Laser osteoperforation for treatment of inflammatory and destructive bone diseases

V.A.Privalova, I.V.Krochek, I.A.Abushkina, I.I.Shumilina, A.V.Lappa

aChelyabinsk State Medical Academy, Vorovskogo 16, Chelyabinsk, 454092, Russia,
bChelyabinsk Municipal Hospital #1, Vorovskogo 16, Chelyabinsk, 454092, Russia,
cChelyabinsk State University, Br.Kashirinykh 129, Chelyabinsk, 454021, Russia

ABSTRACT

The method of laser osteoperforation was developed in experiment and then applied for treatment of 508 patients with osteomyelitis, 51 patients with nonunion and pseudo-joint and 34 patients with different forms of osteochondropathy. The clinical trial proved the efficiency of laser osteoperforation for treatment of both inflammatory and destructive bone diseases. This method is minimally invasive, promotes rapid reduction of bone and soft tissue inflammation, and apparently stimulates bone reparation.

Keywords: laser surgery, laser osteoperforation, osteomyelitis, delayed unions, false joints, osteochondropathy

1. INTRODUCTION

The treatment of destructive diseases of bone tissue, including purulent osteomyelitis, is a major challenge for investigators. A new method of transcutaneous laser osteoperforation, developed by us in the experiment performed on rabbits, has been used then for treatment of acute and chronic osteomyelitis.

The preliminary clinical trials showed that the results of osteomyelitis treatment exceeded the known traditional methods in a number of attributes. Laser osteoperforation was less traumatic, well tolerated by patients, helped coping with the inflammatory process in tissues in short terms. In the early stages of acute inflammation it did not require any additional incisions, soft tissue and bone marrow channel draining. In the cases of advanced purulent process, so-called extramedullary stage of acute osteomyelitis with formation of purulent leakage and phlegmons of soft tissues, laser osteoperforation was combined with operative opening of abscesses in soft tissues. In such situations it was performed as an additional intervention on the second day after opening and drainage of supplicative focuses.

Depending on extensiveness of bone injury, presence of necrotic focuses in bone tissue (sequestrers) in different forms of chronic osteomyelitis, laser osteoperforation can be used, both as independent method, and in combination with operative excision of osteal sequestrers. But in any case the efficiency of the developed method exceeded all known traditional methods.

The experimental results demonstrated that the operation mode of laser radiation did not cause any deep thermal lesions of soft tissues and bone. Dynamic bacteriological researches proved the fast sanitation of a suppurative focus and decrease of the number of pathogens below the critical level.

Thus the experimental results and encouraging results of the first clinical application of laser osteoperforation for treatment of osteomyelites formed the basis for extension and expansion of this method application for treatment of various destructive diseases of bone tissue (not only inflammatory bone affections, but also traumatic damages; delayed unions, false joints, and aseptic osteonecroses, so-called osteochondropathy).

* lappa@csu.ru
2. METHODOLOGY

The immediate and long-term results of treatment of 508 patients with various forms of acute and chronic osteomyelitis aged from 2 to 67 years, 51 patients with nonunions and false joints of bones, and 34 patients with osteochondropathy of different localizations (Perthes, Osgood – Schlatter, Keller diseases, etc) were analyzed in this study. All osteomyelitis patients were divided into two representative groups (the basic and the group of comparison) which differed only by a method of treatment. The general characteristic of the osteomyelitis patients is presented in the Table 1.

<table>
<thead>
<tr>
<th>Forms of osteomyelitis</th>
<th>Basic group</th>
<th>Comparison group</th>
<th>ALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute hematogenous</td>
<td>74</td>
<td>44</td>
<td>118</td>
</tr>
<tr>
<td>Chronic hematogenous</td>
<td>66</td>
<td>52</td>
<td>118</td>
</tr>
<tr>
<td>Chronic posttraumatic</td>
<td>121</td>
<td>90</td>
<td>211</td>
</tr>
<tr>
<td>Primarily chronic</td>
<td>33</td>
<td>28</td>
<td>61</td>
</tr>
<tr>
<td>TOTAL</td>
<td>294</td>
<td>214</td>
<td>508</td>
</tr>
</tbody>
</table>

In the basic group the laser osteoperforation method was used, both as independent, and in combination with surgery, and in the group of comparison the traditional methods of treatment were used, including surgery. Radiography, diagnostic puncture of bone marrow channel, fistulography, transcutaneous oxygenometry, computer tomography, computer roentgen densitometry, ultrasonic osteometry, laser flowmetry were used along with the common clinical methods. Microcirculation in the affected segment of extremity was assessed with the laser Doppler flowmeter BLF 21 «TRANSONIC SYSTEMS Inc» (USA). Transcutaneous oxygenometry was performed with TCM-2 "RADIOMETR" (Netherlands). The density of bone tissue was determined with the ultrasonic osteometry device «Echoosteometer EOM-02 » (Russia). The computer densitometry was carried out with «CT MAX» device applying the program "Diamorph" (Russia). Laser osteoperforation was fulfilled with diode lasers: SRG3-30-980 (20W max, 980 nm), LS-0,97-IRE “Polus” (30 W max, 970 nm), Lahta-Milon 920-70 (70 W max, 920 nm). The radiation was delivered into the tissue through the quartz-quartz monofiber 0.4 mm in diameter with heat-resistant coating.

The technique of laser osteoperforation: The laser osteoperforation is a minimally invasive operation. In the affected site of inflammation or destruction some transcutaneous through holes in the both walls of bone marrow channel are formed with IR laser irradiation in contact mode without any incision (Fig. 1). The average power from 8 to 20 W in pulsed mode with perforation duration 3-8 seconds was used depending on the localization of pathological process. Peak power achieved 20-30 W.

In the group of comparison in the cases of acute hematogenous osteomyelitis the open mechanical drill osteoperforation was performed forming 4 - 6 osteoperforation holes with the electric drill 2 mm in diameter.

In the cases of chronic osteomyelitis in remission with the small centers of bone destruction (up to 0.5-1.0 cm) and small sequestrers (up to 0.5 cm), laser osteoperforation was performed transcutaneously in the areas selected by roentgenogram analysis. From 10 to 20 holes were performed in the bone, 1.0-1.5 cm from each other. In the presence of fistulas, the laser treatment of them was performed with the same light fiber, using continuous mode, 1.5-2.0 W, for 30 seconds.

In the case of extensive bone tissue lesions with massive cortical sequesters, they were removed firstly, and in the end of operation the laser osteoperforation was performed, i.e. combined operative treatment was applied. Laser osteoperforation was repeated, if necessary, but not earlier than 3 weeks after the first operation. In some patients (50.9 %) the only operation was enough, in others two (20.9 %), three (14.1 %) and sometimes four (10.3 %) or 5-6 (3.6 %) operations were performed (usually in chronic osteomyelitis).
The efficiency of this treatment was estimated by clinical improvement and duration of hyperthermia; improvements of blood indexes; decrease of intraosseous pressure; cyto- and bacteriological parameters changes; ultrasonic and computer osteodensimetry, laser flowmetry, radiological changes; duration of treatment and rehabilitation; the presence and character of complications; lethality; the frequency of chronicization (for acute hematogenous osteomyelitis); the duration of remission and recurrences frequency (for chronic processes).

The bone reparation after high-intensity laser irradiation was investigated in experimental fractures of tubular bones in dogs. The dogs were select by analog principle: 18-20 kg weight, 2-3 years old.

The osteoperforation for osteochondropathy, nonunions and false joints was carried out with the same sources of laser radiation and light guides, as for the osteomyelitis treatment. The technique of osteoperforation was actually the same and consisted in transcutaneous creating of 4 - 12 laser osteoperforations, in the area of nonunion or the focus of aseptic necrosis. The pulse contact mode was applied. The complex of measures for treatment of delayed unions and aseptic bone necroses included unload and immobilization of the limb depending on the kind and the stage of disease. The results of the treatment were estimated by the results of clinical and roentgenologic tests. The long-term results were followed in all 118 patients with acute hematogenous osteomyelitis and in 329 patients (84.3%) with chronic osteomyelitis during the observation period from 2 to 7 years.

3. RESULTS AND DISCUSSION

3.1 Osteomyelitis

The outcomes of treatment of 118 patients with acute hematogenous and 320 patients with chronic osteomyelitis showed, that application of laser osteoperforation resulted in the earliest positive changes of the postoperative clinical course. The main group patients with acute osteomyelitis demonstrated the improvement of general condition 2-3 days earlier, than the patients after mechanical osteoperforation. The essential differences of the postoperative course were marked for chronic osteomyelitis too. For example, the terms of fistula epithelization and in-patient treatment halved (Table 2).

The main components in development of acute osteomyelitis are the rising of intraosseous pressure and high concentration of pathogens in the disease focus. Therefore all the modern methods of treatment are aimed at osteal decompression and sanation of the bone marrow canal. Intraosseal pressure reduced faster after laser osteoperforation, than after mechanical. The dynamic of intraosseous pressure after the treatment is demonstrated in the Fig. 2.
Table 2 Dynamics of clinical improvement of patients with osteomyelitis

<table>
<thead>
<tr>
<th>Parameteres</th>
<th>Acute hematogenous osteomyelitis</th>
<th>Chronic osteomyelitis</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Basic group n = 74</td>
<td>Comparison group n = 44</td>
</tr>
<tr>
<td>Pain duration (hours)</td>
<td>17,2±4,8*</td>
<td>21,2±0,3*</td>
</tr>
<tr>
<td>Edema duration (days)</td>
<td>4,0±2,5*</td>
<td>5,3±0,1*</td>
</tr>
<tr>
<td>Hyperthermy duration (days)</td>
<td>2,9±1,7</td>
<td>1,8±0,3*</td>
</tr>
<tr>
<td>In-patient treatment (days)</td>
<td>8,2±3,1*</td>
<td>7,8±0,2*</td>
</tr>
<tr>
<td>Fistula epithelization terms (days)</td>
<td>5,9±0,1*</td>
<td>8,7±0,1*</td>
</tr>
</tbody>
</table>

* - significance of differences between the main group and the comparison group (p<0.05)

Fig. 2. Dynamics of intraosseous pressure in children with acute hematogenous osteomyelitis after the operation

It is known, that the purulent process arises at the presence of critical concentration of pathogens more than $10^5$ colony-forming units in a milliliter or gram of tissue. When the number of pathogens is reduced lower this level, the signs of inflammation are resolved. The tests of pathogen number demonstrated the faster sanation of bone marrow channel in the children with acute hematogenic osteomyelitis after laser application. In contrast to the traditional operations, based only on mechanical elimination of pathogens, bactericidal action of laser quickly resulted in sterilization of bone marrow channel exudation. So the average terms of antibacterial therapy for acute osteomyelitis were reduced to 5-7 days against 2-4 weeks under the traditional methods of treatment.

The decrease of edema, hyperemia and soft tissues tension above the osteomyelitis focus is related to improvement of microcirculation. This local clinical changes usually occurred on the 8-10 day after the traditional operation, and on the 5-6 day after laser treatment. The parameters of capillary blood flow approach to those of the healthy limb by 3-6 months in the laser group, and in the control group even 6 months after the traditional treatment the microcirculation disturbances remained (Fig. 3).
The better blood flow supplies with the better oxygen exchange, and the good tissue perfusion provides steady antibacterial protection and promotes fast reparation of the affected tissues.

The oxygen tension in tissues of the injured limb before operation was reduced by 40-50% in comparison with the healthy symmetric limb. The dynamic researches of patients with acute and chronic osteomyelitis presented the normalization of oxygen exchange parameters (TcPO₂) of tissues 2-3 months earlier in the main groups, than in the groups of comparison. Fig. 4 illustrates the oxygen tension in tissues of patients with acute hematogenous osteomyelitis depending on treatment methods. The application of high-intensive laser for treatment of acute and chronic osteomyelitis promotes the fast normalization of oxygen exchange in the tissues of affected limb segment.
This restoration of microcirculation and elimination of soft tissue hypoxia promoted the better reparation of bone tissue. To confirm this statement we used the ultrasonic osteometry, radiography and computer densitometry. The investigations demonstrated that clinical improvement after surgery was accompanied by normalization of ultrasonic osteometry and computer densitometry values. The significant improvement of these parameters was registered in 25-30 days after laser operations, and only in 3 months after traditional operations. The complete recovery of these values was registered by 6 months in the main group, while in the group of comparison the decrease was marked even in 9 months. The radiograph analysis demonstrated the similar tendency.

Clinical case. A 11-year-old girl M. underwent the operation on account of acute hematogenous osteomyelitis of distal metaepiphysis of tibia in a local hospital. One month after the operation purulent fistulas opened, and the pathologic fracture was revealed 6 months after. The girl was hospitalized and the transcutaneous laser osteoperforation of tibia was performed. Antibiotics were not prescribed. The fistulas closed in 6 days. The girl was discharged from the hospital on the tenth day for the outpatient treatment in a satisfactory state with a plaster splint. In 1.5 months the fracture consolidated. General condition and state of health improved. The control radiograph demonstrated complete consolidation of the fracture and relief of osteomyelitis symptoms (Fig. 5). The complete remission is observed in the follow-up period for 7 years. The patient feels well, goes in for swimming.

The important criterion of osteomyelitis treatment efficiency is the decrease of complications frequency. The application of laser osteoperforation promoted the decrease of complication frequency from 11.4 to 4.3 % in acute osteomyelitis in comparison with mechanical osteoperforation treatment. In the cases of chronic osteomyelitis, the general frequency of complications came to 15.5 % after traditional treatment, and laser osteoperforation reduced it to 3.4%.

The analysis of the remote results of treatment of acute and chronic osteomyelitis in the follow-up period from 2 to 8 years confirmed the advantages of laser osteoperforation. Laser osteoperforation allowed reducing of treatment and rehabilitation period, permitted to achieve complete recovery in 95.6 % of children with acute hematogenous osteomyelitis, and to achieve a permanent and long term remission in chronic forms of osteomyelitis in 94.1 % of patients, thus reducing the frequency of recurrences from 12.7 to 4.3 %.

Fig. 5. Radiographs of left shin bones of the patient M., 11 years old. Hematogenous osteomyelitis of tibia, complicated with pathologic fracture.

a. Before laser osteoperforation. There are destruction focuses, small sequesters and periosteal thickening. Bone marrow channel is not observed. The line of pathological fracture is defined in the low third of tibia.
b. 9 months after laser osteoperforation. There is no destruction focuses and sequesters. The sclerosis area is observed at the site of fracture. The structure of tibia restored.
3.2 Nonunions and pseudo-joints.

The nonunions and false joints are the consequences of disturbance of bone reparative regeneration processes at the certain stages of fracture consolidation. The development of new technologies and methods of operative treatment of fractures, the increasing of operative activity, resulted not only in the progress of complete fractures treatment, but also the increase of pseudo-joints and delayed union, coming to 3.6-51.8% of all complications of long cortical bone fractures. A lot of methods of healing stimulation and the treatment of delayed consolidation exist, but they have some weak points, may cause complications and faults.

We have adapted the laser osteoperforation technique, initially developed for osteomyelitis treatment, for the decision of a new problem, the treatments of false joints and delayed unions. Preliminary modes of laser osteoperforation for stimulation of fracture healing were developed in experiment on 24 mongrel dogs. In aseptic conditions the fracture of radial bone of fore limb was performed. 7 days after the animals were distributed into 3 groups: in the first control group the healing process ran its natural course, in the second control group the mechanic osteoperforation was performed and in the third basic group the laser osteoperforation was performed at the site of the fracture. The laser osteoperforation was carried out transcutaneously by formation of two through holes both in peripheral and in the central bone fragments and one perforation passed directly through the zone of fracture. The laser operating mode was the similar to that used for osteomyelitis treatment. The results of this experiment were evaluated by clinical, radiological, morphological and biochemical data on the 7, 14, 21, 28 and 60th day after the osteotomy.

The normalization of the general condition and clinical convalescence of animals was registered on the 21th day of the experiment. By this time the support ability of the damaged extremity completely recovered, the local sign of tissue inflammation were absent. In the control groups the general condition became normal only by the 28th day, and the reliable support ability of the damaged limb and relief of edema were observed by 30-45 day.

The radiological study demonstrated the consolidation of the fracture in the laser osteoperforation group by the 28th day (Fig. 6c). In the control groups bone fragment diastasis remained, with the more intensive shadow of regenerating tissue in the group of mechanical osteoperforation.

![Fig. 6. Radiographs of forearm bones of dogs on the 28-th day after fracture](image-url)
In the remote period on the 60th day after fracture an expressed periosteal callus was seen in the images of the fracture in the first control group, in spite of apparent clinical recovery. There was no complete restoration of the injured cortical layer of the bone. In the second control group the periosteal callus was more expressed than in the first group, the density of regenerating tissue was more intensive. The complete restoration of the injured cortical layer was not observed. In the dogs of the basic group the complete anatomic restoration of the injured site of the radial bone was seen (Fig. 7c).

![Radiographs of forearm bones of dogs on the 60-th day after fracture](image1)

**Fig. 7. Radiographs of forearm bones of dogs on the 60-th day after fracture**

The histological study of reparative regeneration was carried out on the 14-th and 28-th day of experiment. By the 28-th day histotopographical sections of the first group (Fig. 8) demonstrated the diastasis between the fragments filled with fibrous cartilage with small cystic cavities at the cortical plate of fragments. In the both fragments the regenerating endosteum and periosteal thickening up to 4-5mm were defined. An incomplete periosteal fusion of fragments due to connective tissue with stratifying of spongy bone tissue was observed in the second control group. The end surfaces of the cortical plate of the fragments were porous, with the layers of fibrous connecting tissue between them. In the basic group the complete endosteal and periosteal fusion took place, the callus consisted of fibrous cartilage and bone tissue.

![Histotopographical sections of bone fractures in dogs, the 28th day of experiment](image2)

**Fig. 8 Histotopographical sections of bone fractures in dogs, the 28th day of experiment, van Gizon staining. Magnification X 75.**

The analysis of clinical, radiological and morphological results of this experimental research gave the strong evidence that the mechanical and laser osteoperforation stimulated the processes of reparative osteogenesis. However, the application of high-intensive laser radiation caused more active and expressed stimulation effect on healing of tubular bone fractures in comparison with mechanical osteoperforation.

This experimental research formed the base for clinical application of laser osteoperforation for treatment of 32 patients with nonunions and 19 patients with pseudo-arthrosis of long tubular bones. The laser osteoperforation with the same
fixation as before (49.2%) caused almost no postoperative pain syndrome, and the edema reduction was faster, then in patients who underwent an osteosynthesis additionally. This fact testifies for minimally invasive character of laser osteoperforation and fast inflammation reduction after it.

In the nearest postoperative period 3-5 weeks after laser osteoperforation the space between the fragments became more narrow, a moderate periostal reaction was expressed, the homogenic shadow of regenerating bone tissues appeared on the radiograph, and the graduate formation of continuous cortical layer of callus took place (Fig. 9).

The terms of fusion of delayed unions depended on the anatomic characteristic of the bone, fracture localization, presence and degree of cicatrical changes in soft tissues, conditions of circulation and innervation in the segment. The union terms for the fractures with delayed consolidation after laser osteoperforation were 1.8 times less, than terms of treatment of such fractures before the procedure and did not exceed the average terms of consolidation of bone fractures of the given localization regardless the fixation method.

The union terms for the false joint consolidation exceeded the average union terms for the delayed unions, depending on the kind of this false joint, duration of its existence and pathogen contamination, but after laser osteoperforation they were 2.5 times shorter, than the terms of their treatment before.

The laser osteoperforation resulted in good and satisfactory outcome of delayed union treatment in all patients. Pseudoarthrosis patients demonstrated good and satisfactory results in 81.8% of cases.

So, relying on experimental and clinic investigation it was found that the laser osteoperforation was a highly efficient minimally invasive way of stimulation of consolidation in delayed unions and pseudo-joints. This approach is a promising line in traumatology and orthopedic. The advantages of this method are the high clinical success, the absence of complications, short recovery period, good tolerance to the operation and perfect cosmetic and functional results.

3.3 Acerptic osteonecrosis (osteochondropathy)

The aseptic osteonecrosis make up to 3 % of all primary orthopedic patients, both among children, and among adults. The most frequent osteochondropathies are Perthes (33.4 %) and Osgood – Schlatter (23.7 %) diseases. The Perthes disease is preferably observed in 5-9 year-old boys. Aseptic necroses of the femur head occursin young and middle-aged men more often. All patients with aseptic necrosis become disabled as a rule. Osgood – Schlatter disease usually develops in teenagers engaged in sports and becomes the reason of their leaving sports.

Conservative methods of osteonecrosis treatment are very long-term and frequently inefficient. The common minimally invasive approach for treatment of these diseases is the bone tunneling through the necrosis site and adjacent healthy bone tissue. The tunneling is carried out mechanically with the help of Kirschner's wire or drilling. Various osteotomies are recommended to improve the blood supply of the femur head. This approach is rather traumatic, requires a long term...
immobilization. Simple mechanical drilling of bone canals has limited effectiveness for stimulation of bone regeneration.

We used the method of laser osteoperforation for stimulation of bone regeneration. In the affected site and adjacent tissue the multiply (8-10 and more) osteoperforations were formed in the contact mode. The pulsed mode was used, 20-30 W peak power.

The preliminary results of the treatment of 5 patients with Perthes disease, 23 patients with Osgood – Schlatter disease, 3 patients with Keller disease, one patient with femur head necrosis after acute hematogenous osteomyelitis and one patient with bilateral idiopathic necrosis of femur head demonstrated that laser osteoperforation promotes revascularisation, improves oxygenations and reparations of bone tissue in the affected site.

Clinical Case. A 2.5 year-old boy L. at the age of 1 month had suffered from acute hematogenous osteomyelitis of proximal epimetaphys of the left femur. Physical examination revealed the relative shortening of the left low limb by 2 cm and contracture of the left hip joint. On the radiography image coxa vara sinistra and the expressed destruction of the femoral head are observed. Ultrasonic dopplerography demonstrated the decrease of peak blood flow rate in the left circumflex femoral artery. Transcutaneous oxygenometry (TcPO2) in the projection of the left hip joint demonstrated the local hypoxia up to 46 mmHg (70 mmHg on the right side). Transcutaneous laser osteoperforation of head and neck of the left hip was performed under the ultrasonic control. After this operation the limb was immobilized with an orthesis. 3 months after the operation the blood flow in the right and left circumflex arteries was symmetric and the resistance was normal according to ultrasonic dopplerography. TcPO2 in the projection of the left hip joint became normal: 72 mmHg against to 71 mmHg on the right. The expressed augmentation of the volume of the left femur head with formation of sphere was marked on radiograph. In 8 months the volume of the left femur head was almost like the volume of the right femur head. The left hip range of motions essentially increased keeping small restrictions (by 10 degree) of left hip abduction and the shortening of the left low limb by 2 cm.

4. CONCLUSION

The method of transcutaneous laser osteoperforation is an effective way of treatment both inflammatory, and destructive diseases of bones. It is minimally invasive and tolerable for patients, promotes rapid reduction of inflammatory processes in the bone and soft tissues, and has the expressed ability to stimulate the reparation processes in the bone tissue.

REFERENCES