms of interaction between high-intensity infrared radiation and bone tissue, and to evaluate the clinical effectiveness of LOP.

II. Materials and Methods

In the in vitro experiment, LOP was studied on long tubular pig and bovine bones with cortical plate thickness up to 5 mm. The experiment involved video recording, macroscopic assessment of the specimen, and temperature measurements. Both pulsed-periodic and continuous modes were used, with intermittent and continuous contact of the optical fiber (OF) tip with the bone. The average power for 0.97 μm radiation was 25-30 W, while for 1.9 μm radiation, it reached 80 W. Temperature measurements were taken of the bone surface near the perforation channel using thermocouples and within the channel using spectral pyrometry. The working instrument was a "bare" quartz-quartz OF with a polyimide coating with a diameter of 0.4 mm. Experimentation with OF with a secondary Tefzel coating was also performed. In clinical practice, LOP has been used as part of comprehensive treatment for children and adults with acute and chronic osteomyelitis, various aseptic osteonecroses, and fractures with delayed consolidation. The 0.97 μm radiation was applied, and in recent years, the 1.9 μm radiation was also used in a pulse/pause mode of 100/50 ms with an average power of 20-30 W. The LOP technology with submicron radiation is protected by seven patents in the Russian Federation.

III. Results and Conclusions

The crucial factors for successful LOP include intermittent contact of the OF with the bone and radiation power adequate to the thickness of the cortical plate. For a cortical plate thickness of 3 mm, the optimal power was 40 W, and for 5 mm, it was 60 W. Intermittent contact of the OF tip with the bone was achieved through short reciprocating movements of the surgeon's hand. During LOP, visible flashes (erosive torch) accompany the process, both in experiments and clinical practice. Apparently, the physical processes at the OF tip occur in sequence: contact with the bone, tissue carbonization, and auto-darkening of the OF, followed by an increase in the level of radiation absorption and local bone temperature (inside the channel - above the melting temperature of quartz, 3-5 mm away - 40°C), weakening of contact, and oxygen access, bone and OF pyrolysis (erosive torch). Continuous OF contact with the bone and insufficient power led to a slowdown in the advancement of the emitting OF into the bone, and increased carbonization and coagulation volume. In treating patients with acute osteomyelitis comprehensively, LOP contributes to adequate bone decompression and rapid focus sanitation. In chronic osteomyelitis, LOP helps avoid extensive bone resections performed earlier. In degenerative-dystrophic diseases of bones and joints, LOP promotes the revascularization of affected areas, pain relief, and improved joint function. Complications of LOP are rare and primarily associated with a violation of its technology. Thus, LOP can be recommended for broad application in clinical practice.

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