1. INTRODUCTION

Aged cartilage tissue looses its regeneration ability. The regeneration of damaged cartilages remains an unsolved problem owing to an extremely low rate of reparative processes. However, the topicality of this problem is related to the widely spread spinal osteochondrosis (degenerative disease of the discs) and the osteoarthrosis of joints [1, 2]. It has been demonstrated in the experiments with auricle cartilages [3] that relatively soft (nonablative) regimes of laser irradiation induce the proliferation of chondrocytes, the regeneration of perichondrium, and the cartilage formation. The experiments on various irradiation regimes of rabbit joints using Ho:glass and Er:glass fiber lasers [4] have shown that the hard radiation causes the destruction of the cartilage plate to the subchondral bone plate, which results in the growth of the granulation tissue. This tissue is partially transformed into the chondroid tissue and the fibrocartilage that replace the damaged hyaline cartilage. In the case of the soft (nonablative) regimes of the laser irradiation, the dystrophically modified cartilage tissue exhibits the proliferation of chondrocytes presumably from the reserve of the undifferentiated cells of the hyaline cartilage. This type of the regeneration is substantially more developed for the soft regimes (in comparison with the hard regimes), which indicates the specific regeneration activity of the nonablative laser radiation. The targeted analysis of various regimes of the laser irradiation of the intervertebral discs (IVDs) of rabbits has yielded the nonablative laser action that induces developed regeneration processes: the proliferation of chondrocytes of the annulus fibrosus (AF) and nucleus pulposus (NP) and the metaplasia of the AF inner layers and the damaged NP into the transient fibrous–hyaline or the typical hyaline cartilage. The experimental results have been used to develop a new branch of the modern spinal surgery—the laser reconstruction of discs (LRD), which is successfully employed in clinical practice [5–11].

The controlled nonablative laser irradiation makes it possible to restore the regeneration ability of cartilage. The optical, thermal, and mechanical action of the time- and space-modulated laser radiation activates the malfunctioning cartilage cells. This activation enables one to grow normal cartilage in the damaged IVD.

In this work, we consider the LRD method and the differences of this approach from the alternative physical methods of the medical treatment of IVD, present the histological analysis of the newly formed tissues of experimental animals and humans, discuss the possible regeneration processes, develop a control system that provides for the treatment efficiency and safety is developed. The new laser medical equipment that is designed for the laser engineering of intervertebral discs is described, and the corresponding results of the clinical application are presented.

2. FUNDAMENTALS OF THE LRD TECHNOLOGY AND THE COMPARISON OF THIS METHOD WITH ALTERNATIVE PHYSICAL METHODS OF THE IVD MEDICAL TREATMENT

The osteochondrosis is a spinal disease that is accompanied by various pathological processes in the spinal structures. The IVD degeneration is the main
pathological process. The disc disruption is clinically manifested as the pain syndrome. The reason for the pain syndrome is alterations in the anatomical, morphological, and biochemical state of the disc. The pathological vascular and nociceptive nerve ingrowth in the degenerative disc, and the entrapment of the fragments of the damaged NP in the annular tears maintain the inflammation inside the disc and provide the morphological substrate for pain. The successful treatment of the permanent pain syndrome of the patient suffering from the osteochondrosis necessitates a modification in the inner state of the disc cartilage. The LRD method is based on the regeneration of the cartilage tissue under the nondestructive laser irradiation. The medical effect is owing to the creation of the spatio-temporal nonuniformities of temperature and mechanical stress in the biological tissue when the tissue is heated by the repetitively pulsed laser radiation. The defects of the disc tissue are replaced by the newly formed hyaline cartilage in the IVD from two to six months after the local laser irradiation. The disc and, in particular, the region of the pain generator are morphologically modified. The clinical study indicate a relatively high efficiency of the LRD in the treatment of the permanent discogenic pain syndrome. Twelve months after the procedure, 86% of patients exhibit a positive effect of the laser treatment that is manifested as a reduction of the pain syndrome, a decrease in the rate of the attacks of pain, the refusal of anesthetics, etc. The visualization of the discs proves the morphological modifications. The post-LRD discography yields the disappearance of the annular tears, and the NMR tomography shows the appearance of a new dense tissue. The LRD method is employed as a puncture procedure and in combination with the open discectomy when the removal of the hernial fragment is followed by the LRD at the last stage of the operation which substantially diminishes the hernia recurrence probability.

Thus, the LRD is a new effective and safe approach in the treatment of the IVD degeneration among the methods of the minimally invasive spinal surgery.

The conventional treatment of the spinal osteochondrosis involves both conservative and surgical procedures. The minimally invasive methods [12, 13] have gathered much recent interest, since they make it possible to avoid negative consequences of the surgery and provide for a relatively low traumatism, the absence of general anesthesia, and a significant reduction of the recovery period. The puncture methods for the physical action [14], in particular, heating [15] of the IVD tissues have been developed in the framework of this approach. The IVD decompression can be characterized as the patriarch of the intradisc therapy. This approach is aimed at a decrease in the intradisc pressure owing to a partial removal of NP using either mechanical technique or chemical agents or the laser, or RF [16–18] evaporation of the tissue. The creation of cavities (or several channels) in the disk could have led to a decrease in the pressure and, hence, a decrease in the painful stimulation of the disk and the nervous roots. However, the NP tissue remains degenerative after the procedures and the IVD height decreases by 5–7%. Such modifications cause a decrease in the strength of the disk and its stability against compressions, the further degeneration, and development of the AF circumferential tears [19].

The intradiscal electrothermal therapy (IDET) is another puncture method for the treatment of the discogenic pains [20]. In accordance with the author’s concept, the local heating of the rare part of the AF must inactivate the pathological nerves and cause the denaturation of the AF collagen for the tear welding. However, the experimental results from [21, 22] do not prove the positive effects. In spite of the positive initial results on the IDET treatment of the degenerative IVD diseases, significant postoperative complications [23] minimize the efficiency and the randomized control trials indicate either zero or insignificant advantage of this procedure in comparison with placebo [24].

In comparison with the above methods, the LRD involves a moderate laser action on the IVD, which is not accompanied by the destruction or partial removal of the disc, does not lead to the necrosis of the disc tissues, and does not damage the nerve and vessel spinal structures in the vicinity of the disk. Thus, the LRD method is based on the activation of the regeneration processes in the IVD tissues, which makes it possible to eliminate the reasons for the disease and to reach the long-term positive effect.

3. LASER-INDUCED GROWTH OF NEW TISSUE IN IVDs

The results obtained in the in vivo experiments [5, 8] and in clinics [9, 11] demonstrate the formation of new cartilage tissue of the fibrous–hyaline and hyaline types in the IVDs under the laser irradiation of NP. In addition, a part of the irradiated discs exhibit the formation of the bone or bone-like tissue that contains specific cells (osteocytes) and the mineral component of the matrix [6, 25].

Fifteen skeletal-mature Chinchilla rabbits were used in the in vivo experiments on the remodeling of the IVD tissue in the presence of the nondestructive laser irradiation. We studied 90 lumbar discs: 60 discs were laser-irradiated, 15 discs served as placebo, and 15 discs were used for control. The radiation of the Er:glass fiber laser with a wavelength of 1.56 µm was delivered to the center of the IVD NP using a quartz optical fiber with a diameter of 400 µm and the puncture needle. The laser irradiation regimes were chosen based on the preliminary temperature measurements. We used the following ranges of the parameters: pulse duration, 10–2000 µs; repetition rate, 0.3–2.0 Hz; and pulse energy, 0.03–3.50 J. For the animals, the experiments were terminated 4, 30, and 90 days after the operation. The lumbar discs were extracted for the histological analysis