Regeneration of spine disc and joint cartilages under temporal and space modulated laser radiation

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ABSTRACT

The effect of laser radiation on the generation of hyaline cartilage in spine disc and joints has been demonstrated. The paper considers physical processes and mechanisms of laser regeneration, presents results of investigations aimed to optimize laser settings and to develop feedback control system for laser reconstruction of spine discs. Possible mechanisms of laser-induced regeneration include: (1) Space and temporary modulated laser beam induces non-homogeneous and pulse repetitive thermal expansion and stress in the irradiated zone of cartilage. Mechanical effect due to controllable thermal expansion of the tissue and micro and nano gas bubbles formation in the course of the moderate (up to 45-50 oC) heating of the NP activate biological cells (chondrocytes) and promote cartilage regeneration. (2) Non-destructive laser radiation leads to the formation of nano and micro-pores in cartilage matrix. That promotes water permeability and increases the feeding of biological cells. Results provide the scientific and engineering basis for the novel low-invasive laser procedures to be used in orthopedics for the treatment cartilages of spine and joints. The technology and equipment for laser reconstruction of spine discs have been tested first on animals, and then in a clinical trial. Since 2001 the laser reconstruction of intervertebral discs have been performed for 340 patients with chronic symptoms of low back or neck pain who failed to improve with non-operative care. Substantial relief of back pain was obtained in 90% of patients treated who returned to their daily activities. The experiments on reparation of the defects in articular cartilage of the porcine joints under temporal and spase modulated laser radiation have shown promising results.

Keywords: laser regeneration, cartilage, tissue structure

1.INTRODUCTION

The Problem: Back pain will affect 80-90% of the population. Direct and indirect yearly medical expenses in the USA are more than 50 billions. To avoid the negative effects of surgery minimally invasive methods have been increasingly adopted during the last years [1]. This trend includes puncture techniques conducting various physical stimuli [2, 3], particularly heating [4], to the disc tissues. However, despite the clinical use of intradiscal therapy, its medical efficacy seem doubtful today [5, 6, 7]. Many medical doctors say about serious complications after IDET and RF treatment of spine discs aimed in denervation of annulus fibrosis. The decrease pain but do not effect on the reason of the disease.

Laser regeneration of cartilage has opened new opportunities in orthopedics for minimaly invasive treatment of arthitis and degenerated discs [8-13]. This new technique uses local, non-destructive laser irradiation for the controlled-activation of regenerative processes in a targeted zone with minimal nonspecific effects in neighboring areas.

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Advantages of this approach compared to other techniques are creation of a spatially-localized thermo-mechanical effect in cartilage using laser radiation with relatively weak heating and the controlled character of tissue modification and regeneration resulting in the growth of hyaline type cartilage in the laser-irradiated zones. The aim of this paper is to present our recent results in laser regeneration of cartilage in spine and joints.

2. LASER RECONSTRUCTION OF DISCS (LRD)

In 2000 we have introduced a novel approach to the treatment of spine disc degeneration based on the thermomechanical effect of modulated laser irradiation without strong heating of the tissues [8]. The results of animal experiments have shown that non-destructive laser radiation can activate regeneration processes in damaged spine disc cartilage. We have demonstrated that heterogeneous heating under modulated laser radiation creates new nano- and micro-pores increasing water permeability and nutrient flow to chondrocytes. Repetitively pulsed mechanical stress of a specific amplitude can activate chondrocyte proliferation and production of a new cartilage matrix. As a result, the controlled effect of laser radiation on tissue microstructure and stress distribution leads to the growth of a new cartilage of the hyaline type. The new medical technology – laser reconstruction of discs (LRD) - has been developed, tested in clinics and obtained approval from the the Russian Federal Office on Health and Social development.
The LRD procedure involves puncture of the disc, laser irradiation of the nucleus pulposus to facilitate the reparative processes in the tissue [9-12].

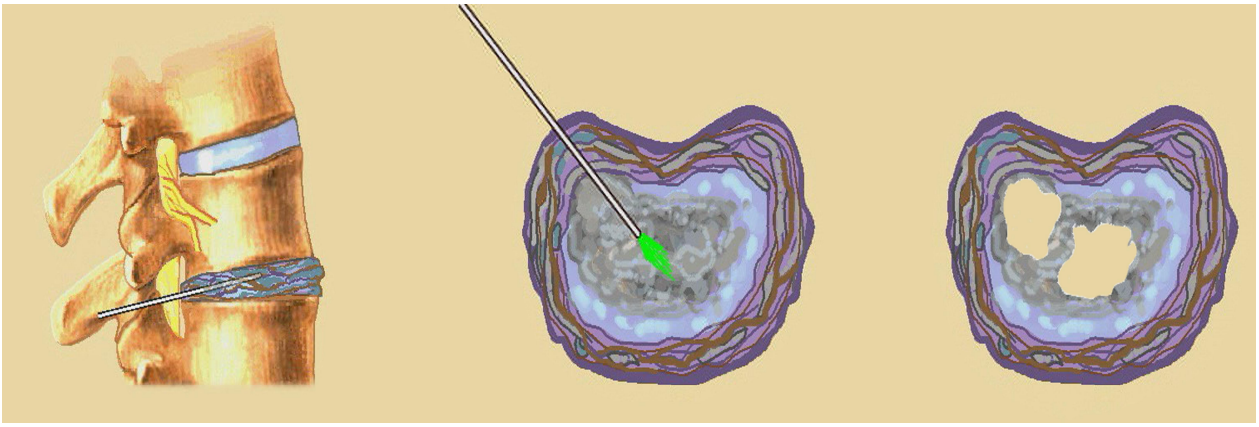


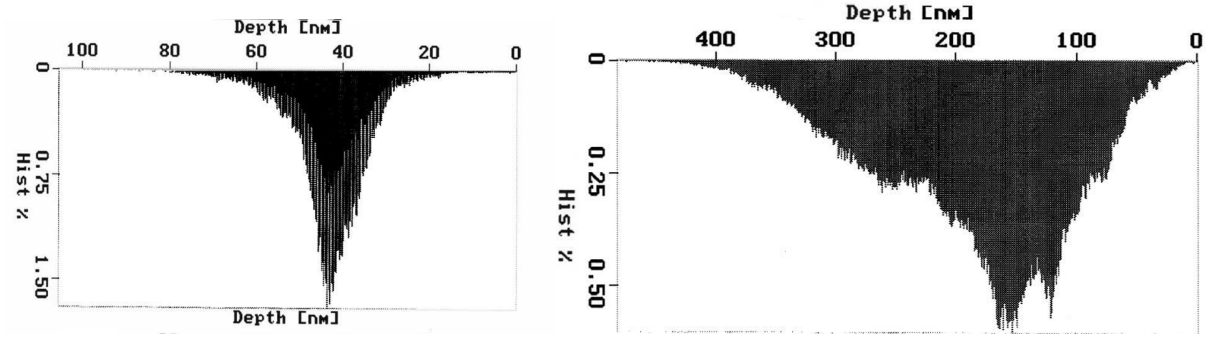
Fig.1. Principal scheme of the laser reconstruction of disc procedure

Regeneration (recovery) is a typical response of the living tissue on any external (physical or chemical) effect. The question is how to control the process, what type of response, what type of tissue we would like to growth as a result of irradiation. The results, the level of the response and the mechanisms of laser induced tissue regeneration can be different.
Our studies of laser-spine discs interactions and the results of clinical trials have shown that LRD procedure doesn't cause any destruction of the discs, does not lead to the tissue necrosis, injury of adjacent spinal nerves and vessels.

Mechanism of Tissue Regeneration

Mechanism of Tissue Regeneration is still under investigations.
Our preliminary results shown that it includes

(1) Micro-pores in cartilage matrix promote water permeability and increase the feeding of biological cells [10, 14].
(2) Dynamic mechanical oscillations activate tissue regeneration [10, 12].



(a) (b)

Fig 2…Atomic Force Microscopy of Laser-treated Cartilage: (a) intact cartilage, (b) laser treated cartilage

Laser equipment for LRD

Laser equipment for LRD (Arcuo Medical Inc.) includes:
Erbium-glass fiber laser, feedback control system, disposable instrument
Wavelength 1.56 micrometers
(Absorption depth of about 1 mm)
Average power 0.3 – 3 W,
Beam Modulation:
Pulse duration from 10 ms to 2 s
Pulse repetition rate 0.3 – 10 Hz
Exposure time 10 – 30 s
A number of pulse series 3 - 5
Pause between pulse series 10 – 30 s
The time of laser procedure 20 – 30 minutes
A number of laser procedures for each disc - 1

LRD procedure can be performed in outpatients setting without general anesthesia.

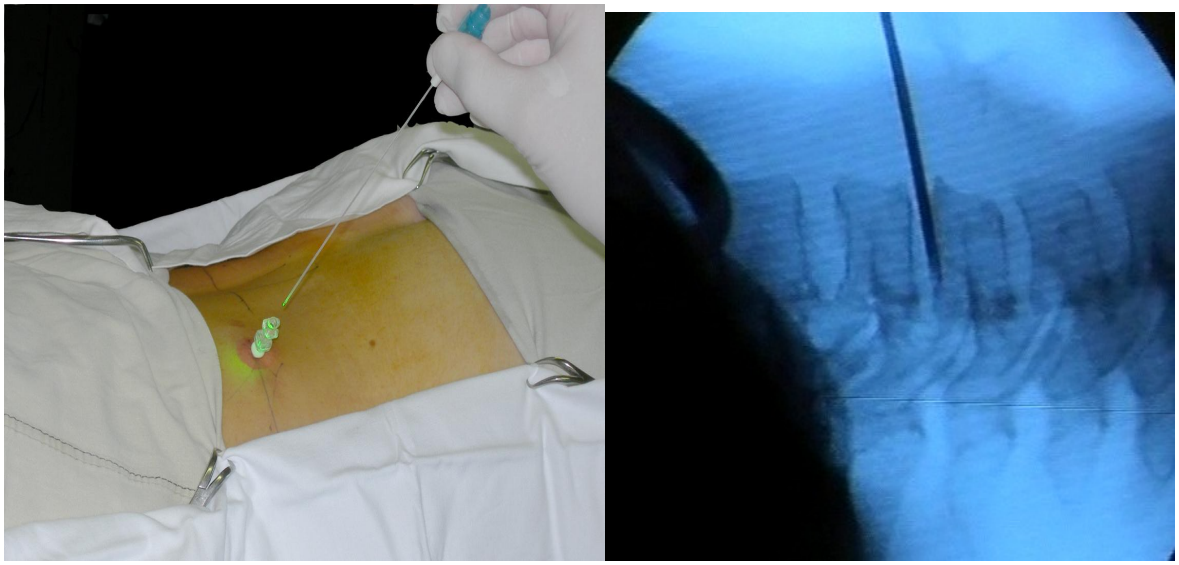
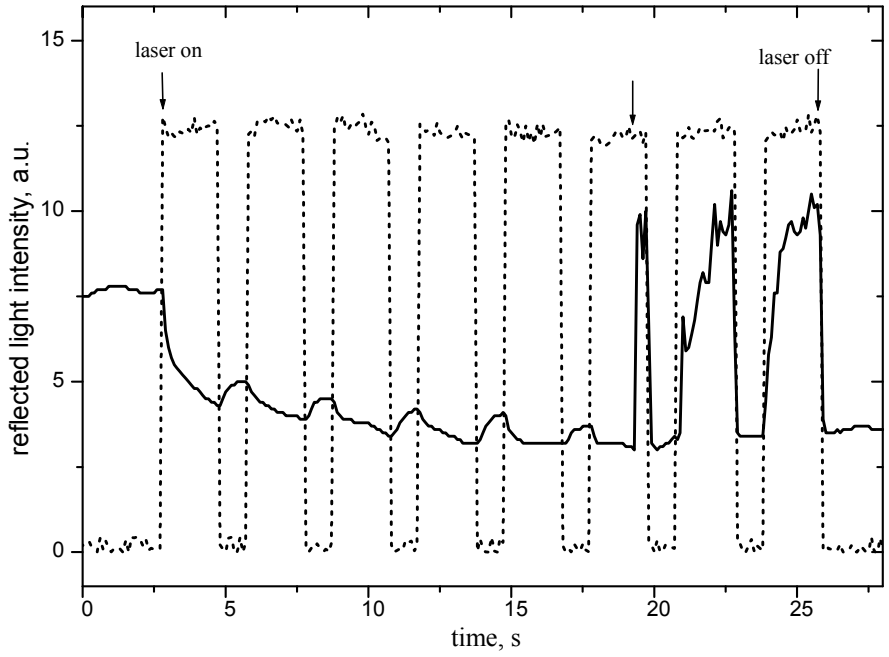


Fig. 3…LRD is performed trough a needle inserting into the discs under the XR control.



Fig…4.. Typical time dependence of the optical signal of the feedback control system in the course of laser irradiation of spine disc.

Fig 5... General view of the equipment for LRD.

The advantages of LRD

1. LRD is directed to the reason of the disease due to activation of tissue regeneration.
2. We do not heat AF. The effect of LRD is not governed by the denervation of the AF.

The locality, the efficacy and safety of LRD can be controlled by the stress distribution and dynamics using space and temporal modulation of laser radiation

3. The positive dynamics of the results. The stability of the improvement of life and pain relief

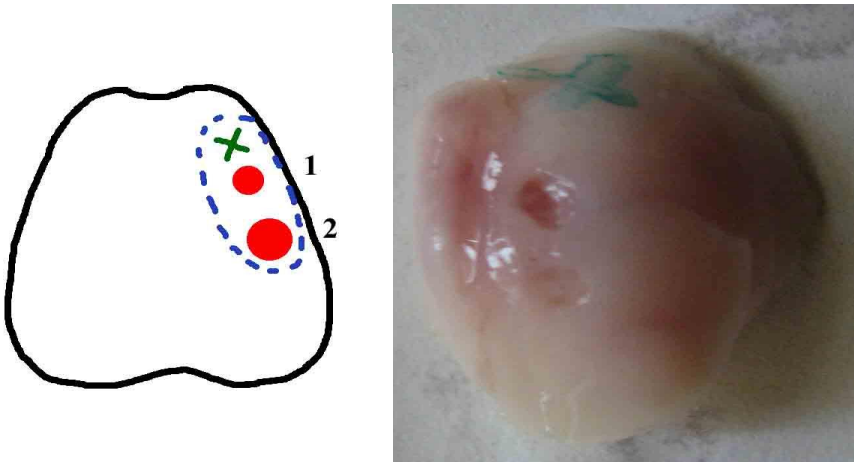
LRD Results:

Since 2001 LRD has been applied for 340 patients in Moscow. Most patients (90 percent) have shown significant improvement of life and pain relief.

3. LASER REGENERATION OF PORCINE JOINT CARTILAGE

We have completed animal model experiments on laser treatment of articular cartilage in rabbit joints [10,13] which indicate good potential for the application of laser regeneration technology in orthopedics. The next set of in-vivo animal experiments have been performed on 16 defects preliminary created on the 8 joints of 4 mini pigs. The defects had a depth of 0.5 -0.7 mm, and a size of 3-15 mm. The typical defects are shown on the fig6 and 7.
The laser treatment has been performed in six weeks after the creating of the defects. The Erbium –glass fiber laser (1.56 microns, pulse duration of 100 ms, pulse repetition rate of ….. Hz, laser beam diameter – of 400 microns) have been used for

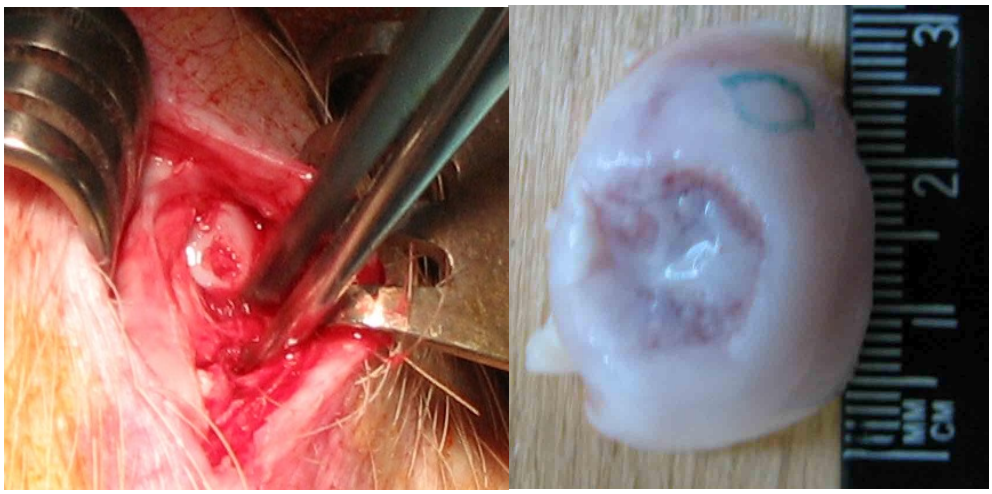
laser irradiation. The temperature during laser treatment (measured using thin thermocouple and IR radiometer) was reached 45 ^{0}C. for a few second.



……a……..……b…….

Fig 6. Two defects in porcine joint cartilage
Defect depth is 0.7 mm
1- non-radiated, 2- irradiated

a – scheme of the defects, b – photography of the defects in six weeks after laser treatment



……a……b…….

Fig. 7. A large defect in joint cartilage (a) before laser treatment, and (b) its recovery in six weeks after laser treatment

The animals have been sacrificed in six week after laser treatment. All laser treated defects have been covered by a new tissue (figs. 6 and 7). Non-treated defect did not recover. The histological examinations of the new growing tissue have shown hyaline and hyaline –fibrous cartilages in the laser-treated zones.

• 4. CONCLUSIONS:

1. Laser reconstruction of spine discs is a novel effective and safe approach for the treatment of intervertebral disc diseases.
2. Since 2001 LRD procedure has been performed for 340 patients. Most of the patients demonstrated significant improvement, returned to the work and normal life.
3. Temporal and space modulation of laser radiation is of importance for activation of cartilage regeneration
4. The in-vivo animal experiments on joint cartilage have shown a possibility to recover a large defect with hyaline type cartilage.

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