Ministry of Health of Russian Federation
FSBEI HE “Ural State Medical University”
FSBEI HE “A.I. Yevdokimov Moscow State University of Medicine and Dentistry”

ULTRASONIC CAVITATION TECHNOLOGY FOR WOUND DEBRIDEMENT

Guidelines for doctors





2020

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The guidelines are written for surgeons, interns, and clinical residents, as well as for students who deal with surgical infection problems. The authors substantiated the use of low-frequency ultrasound for the wound debridement and summarized own experience in treating this category of patients. Based on the results, it was developed and presented in the current guideline how original technology allows improving the treatment results for surgical infection foci.

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List of abbreviations

AMR — antimicrobial resistance
ESR — erythrocyte sedimentation rate
FMBA — Federal Medical-Biological Agency
LFUS — low-frequency ultrasound
NSTI — necrotizing soft tissue infection
RT — recalcification time
SI — surgical infection
USC — ultrasonic cavitation
VRS — verbal rating scale

Introduction

Surgical infections (SIs, infections that require surgical intervention or management) remain one of the most common causes of serious surgical complications and account for 30–45% hospitalization causes [10, 13].

The number of patients with purulent-inflammatory diseases tends to increase and, despite the variety of treatment methods used in purulent surgery, the time and cost of treatment remain significant [12, 26, 43, 52].

SIs are the most common and costly of all hospital-acquired infections, accounting for 20% of all hospital-acquired infections.

According to experts, annually about 700,000 patients have SIs in the Russian Federation. SIs are detected in an estimated 2% to 5% of patients undergoing inpatient surgery. The estimated annual incidence of SIs in the U.S. ranges from 160,000 to 300,000 cases, and the estimated annual cost ranges from $3.5 billion to $10 billion [37].

The importance of the problem can also be evidenced by the fact that necrotizing soft tissue infections (NSTIs) have mortality rates of 50% or more [21, 42].

Recently, the situation has been complicated by an increase in the emergence of antibiotic-resistant microorganisms [49, 63]. Antimicrobial resistance (AMR) threatens the effective prevention and treatment of an ever-increasing infections' range caused by bacteria, parasites, viruses, and fungi.

The treatment of patients with intra-abdominal infection (peritonitis, infected pancreatic necrosis) is a particular problem.

The development of infectious pancreatic necrosis complications recorded in 10–20% of cases [5, 6, 7, 51]. Moreover, the mortality rate due to pancreatic necrosis varies from 10 to 70% [5].

It is well known that the process in the pancreas and retroperitoneal fiber continuous, so it is impossible to conduct single-step debridement during the initial operative intervention. This feature of pancreatic necrosis reveals the need in programmed debridements, which act as staged sequestrectomy. In this regard, the fundamental task is to ensure less traumatic, complete, and timely debridement of pancreatic necrosis sites.

The treatment of widespread peritonitis cannot be considered satisfactory either. According to V.K. Gostishcheva et al., the mortality rate due to peritonitis in various clinics of the Russian Federation ranges from 6.2 to 42.2%. The highest mortality rate is observed in postoperative peritonitis (26.8–58.3%) [28].

The main problem of surgical treatment for widespread peritonitis is the impossibility of single-step debridement of the entire abdomen and inefficiency of closed drainage methods. In this regard, the "semi-open" management with programmed planned

abdominal debridements is currently recognized as the generally accepted technique for managing peritonitis.

Thus, despite significant progress in the understanding of basic pathogenesis, the problem of treating patients with SI, improvement of diagnostic technology and medical methods of treatment and intensive care, is still relevant for modern surgery.

There are many various methods of improving the surgical treatment for infection sites based on physical methods of influencing tissues (treatment with a pulsating liquid flow, the use of debridement with vacuum, laser and cryosurgical technologies, etc.). Our attention was drawn to the possibility of using low-frequency ultrasound (LFUS) to solve this problem.

It is known the use of LFUS in SIs for the treatment of purulent diseases of soft tissues, burns, purulent destructive kidney diseases, periodontitis, peritonitis [8, 14, 16, 17, 22]. The researchers ascertained that LFUS accelerates clearance of the wounds from necrotic tissues, stimulates repair processes, allows sparing necrotomy combined with disinfecting wounds due to the bactericidal action [19, 20, 22, 55].

These guidelines were written to determine the optimal techniques of using LFUS to improve the treatment for SI of soft tissues and the primary site of intra-abdominal.

1 Effects of LFUS and its use for wound debridement

Ultrasound is defined as sound waves with frequencies of over 20 000 Hz (cycles per second). LFUS spans the range between 20 and 80 kHz and has longer wavelengths and greater amplitude for given input energy, which results in greater movement of molecules within tissues.

Physical effects of LFUS:

1. Ultrasonic cavitation (USC) is the formation of vapor bubbles in a medium where the pressure of the liquid falls below its vapor pressure [31]. The extreme pressure reduction literally "rips" the water molecules apart and creates bubbles. These bubbles contain gas that had been dissolved in the liquid. When there is an external excitation, such as an ultrasound wave, cavitation bubbles are nucleated from gas pockets in the liquid. Bubbles' "explosions" at the border with the wound bed lead to the removal of purulent-necrotic coating, mechanical destruction of bacterial films, the disintegration of microorganisms' cell membranes, micro-massage of adjacent tissues.

2. Cavitation bubbling is the process of mixing liquid in a cavity by cavitation bubbles' flows which are created by an ultrasonic wave. Cavitation bubbling promotes greater contact of the drug with infected tissue. It allows the impregnation of drugs into the deeper layers of tissues due to the hydrodynamic impulse of the cavitated flows.

3. The thermal effect occurs mainly during the contact of the ultrasonic instrument (sonotrode) with the tissue. The mechanical vibrations' energy of the instrument turns into heat and at a low power causes the expansion of the microvasculature's vessels, at high power causes the coagulation of tissues. Due to energy conservation, all the sound energy attenuated by tissues must be converted to other forms of energy. The majority of this is turned into heat. As such, ultrasound can raise tissue temperature by up to 1.5 °C.

The disintegration of water molecules. A local increase in extreme temperature and pressure leads to the decomposition of water vapor into hydroxyl radicals and hydrogen atoms. Hydroxyl radicals can form hydrogen peroxide (H_2O_2), which can initiate different biochemical reactions, i.e., the cascade of free radicals' production. As a result, there is the formation of free radicals like hydrogen peroxide, singlet oxygen, and superoxide ions [18, 56].

4. Tissue fragmentation. Ultrasound selectively emulsifies necrotic tissues. Fragmentation occurs due to direct contact of a sonotrode with a tissue, vibration of a liquid, waves of increased and negative pressure, as well as the cavitation effect.

Biological effects of LFUS

Biological effects depend on the frequency, power, and exposure to ultrasound, which make it possible to get effects from stimulation to destruction [1, 3, 9, 25, 30, 45, 50]. The biological effect of ultrasound is also determined by the type and functional state of the exposed tissue.

The absorbed energy of ultrasonic vibrations causes endogenous heat production, contributes to a complex set of physicochemical and biological processes in tissues. The biological effects of ultrasound can be conditionally divided into the following:

1. Bactericidal effect

At high LFUS intensities, microbubbles form around cells and, through their oscillations, disrupt the cell membrane [45, 48, 58].

Bubbles act on biofilms and increase its permeability to antimicrobial agents or even kill bacteria in biofilms. LFUS acts on the extracellular matrix of bacterial biofilm to destroy the cytoplasmic structures of bacterial cells [1, 3, 32].

Many factors affect the activity of LFUS against biofilms. For example, the LFUS parameters, including intensity, frequency, tissue contamination, irradiation time, and chemical composition of the drug solution, are of significance [57, 59, 60, 64].

2. Phonophoresis

Cell membranes often prevent large molecules such as drugs and genes from entering cells and taking effect [57]. The mechanical force of focused ultrasound via cavitation can change the permeability of cell membranes and enhance the absorption of these molecules [40, 41].

Stable cavitation can induce moderate and reversible changes at the cellular level, creating pores in cell membranes, allowing a greater volume of compounds to enter the cell.

3. Anti-inflammatory effects

LFUS was shown to be effective in mitigating inflammation and facilitating tissue repair in various pathologies.

LFUS anti-inflammatory effects are mediated by upregulating anti-inflammatory gene expression. LFUS induces the upregulation of the markers and master regulators of immunosuppressor cells. LFUS-mediated physical effects on tissues may activate specific cellular sensors that activate downstream transcription factors and signaling pathways [4, 62].

4. Stimulating effects

Ultrasound selectively emulsifies dead and dying tissues with gas microbubbles,

stimulating the membranes of surrounding healthy cells, and rendering bacteria more susceptible to antibiotic treatment [29, 33, 54, 61]. As a result, this modality is thought to both debride the wound and promote healing by upregulating cellular activity, promoting growth factor (and protein) synthesis and fibrinolysis, disrupting biofilms [36, 61].

5. Effects on microcirculation

LFUS causes the vasodilation and the increase in local blood flow by 2–3 times, initiates the development of collateral blood flow [27, 36]. The energy of mechanical vibrations turns into heat and causes the expansion of the microvasculature's vessels. Under the influence of LFUS endothelial cells increase in NO production in the focus of ischemia: it is one of the mechanisms for improving tissue perfusion [2, 53].

6. Necrolytic effect

Selective ultrasound destruction is used for necrotomy. It is based on the cavitation effect and mechanical removal of non-viable tissues by the vibrating working surface of the sonotrode. A specific feature of ultrasonic necrotomy is minimal invasiveness [11].

Controlled necrotomy preserves intact tissues, vessels, and nerves. At the same time, since tissues, depleted in the liquid, do not collapse under the ultrasonic influence, stromal elements are preserved. This provides necrotomy with minimal blood loss and minimal damage to healthy tissue.

Thus, the varied clinical effects of using LFUS have made it possible to successfully use this technology in the treatment for wound infections [15, 34, 38, 46], pathology of ENT organs [39, 47], as well as in dermatovenereology [24], abdominal surgery [23, 38], obstetrics and gynecology [44].

Ultrasonic treatment is an effective complement to the conventional surgical debridement of purulent wounds. It allows using of primary sutures more widely and with favorable outcomes. A drastic reduction of the inflammation phase allows applying early secondary sutures to close the wound defect. Using LFUS in the complex treatment of purulent wounds, the average length of stay in a hospital, the cost of their treatment, the number of undesirable complications are reduced. All the above allows us to consider the method quite promising and reliable.

2 Overview of the ultrasonic surgery cavitation device “FOTEK”

2.1 Operating principle of the device

The ultrasonic surgery cavitation device “FOTEK” (Fig. 1) is intended for wound treatment in various fields of surgery. The device uses low-frequency ultrasonic vibrations and cavitated drug solutions to remove purulent-necrotic deposits from the wound bed.

The device is easy to use. The trolley for the device (Fig. 1) and the set of ultrasonic handpieces and tips (Fig. 2) are included in the delivery set.

The ultrasonic generator produces an alternating current of ultrasonic frequency. It also sets and automatically maintains the operating mode of the ultrasonic tip. Piezo electronics convert the electrical signal from the ultrasonic generator into mechanical energy that can result in the vibration of the sonotrode at an ultrasonic frequency of 25 kHz.

The required irrigation which is provided by an irrigation channel is incorporated into the ultrasonic tip. The solution is supplied to the handpiece through the infusion system.

The ultrasonic debridement is triggered by a footswitch.



Fig. 1 — Ultrasonic surgery cavitation device “FOTEK” (ACTITON-A model)

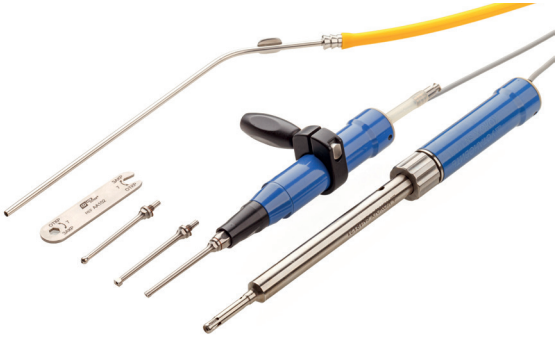


Fig. 2 — Ultrasonic handpieces and tips

2.2 Types of ultrasonic exposure

Depending on the tools and modes, the ultrasonic system allows to implement:

1. Non-contact spraying

Ultrasonic vibrations transform the drug solution supplied through the ultrasonic tip into a directed fine jet of liquid (so-called cavitation jet), which contains many cavitation bubbles filled with gas and/or steam (Fig. 3).

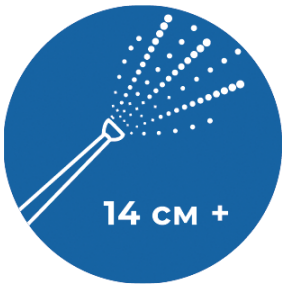


Fig. 3 — Cavitation jet

The intensity of the cavitation jet is determined by the power level of ultrasonic vibrations, the set liquid flow rate, and hydrostatic pressure of the liquid in the handpiece's irrigation channel. Hydrostatic pressure depends on the height of the infusion bottle.

The closer the ultrasonic tip is to the surface to be treated, the stronger the bactericidal effect.

As a result of the cavitation jet's soft exposure, the fibrin coating is removed, the blood supply in the adjacent area is increased, the tissues are saturated with the drug solution.

2. Contact ultrasonic debridement

Contact ultrasonic debridement is the effect of a vibrating sonotrode, which produces about 25,000 oscillations per second with an amplitude of several tens of micrometers on a tissue. This type of debridement allows you to carry out controlled destruction and fragmentation of tissues (Fig. 4).



Fig. 4 — Contact ultrasonic debridement

The combined action of mechanical vibrations and cavitated drug solution allows providing a strictly dosed controlled necrotomy with the preservation of intact tissues, vessels, and nerves.

Contact ultrasonic debridement helps to improve microcirculation, normalize metabolic processes, and decrease microbial contamination in the treated area.

This method of exposure is applicable if the wound is not deep and a doctor can see the treated area.

To treat deep wounds, it is recommended to use an ultrasonic handpiece with a special protective cover that protects tissues from accidental damage by an ultrasonic tip.

3. Cavitation bubbling

The principle of the cavitation bubbling method based on the active mixing of the drug solution in the cavity with cavitation bubbles (Fig. 5). Devitalized tissue and foreign bodies are removed from the wound bed, biofilms and cell membranes of microorganisms disrupted, while trauma to the surrounding vital tissue is minimized.



Fig. 5 — Cavitation bubbling

The cavitation bubbles, due to their small size and high speed of movement in the liquid, penetrate even the most inaccessible places and deepenings of purulent cavities, ensuring their thorough cleaning.

It is possible to observe the turbidity of the solution in the cavity due to the discharge of fibrin from the walls of the cavity during processing.

Active mixing of the drug solution promotes greater contact of the drug with the infected tissue. Bubbling causes micro-massage of tissues and improves microcirculation. The combination of all factors leads to gentle wound cleansing and acceleration of healing.

The cavitation bubbling method allows for the rehabilitation of wounds of various sizes and configurations.

Thus, various options of the ultrasonic action make it possible to differentially approach the use of the method depending on the phase of the wound healing process, the location and configuration of the purulent foci.

2.3 Operating modes of the ultrasonic surgery cavitation device “FOTEK”

In the ultrasonic surgery cavitation device “FOTEK” (Fig. 6) there are two modes for ultrasonic exposure: “BASIC” and “SELECTIVE”. Depending on the model, the cavitation system has “IRRIGATION” and “SUCTION” modes (ACTITON-A) or only “IRRIGATION” mode (ACTITON).



Fig. 6 — Front and rear sides the ultrasonic surgery cavitation device “FOTEK”:
1 — button for switching on the “ULTRASOUND” mode; 2 — button for switching on the “SUCTION” mode; 3 — button for switching on the “IRRIGATION” mode; 4 — display of the ultrasonic power; 5 — button for adjusting the “TIMER” function; 6 — buttons for adjusting the ultrasonic power; 7 — button for calling up information about the connected ultrasonic handpiece; 8 — irrigation control valve; 9 — information about the connected footswitch and assignment of its functions; 10 — “STB” button (Stand-by — sleep mode); 11 — “ULTRASOUND” connector socket for an ultrasonic handpiece; 12 — connector socket for a footswitch; 13 — “SUCTION” connector socket for the suction tubing; 14 — mains switch; 15 — connector socket for the mains cable

The modes for ultrasonic exposure:

The “BASIC” mode — ultrasonic acoustic oscillations intensive effect on biological tissues. In case of contact exposure in this mode, enhanced destruction, and fragmentation of necrotic tissues proceeds. Cavitation spraying and bubbling of solutions in the “BASIC” mode occur with higher intensity than in the “SELECTIVE” mode.

The “SELECTIVE” mode — ultrasonic acoustic oscillations sparing effect on biological tissues. It is used for contact wound cleansing to ensure maximum tissue selectivity when there is a risk of damage to the neurovascular structures or fresh granulations. Cavitation bubbling and spraying of solutions in this mode occurs with small pulsations.

During usage of a double-pedal footswitch, the “SELECTIVE” mode is activated by pressing the blue pedal and the “BASIC” mode is activated by pressing the yellow pedal. To use a single-pedal footswitch, it is necessary to select the mode activated by footswitch pedal (Fig. 6, pos. 9).

The ultrasonic power (from 1 to 100 units) is adjusted by the buttons “+” and “-” on the touch screen (Fig. 6, pos. 6). The set value of the ultrasonic power is displayed above (Fig. 6, pos. 4). When working with the ultrasonic handpiece AA207.5 for deep purulent wounds (the description of the handpiece is in chapter “2.4.2 Ultrasonic handpiece for the deep wound debridement (AA207.5)”), the level of ultrasonic vibrations is set automatically by the device (the inscription “AUTO” appears on the touch screen).

The “IRRIGATION” mode supplies drug solution through the internal irrigation channel of the ultrasonic handpiece simultaneously with the activation of ultrasonic exposure. This mode is turned on by pushing the “IRRIGATION” button on the touch screen (Fig. 6, pos. 3) and activated by pressing the footswitch.

If the mode is on and the footswitch is pressed, the solution from the container enters the ultrasonic handpiece. The solution flow stops after releasing the footswitch.

The “IRRIGATION” mode is recommended to be used only with the infusion system “Infusomat Space Line”, REF 8700036SP (B. Braun Melsungen AG, Germany). A pack of such infusion systems is included in the device set under the article AA120 (Fig. 7).

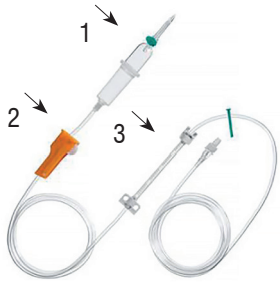


Fig. 7 — Infusion system “Infusomat Space Line” REF 8700036SP, B. Braun Melsungen AG, Germany (AA120):
1 — drip chamber;
2 — roller clamp;
3 — silicone pump segment

This infusion system contains a silicone pump segment (Fig. 7, pos. 3), which is inserted into the slot of the irrigation control valve (Fig. 6, pos. 8) by pressing the button in the valve center (Fig. 8).

NOTE: when using another infusion system, it is necessary to close and open the solution supply manually (using a roller clamp). In this case, the “IRRIGATION” mode should be turned off.



Fig. 8 — The silicone pump segment of the infusion system 8700036SP (AA120) is inserted into the slot of the irrigation control valve

CAUTION! When the distal end of the ultrasonic tip is immersed in a cavity with liquid, liquid may produce backflow from the cavity into the irrigation channel of the handpiece and in the infusion system connected to it (Fig. 11, a).

To avoid backflow, a back check valve "Infuvalve", REF 4094000N, B. Braun Melsungen AG, Germany (hereinafter referred to as the back check valve, Fig. 9) is used. It is installed between the infusion system and the ultrasonic handpiece (Fig. 10). Using the adapter AA121, included in the set of each handpiece, the back-check valve is connected to the ultrasonic handpiece. A pack of back check valves is included in the device set under the article AA118.



Fig. 9 — Back check valve "Infuvalve", REF 4094000N, B. Braun Melsungen AG, Germany (AA118)

The back-check valve does not allow fluid to rise along the channel of the ultrasonic handpiece in a reverse direction and prevents the possible entry of fluid from the treated cavity into the infusion system (Fig. 11, b).

NOTE: it is allowed to work without the back-check valve 4094000N (AA118) when using a sterile infusion system and a sterile ultrasonic handpiece for each procedure, as well as when performing non-contact ultrasonic debridement (when there is no contact between the patient's tissues and the handpiece elements during the procedure).

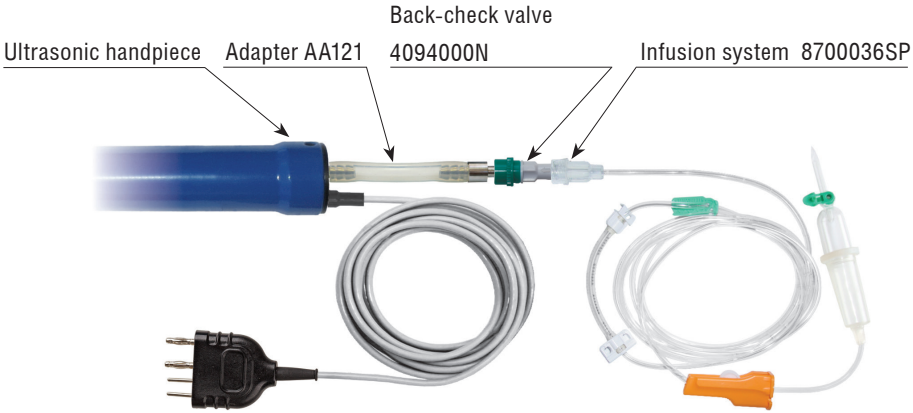


Fig. 10 — Connection to the acoustic handpiece with the adapter AA121, the back-check valve 4094000N and infusion system 8700036SP

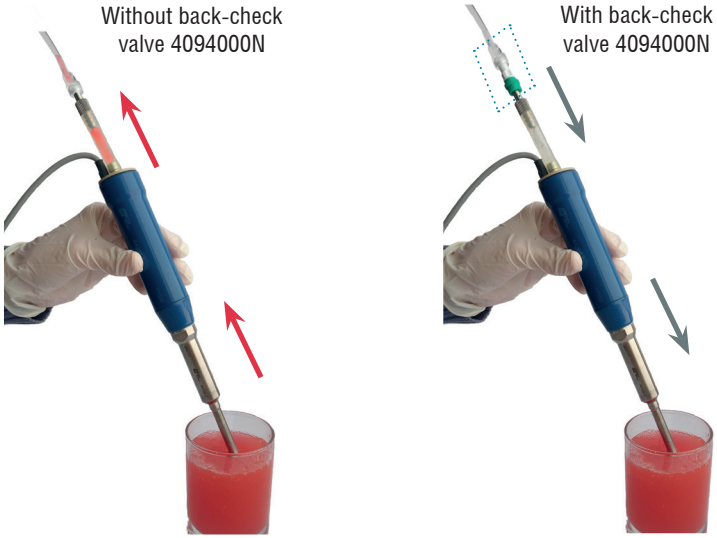


Fig. 11 — Immersion of the distal end of the ultrasonic tip in the cavity with the liquid:
a — without connected back-check valve 4094000N;
b — with connected back-check valve 4094000N

The "SUCTION" mode (only in the ACTITON-A model) is designed to remove fluid from the treated area. It is convenient for ultrasonic cavity debridement. This mode is turned on by pushing the "SUCTION" button on the touch screen (Fig. 6, pos. 2) and activated by pressing the footswitch. The liquid is removed using disposable or reusable suction nozzles. After releasing the footswitch, the suction lasts for 3–4 seconds, that allows removing the remaining fluid after the termination of ultrasonic exposure.

2.4 Ultrasonic handpieces

2.4.1 Ultrasonic handpiece for the purulent wound debridement up to 10 cm deep (AA201.5)

The ultrasonic handpiece AA201.5 is used with replaceable ultrasonic tips with irrigation channel AA112.1 "Hoof", AA113.1 "Ball" and AA114.1 "Spatula" (Fig. 14).

This handpiece is designed for wound debridement up to 10 cm deep.

The handpiece cleans tissues from purulent deposits with the mechanical action of the ultrasonic tip and/or cavitated jet supplied through the channel inside the handpiece, as well as for the cavitation bubbling.

Examples of the application are the treatment of trophic ulcers, diabetic foot ulcers, soft tissue phlegmons, burns, pressure ulcers, etc.



Fig. 12 — Assembled ultrasonic handpiece AA201.5

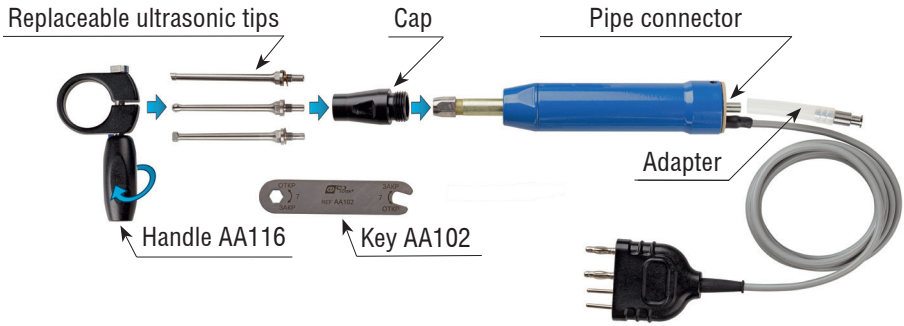


Fig. 13 — Disassembled ultrasonic handpiece AA201.5 with accessories

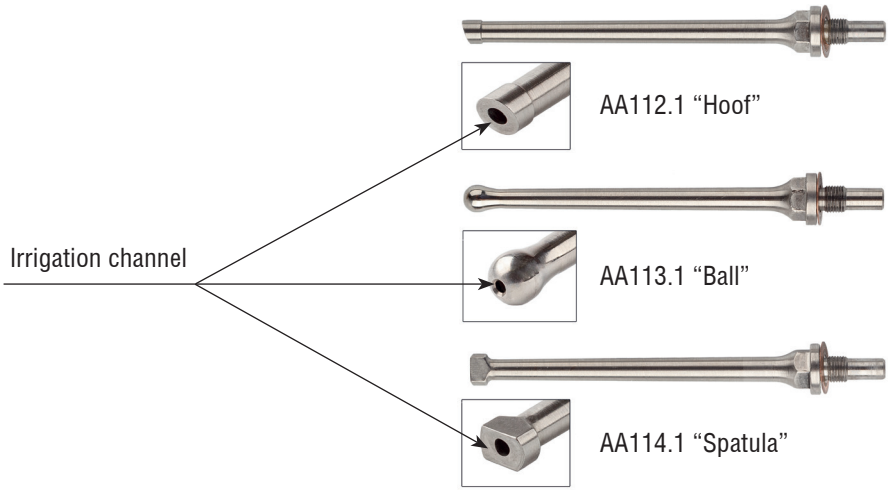


Fig. 14 — Replaceable ultrasonic tips

Replaceable ultrasonic tip with irrigation channel AA112.1 “Hoof” (Fig. 14) is used to treat wounds covered with loose fibrinopurulent deposits. Contact cleansing of the wound is carried out by a flat platform of the tip or its tapered pointed part. Due to an irrigation channel, purulent plaque can be washed out from the wound bed with a jet of cavitated solution. The tip can be used for wound cavities debridement by cavitation bubbling.

Replaceable ultrasonic tip with irrigation channel AA113.1 “Ball” (Fig. 14) is used for the gentle (soft) treatment of cavity wounds, as well as granulating wounds in the 2nd–3rd phase of inflammation. The smooth edges of the “Ball” do not injure granulation. This tip can be used for the gentle (soft) treatment of nooks and cavities.

Replaceable ultrasonic tip with irrigation channel AA114.1 "Spatula" (Fig. 14) is used to affect wounds covered with dense fibrinous plaque. Purulent discharges are removed with the sharp edge of the tip, a hard-to-remove necrotic coating is separated by the supply of the drug solution. (Fig. 15). This tool is better not to use for cavitation bubbling because splatter may form.



Fig. 15 — Purulent wound debridement with the ultrasonic tip "Spatula"

Features of the ultrasonic handpiece AA201.5 work:

- Ultrasonic tips AA112.1, AA113.1, and AA114.1 are attached to the ultrasonic handpiece AA201.5 using a key for fixing ultrasonic replaceable tips AA102 (Fig. 13).
- When connecting the tip to the ultrasonic handpiece, do not twist the threaded connection and do not apply excessive force.
- It is more convenient to connect and disconnect the tip using the handle for ultrasonic handpiece AA116 (Fig. 13), which is installed on the ultrasonic handpiece (Fig. 12).
- If the cavitation of the solution is absent or unstable, it is necessary to tighten the threaded connection between the tip and the ultrasonic handpiece with a key AA102 slightly.
- After the procedure is completed, the ultrasonic tip is unscrewed from the ultrasonic handpiece using the key AA102. The ultrasonic handpiece, tip, key, handle and adapter are disinfected and sterilized disassembled, as shown in Fig. 13. The infusion system, back-check valve, and cover for medical equipment are disposable and must be disposed of.

2.4.2 Ultrasonic handpiece for the deep wound debridement (AA207.5)

An elongated ultrasonic handpiece AA207.5 with an internal irrigation channel completed with a nondetachable ultrasonic tip and a protective cover (Fig. 17).

This handpiece is designed for the purulent wound debridement up to 20 cm deep. The protective cover prevents tissues from accidental contact with an activated ultrasonic tip during blind manipulations in the cavity. The elongated length of the handpiece allows the treatment of deeply located purulent foci. Tissue debridement is achieved by exposing them to a cavitation jet, as well as by cavitation bubbling of the fluid in the wound cavity.

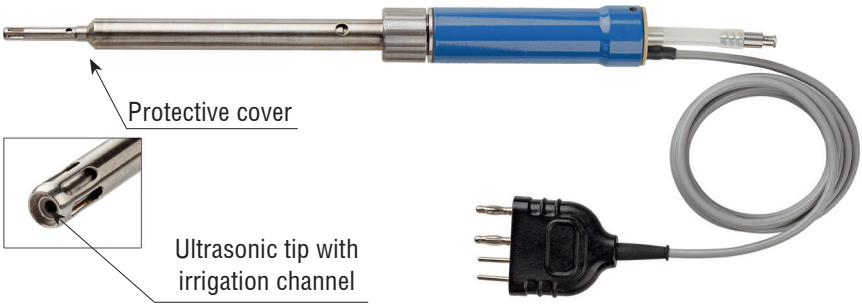


Fig. 16 — Assembled ultrasonic handpiece AA207.5

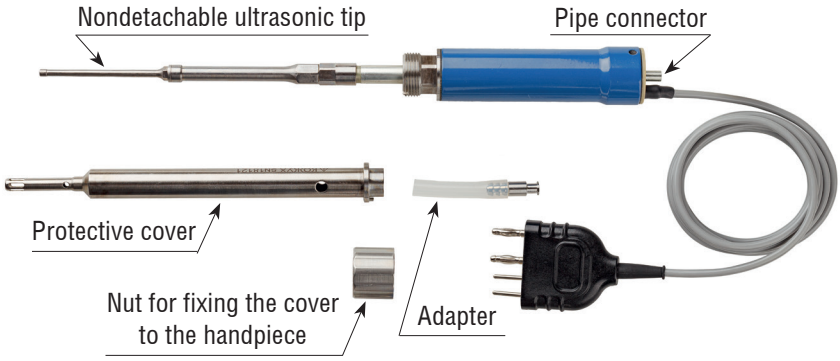


Fig. 17 — Disassembled ultrasonic handpiece AA207.5 with accessories

Features of the ultrasonic handpiece AA207.5 work:

- The ultrasonic tip of the handpiece AA207.5 (Fig. 16, Fig. 17) is nondetachable, do not try to unscrew it.
- The protective cover of the ultrasonic handpiece (Fig. 16, Fig. 17) protects tissues from damage by the activated ultrasonic tip.

- After the procedure is completed, the ultrasonic handpiece is disinfected and sterilized disassembled, as shown in Fig. 17. The infusion system, back-check valve, and cover for medical equipment are disposable and must be disposed of.

2.5 Disinfection and sterilization of the ultrasonic unit and accessories

1. The ultrasonic unit, double-pedal footswitch, and trolley must be chemically disinfected by wiping twice with disinfecting wipes.

2. The suction jar is disinfected by autoclaving for 20 min at 110 °C, pre-sterilization cleaning using its manufacturer's recommended agents. The suction jar can be sterilized by autoclaving for 20 min at 121 °C. Since there is no contact between the jar and the patient's tissues, it is allowed only to disinfect it.

3. The infusion system 8700036SP and back-check valve 4094000N are disposable and must be disposed of.

4. The ultrasonic handpieces and their accessories (adapters, protective covers, replaceable ultrasonic tips, keys for fixing tips, handles), as well as reusable suction nozzles and suction tubings (hereinafter referred to as "the accessories") included in the delivery set, are disinfected, pre-sterilized and sterilized in the disassembled form (Fig. 13, Fig. 17) according to the recommendations below.

WARNING! Do not sterilize the ultrasonic handpiece with hot air ovens.

WARNING! Do not use ultrasonic cleaners.

WARNING! Do not use agents containing hydrogen peroxide for disinfection, pre-sterilization cleaning, and sterilization of accessories.

Disinfection

Disinfection is recommended to be performed using the steam method (autoclaving) for 20 min at 110 °C. If it is not possible to perform the recommended autoclaving method of disinfection, it can be carried out chemical disinfection with agents recommended by their manufactures for medical products made of metal, plastic, and rubber. Chemical disinfection is carried out according to the instruction manual for the cleaning chemical used.



Fig. 18 — A rinse of the channels with a solution using a syringe

For manual disinfection, accessories must be completely immersed in the agent. All accessible irrigation channels must be filled without airlocks. Be sure to rinse the channels with a disinfectant agent from the side of the proximal end using a syringe (Fig. 18) or other devices.

After chemical disinfection, the accessories must be thoroughly washed from the agent. Special attention should be paid to washing the internal channels of the ultrasonic handpiece. Accessory channels are rinsed with a syringe or a water jet pump for 3–5 minutes. The remaining contaminants are thoroughly washed mechanically (with wipes, brushes, ruffs, etc.).

Pre-sterilization cleaning

Pre-sterilization cleaning is carried out manually or by machine according to the instruction manual for the product used. Pre-sterilization cleaning can be combined with disinfection if this is indicated in the instruction manual for the product used.

After pre-sterilization cleaning, the accessories must be thoroughly washed from the agent. Special attention should be paid to washing the internal channels of the ultrasonic handpiece. Accessory channels are rinsed with a syringe or a water jet pump for 3–5 minutes.

Further, the wash water should be removed from the internal channels of the accessories with a syringe or medical balloon inflation device, accessories should be completely dried.

Sterilization

Sterilization is recommended to be performed using the steam method (autoclaving) for 5 min at 134 °C.

If it is not possible to perform the recommended autoclaving method of disinfection, it can be carried out a chemical disinfection with agents recommended by their manufactures for medical products made of metal, plastic, and rubber.

During the manual chemical sterilization, all manipulations must be carried out following aseptic conditions, using sterile water containers, sterile water, instruments, as well as sterile gloves to protect the hands' skin.

Accessories must be completely immersed in the sterilization agent. All accessible irrigation channels must be filled without airlocks. Be sure to rinse the channels with a disinfectant agent from the side of the proximal end using a syringe (Fig. 18) or other devices.

After chemical sterilization, the accessories must be thoroughly washed from the agent. Special attention should be paid to washing the internal channels of the ultrasonic handpiece. Accessory channels are rinsed with a syringe or a water jet pump for 3–5 minutes.

Further, the wash water should be removed from the internal channels of the accessories with a syringe or medical balloon inflation device, accessories should be completely dried.

3 Techniques and results of wound debridement using LFUS

3.1 Indications and contraindications. Medicines. Infectious safety. Anesthesia procedure

Indications for the method:

- purulent-necrotic diseases of:
  - skin and soft tissues (abscesses, phlegmon, bedsores, carbuncles);
  - locomotor apparatus (osteomyelitis);
  - perineum and pararectal space (perirectitis, Fournier gangrene);
  - abdominal cavity and retroperitoneal space (peritonitis, pancreatic necrosis);
  - lungs and pleural cavity (pleural empyema, lung abscess);
- long-term non-healing wounds;
- trophic ulcers of various origins;
- burn wounds and frostbite;
- gunshot and mine explosive wounds;
- SIs.

Relative contraindications to the method:

- allergic reactions to drugs used for processing;
- blood clotting disorder (thrombophilia or hypercoagulation state);
- use of therapeutic doses of anticoagulants by a patient;
- emotional lability of the patient;
- localization of the wound bed near large vessels (arteries and veins).

Ultrasonic debridement should be used with caution if in the wound:

- there are oncological purulent-necrotic processes;
- there are large areas of mature granulation tissue.

Medications recommended for USC:

- 0.9% sodium chloride solution (normal saline solution);
- 0.02% or 0.05% aqueous chlorhexidine gluconate solution;
- 0.1% or 0.2% Lavasept solution (1.0 or 2.0 ml of concentrated Lavasept solution per 1000 ml of 0.9% sodium chloride solution);
- Metronidazole solution, 5.0 mg/mL with 1% Dioxidine solution in proportion of 5:1 (100 ml of Metronidazole solution + 20 ml of Dioxidine solution);
- other antiseptics or antibiotics, diluted in saline solution.

Infectious safety

Infectious safety during the procedure is achieved by complying several requirements:

- procedure is carried out in a treatment room or operating room;
- staff wears medical uniform and footwear;
- to use personal protective equipment (gloves, masks, shields, glasses);
- to use sterile instruments and consumables.

Anesthesia procedure

In the case of large treatment areas (for example, in the abdominal cavity), ultrasonic debridement is carried out in an operating room under general anesthesia.

When treating flesh wounds and shallow purulent cavities, the procedure can be performed in a treatment room. In this case, anesthesia is not necessary, but to reduce the pain of the procedure, it is recommended to add an anesthetic (Novocaine, lidocaine) to the cavitated solution (for example, 2 ml of 2% lidocaine solution per 200 ml of treatment solution). It is also possible to carry out the treatment of the wound with a 10% lidocaine spray for local use or to make applications with a 0.5% Novocaine solution before performing the procedure.

The advantages of wound ultrasonic debridement:

- deep wound disinfection due to the bactericidal action of LFUS;
- minimally invasive wound debridement;
- gentle cleansing of the wound from necrotic tissues and fibrin;
- reduction of wound healing time;
- reduction of hospitalization time;
- the possibility of applying the method both on an inpatient and outpatient basis.

3.2 The use of LFUS in wound debridement of the skin and soft tissues

3.2.1 The technique of low-frequency ultrasonic wound debridement of the skin and soft tissues

Initially, patients undergo surgical purulent wound debridement. Extensive purulent-necrotic processes are dissected, and its purulent foci are sanitized with the removal of purulent-necrotic deposits. Complicated by suppuration, trophic ulcers of the lower extremities are treated surgically with the removal of purulent-necrotic content.

The selection of terms and intervals between the procedures for ultrasonic wound debridement is defined individually and is determined by the condition of the purulent wound, the area of purulent foci, and the condition of the patient. Ultrasonic debridement of the wound can be performed during surgery. In the postoperative period, it can be performed from the 1–3rd day after surgery. If the risk of bleeding is high, treatment should be carried out no earlier than three days later. Ultrasonic debridements can be performed daily or with an interval of 2–3 days until the wound is completely cleansed and active mature granulations appear in it.

The technique for ultrasonic debridement of a purulent wound with the ultrasonic surgery cavitation device "FOTEK":

1. Depending on the type of wound, the ultrasonic handpiece AA201.5 or AA207.5 is used (the description of the handpieces is in the chapter "2.4 Ultrasonic handpieces").

2. The infusion system is connected to the ultrasonic handpiece through the back-check valve. A jet or drip supply of the drug solution inside of the drip chamber is installed.

3. The power level of ultrasonic vibrations is set. Debridement should be started with low power (30–50 units) in the "SELECTIVE" mode. If the procedure is normally tolerated by the patient, you can increase the power level and / or switch to the "BASIC" mode.

4. In the case of contact ultrasonic debridement (Fig. 19), it is not recommended to apply excessive mechanical force, because the tissue of the wound bed can be damaged. The wound is treated both by cavitation and by the mechanical vibrations of the instrument on the tissue. The movement of the working tip should be light and smooth, the ultrasonic handpiece should be held like a pen (Fig. 19). If the wound has cavities, then the ultrasonic debridement is supplemented by the method of cavitation bubbling (Fig. 20).



Fig. 19 — Contact ultrasonic wound debridement

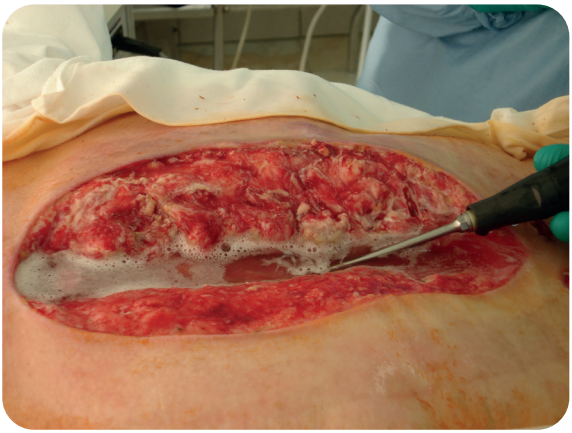


Fig. 20 — Cavitation bubbling of the solution in the wound cavity

5. Areas with granulation tissue should be handled with care. If purulent and fibrinous discharge are located next to granulations, you can aim it with a cavitation jet from a distance of 0.2–0.5 cm in the "BASIC" mode with a vibration level of 50 units or more. A jet supply inside of the drip chamber must be installed. You can also conduct gentle wound debridement in the "SELECTIVE" mode with a vibration level of 50 units or higher.

6. The exposure time is selected individually and depends on the size of the wound bed, the number of purulent deposits, the stage of inflammation, tolerance of treatment by the patient. On average, debridement lasts 5–10 minutes. For convenience, you can use the "TIMER" function. If the "TIMER" function is disabled, then the device turns off automatically every minute for convenience of counting minutes. To resume the operation of the device, you must press the footswitch again.

7. The procedure consumes from 100 to 1000 ml of a drug solution.

8. On average, from 1 to 10 ultrasonic debridements are performed during the treatment period.

Safety instructions

The ultrasonic handpiece contains fragile elements, it should be protected from bumps and falls.

There is a danger of piercing tissue during contact ultrasonic debridement at high power in the "BASIC" mode. Avoid excessive force when using a contact debridement, ensure a jet supply of the solution to the treated area.

During contact ultrasonic debridement of wounds with active marginal and insular epithelization, there is a risk of damage to the newly formed epithelium. In these cases, it is recommended to use non-contact spraying.

There is a risk of damage to nerves, blood vessels, etc. during contact debridement at high power in the "BASIC" mode. This danger is reduced in the "SELECTIVE" mode. In non-contact operation, this danger is minimal.

At low speed of irrigation, the ultrasonic handpiece heats up during the procedure, heating the outflowing solution. It is necessary to monitor the flow of the solution.

3.2.2 Results of ultrasonic debridement

Materials and methods

The results of the treatment of 79 patients with purulent-necrotic soft tissue diseases who were on an outpatient basis were analyzed. The research was carried out in the surgical departments of the Federal Medical-Biological Agency (FMBA) of the Russian Federation from July 2012 to May 2014 [46].

Based on the classification of diseases and treatment methods, all patients were divided into 4 groups: 2 treated with USC — first (24 patients) and second (17 patients) — and 2 control — first (22 patients) and second (16 patients) — groups. Patients in the treatment and the control groups were comparable by sex, age, disease duration, classification of diseases, localization and area of the purulent wound, as well as by the level of soft tissue damage.

The first groups included patients with acute purulent diseases of the soft tissues (abscessed furuncles, abscesses, purulent wounds); the second groups included patients with sequela (purulence) of trophic disturbances due to varicose veins of the lower extremities and chronic venous insufficiency. A comparative analysis was carried out between the treatment and the control groups: only between the first treatment and the first control groups, and between the second treatment and the second control groups.

The initial stage of treatment in all groups was surgery: in the treatment groups — dissection the abscess, debridement of the purulent wound with the removal of necrotic tissues; in the control groups — surgical debridement of wound bed with the removal of necrotic tissues.

In the control groups, standard methods of surgical debridement and conventional local debridement of purulent wounds were used. The local debridement consisted in treating the wound bed with antiseptics (Metronidazole solution, 5.0 mg/mL with 1% Dioxidine solution in the proportion of 5:1) and in the use of ointments following the phase of the wound healing process (in the first phase — Levomekol ointment, in the second phase — Solcoseryl gel, Actovegin ointment).

In the treatment groups, the standard treatment was supplemented by ultrasonic debridement with antiseptic solutions (Metronidazole solution, 5.0 mg/mL with 1% Dioxidine solution in the proportion of 5:1). Ultrasonic debridement was performed

during the surgery, then at the 1st, 3rd, 5th, 7th, etc. day till the complete cleansing of the wound bed or the formation of active mature granulation. For a gentler effect on the tissue, ultrasonic wound debridement began with the "SELECTIVE" mode with a vibration level of 30–50 units. Then the power gradually was increased and the switch to the "BASIC" mode (50 units or more) was made. The total processing time was 5–12 minutes.

For patients with acute purulent diseases of the soft tissues, treatment is supplemented by systemic antibiotic therapy according to indications. Patients with varicose veins used compression hosiery and venotonics.

Evaluation of treatment results

To assess the effectiveness of the treatment of all patients, there were used clinical, planimetric, cytological, and histological methods.

For all patients, the general body temperature reaction was measured, and the course of the wound process was laboratory-evaluated. There were no significant differences in the patients' body temperature.

The study and analysis of the leukocyte dynamics, the neutrophils count, ESR in the clinical analysis of blood in patients showed that there were no significant differences in the groups. This is most likely due to the localization of the foci and early seeking medical care.

There were clinically evaluated: the timing of pain relief, regression of local inflammation, exudation in the purulent foci, cleansing of the wound bed from the purulent coating, necrotic tissues, and fibrin.

The period of the granulation formation, marginal epithelialization and wound healing (in the first groups), or reduction of the wound area by 50% (in the second groups) were also clinically studied.

Patients evaluated their pain using a verbal rating scale (VRS) of five points (Frank A.J.M., Moll J.M.H., Hort J.F., 1982).

The following indicators were analyzed.

Pain syndrome's dynamics. The first groups: treatment group did not have pain by the 9th day patients; in the control group — pain remained in 11.7% of patients by the 11th day. The second groups: treatment group did not have pain by the 13th day; in the control group — pain remained in 31.2% by the 13th day and in 12.5% of patients by the 15th day.

Perifocal edema. The first groups: In the treatment group it was completely resolved by the 9th day; in the control group it remained in 29.4% of patients by the 9th day. The second groups: in the treatment group it was not observed by the 13th day; in the control group it remained in 50% of patients by the 13th day, and in 31.2% of patients by the 15th day.

Hyperemia in the wound area. The first groups: in the treatment group it was not observed by the 11th day; in the control group it remained in 29.4% of patients by the 11th day. The second groups: in the treatment group there were no patients with hyperemia by the 15th day; in the control group it remained in 18.7% by the 15th day.

Complete cleansing of the wound from necrotic tissue. The first and second treatment groups: it was reached by the 7th day. The first and second control groups: it was reached by 11th day.

The removal of fibrin clots. The first groups: in the treatment group — by the 9th day; in the control group it remained up to 11 days in 11.7% of patients. The second groups: in the treatment group— by the 9th day; in the control group it remained on the 9th day in 18.7% of patients.

The reveal of fine-grained granulation tissue. The first groups: in the treatment group — by the 4.6 ± 0.5th day; in the control group — by the 8.2 ± 1.1th day. The second groups: in the treatment group — by the 8.66 ± 0.7th day; in the control group: only by the 11.4 ± 1.4th day.

The average time of marginal epithelization formation. The first groups: in the treatment group it takes 4.7 ± 0.4 days; in the control group it takes 8.6 ± 1.1 days. The second groups: in the treatment group it takes 11.16 ± 1.2 days; in the second control group it takes 14.6 ± 2 days. Thus, the ultrasonic debridement led to a reduction in the wound size by 50% of the initial area 1.3 times faster than in the second control group.

All patients underwent a cytological examination of wounds by the Pap test. The dynamics of the inflammatory process in the wound were assessed with cytogram by determining the cellular composition, including neutrophilic granulocytes, histiocytes, lymphocytes, eosinophils, and tissue elements — fibroblast cells and fibrocytes, as well as by the intensity of the inflammation.

The regression of the inflammation occurs 1.8 times faster under the influence of ultrasonic debridement, the regression of the neutrophils count is 2.2 times faster, the increase in the number of cells with protective and phagocytic mechanisms (histiocytes, lymphocytes, eosinophils) is 2.37–3.71 times faster, that demonstrates more active anti-inflammatory effect of cavitation compared to the conventional method. The dynamics of reparative and regenerative processes in the wound is indicated by the fibroblasts and fibrocytes count, the increase of which occurs 1.6 times faster under the influence of LFUS rather than under the conventional method.

According to the results of histologic examination of biopsies, which were obtained on the 5th and 9th day after surgical debridement, the segmented neutrophils, lymphocytes and histiocytes, plasmocytes, macrophages, fibroblasts, and neoplasms count was determined.

Regression of neutrophil infiltration in the edges of purulent wounds occurs 2–2.3 times more actively under the influence of ultrasonic debridement than under conventional treatment. In the first phase of the inflammatory process the growth of histiocytes and lymphocytes (total) count occurred faster 2 times, the plasmocytes count — faster 2.3–2.6 times, the macrophages count — faster 2.3–2.8 times, which confirms the more active process of resolving inflammation. Acceleration of repair processes in the wound is confirmed by the fibroblasts count in the tissues, the growth of which is determined by 2.16–2.5 times more under the influence of cavitation than with conventional treatment. Active repair is also provided by more active growth of blood vessels in tissues — 2.4 times faster in the treatment groups.

In Fig. 21 it is shown the dynamics of the shin wound healing through ultrasonic debridement. Fig. 21, a — the wound on the 5th day after the initial surgical debridement (after 4 ultrasonic debridements) — it contains necrotic tissue, purulent discharge, fibrin; the presence of granulation tissue is noted. By the 9th day, the wound had completely cleared of purulent discharge and necrotic tissue (Fig. 21, b), active granulations appeared. During debridement, active wound epithelization was noted. Within 16 days, the area of the wound decreased 3.3 times (Fig. 21, c). On average, the area of the wound was decreasing by 4.1% per day.

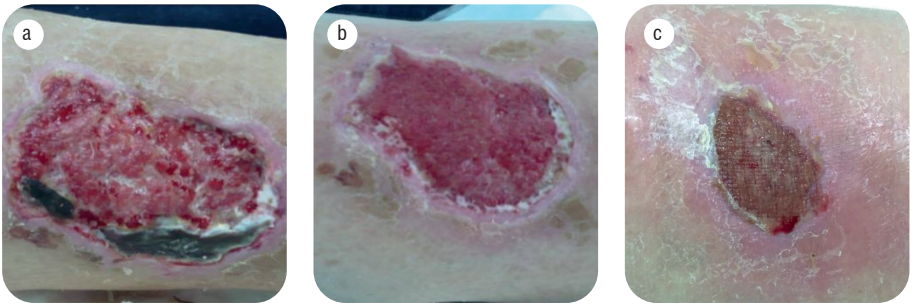


Fig. 21 — Dynamics of the shin wound healing:
a — the 5th day after the initial surgical debridement (after 4 ultrasonic debridements);
b — the 9th day after the initial surgical debridement (after 5 ultrasonic debridements);
c — the 16th day after the initial surgical debridement

In Fig. 22 it is shown the trophic defect of the ankle before ultrasonic debridement (Fig. 22, a) and right after it (Fig. 22, b). Pictures were taken on the 5th day from the start of ultrasonic debridement. It can be noted that after 6 minutes of active debridement, the wound defect is completely cleansed of the purulent discharge and fibrin. By the 5th day there is practically no hyperemia in the surrounding tissues, moderately expressed peripheral edema remains, granulation appears.

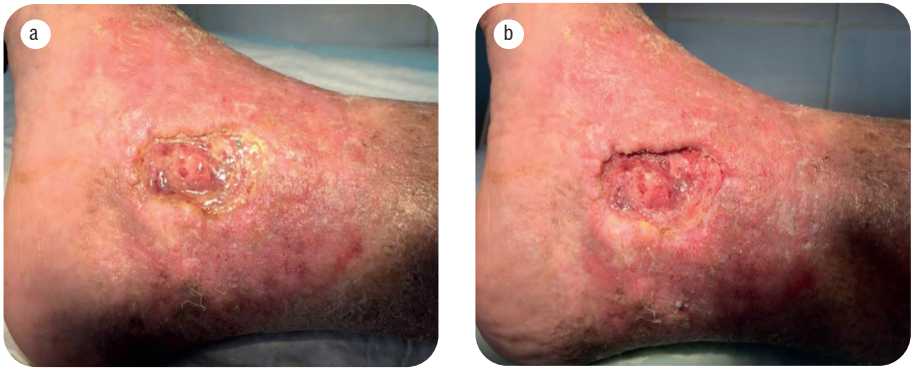


Fig. 22 — Trophic purulent ulcer of the ankle:
a — before ultrasonic debridement;
b — right after ultrasonic debridement

Conclusions

The use of ultrasonic debridement for the healing of purulent-necrotic soft tissue diseases reduces the treatment time by an average 1.5 times, accelerates the resolution of the inflammatory process in wounds by 1.6–1.8 times faster; activates the repair process in the wound. The application of this method provides high treatment efficiency due to the possibility of combined use of antiseptic drugs and LFUS with mechanical wound cleansing.

The method is easy to use. It does not require long preparation and provides intensive cleaning of the purulent foci.

3.3.3. Case reports

Case 1

K., 34-year-old man, was treated in the surgical departments of the Federal Medical-Biological Agency (FMBA) of the Russian Federation with diagnosis: persistent foot wound.

The wound was formed after a heavy object fell on the foot. Before hospitalizing, the patient was treated on an outpatient basis for 1.5 months with ointment and solution of Betadine. Dressings were changed 2–3 times per week.

On the day of hospitalization, a wound with purulent-necrotic tissues and fibrin was observed on the bridge of the foot between the 2 and the 4 metatarsal bones (Fig. 23). Hyperemia, edema, infiltration, pain during walking indicated intense inflammation in the surrounding tissues.

The initial surgical debridement of the purulent foci was performed (partial removal of devitalized tissue and purulence), after which the wound was treated with ultrasonic

debridement. The ultrasonic handpiece AA201.5 was used with the “Hoof” tip AA112.1. The drug solutions (Metronidazole solution, 5.0 mg/mL with 1% Dioxidine solution in the proportion of 5:1) were supplied with a drip supply of 3–4 drops per sec inside of the drip chamber. The exposure on the wound was made in the “SELECTIVE” mode with a vibration level of 50 units.



Fig. 23 — Purulent wound of the foot on the day of hospitalization

The tip was located at 0.5 cm above the wound bed and within 30 seconds gradually approached it until full contact. No pain was observed during debridement. In this mode, the effect on the wound was continued for 2 minutes with the mechanical removal of fibrin and purulent-necrotic tissue. Further, debridement implemented in the “BASIC” mode (at 50 units) with a gradual increase in the vibration level by 10 units every minute to 70 units with a jet supply of solution. For the procedure, 180 ml of solution was spent.

USC wound debridement was applied on the hospitalization day, on the 1st, 3rd, 5th, 7th, 9th, and 11th days after it. Thus, 7 procedures were performed.

By the 1st day after the initial wound debridement with the USC, no necrotic tissue was found in the wound, purulent and fibrin remained. After the 4th procedure, there were signs of a decrease in purulent and fibrinous deposits in the wound, the formation of immature granulation tissue (Fig. 24).

From the 5th debridement (the 7th day of hospitalization), the ultrasonic handpiece with the tip was installed at 0.2–0.5 cm from the wound bed due to the formation of granulation tissue. The t debridement implemented in the “BASIC” mode at 70 units with a jet supply of solution.



Fig. 24 — Purulent would after the 4th debridement

By the 11th day, edema, infiltration, hyperemia at the edges of the wound decreased significantly. Active mature granulations in the wound, active marginal epithelization (Fig. 25) appeared. The course of application of LFUS was over.



Fig. 25 — Purulent would after the 7th debridement

The wound was treated with Solcoseryl ointment and Actovegin ointment every 2 days within 7 days. Active epithelization at the edges was noticed. The wound was filled with active mature granulation tissue by the 18th day (Fig. 26).



Fig. 26 — Purulent would on the 18th day after surgical debridement

Complete epithelization, wound healing were noted on the 27th day from the initial wound debridement of the patient.

The clinical picture was confirmed by cytologic examination of smears from the surface of the wound: by the 3rd day, there was a decrease in the severity of the leukocyte reaction, a decrease in the neutrophils count, an increase of histiocytes, lymphocytes in the cellular composition. Results of the cytologic examination indicated an active process of cleansing the wound, and a decrease in the inflammatory process in the wound by the 3rd day. By the 5th day, there was an increase in the fibroblasts and the fibrocytes counts, which reflected an active regenerative process in the wound.

Case 2

S., 61-year-old man, applied to the Municipal Budgetary Institution "Central City Hospital No.7", Ekaterinburg, Russia on July 28, 2013.

The patient's left thigh was sore and swollen. He mentioned general weakness, malaise, fever up to 39.5 °C.

According to the patient, from 07.21.2013 to 07.23.2013, he was treated in the surgical department of the district hospital of the Sverdlovsk region, Ekaterinburg, Russia with a diagnosis: Infected intermuscular hematoma of the left thigh. 07.21.2013, an excision of the thigh hematoma was performed. After 3 days, the patient refused inpatient treatment. He also was not observed on an outpatient basis by the surgeon. The patient applied dressings with Levomekol ointment on his own. On 07.24.2013, he noticed chills and pain in the wound. The pain intensified, swelling of the thigh increased, body temperature

increased to 39.5 °C.

Upon admission, the patient was critically ill. The skin and mucous membranes were pale pink, dry. The body temperature was 38.0 °C. The breathing was rhythmic, respiratory rate was 19 breaths per minute. The heart rate was 88 beats per minute, the level of blood pressure was 110/70 mm RT. Art. The tongue was dry. The abdomen was soft, painless.

At the examination along the posterior surface of the left thigh, the infiltrate 60×30 cm in size was detected. In the middle part of the infiltrate, the wound was 8×2×4 cm in size with copious purulent hemorrhagic discharge. Along the perimeter of the wound, there was a skin necrosis 30×20 cm in size. The palpation of the infiltrate was sharply painful. Diagnosis: necrotic fasciomyositis of the left gluteal region, left thigh, and shin with wound sepsis.

After a short preoperative assessment, the patient was taken to the operating room. During the operation, an excision of the purulent foci and necrotomy ware performed. The purulent-necrotic process spread into the intermuscular spaces. The superficial fascia with the underlying muscles was necrotic. Surgical removal of necrotic areas was performed. As a result, a skin-fascial defect measuring 35×20 cm was formed (Fig. 27).



Fig. 27 — Wound on the 1st day after surgical debridement (before the 1st ultrasonic debridement)

After the operation, an antibacterial, detoxification, anti-inflammatory, anticoagulant therapy was carried out.

From the 1st days after the surgical debridement, the method of ultrasonic debridement was used. During the ultrasonic wound debridement, contact and non-contact debridement of the wound was performed using the ultrasonic handpiece AA201.5 and tips “Hoof” AA112.1 and “Spatula” AA114.1 on the visible wound bed, as well as the ultrasonic handpiece AA207.5 during the processing of intermuscular cavities. Dressings using USC were performed daily up to 10 days after surgery, then every other

day. The level and mode of exposure were selected following the phases of the wound healing process. In the first phase, for fast wound cleansing, the debridement was carried out in the “BASIC” mode with a vibration level of 60–70 units. In the second phase of the wound healing process, the “BASIC” mode was also used. In the third phase, the “SELECTIVE” mode at 30–40 units was implemented.

The average duration of the ultrasonic debridement procedure was 6–10 minutes. An aqueous solution of 0.05% chlorhexidine was supplied. The average volume of spent antiseptic per procedure was 500–700 ml. After debridement, the wound defect was covered up with a gauze pad with put hydrophilic ointment on it.

Before the contact ultrasonic wound debridement, applications of 0.5% Novocaine solution were used for 3–5 minutes, which allowed reducing pain during dressing.

From the 1–4th days after the surgical operation, the contact debridement with the “Spatula” AA114.1 tip was used. This processing method allowed removing fibrin plaque and necrotic tissue effectively. After USC, a decrease in wound exudation, fast cleansing, and early formation of granulation tissue were noted (Fig. 28).



Fig. 28 — Wound on the 4th day of ultrasonic debridement

From the 5–10th day, wounds were treated using the “Hoof” AA112.1 tip. This type of tip was used for non-contact wound debridement, as well as for local exposure to necrotic tissue sites. During this period, USC accelerated reparative processes, allowed to remove necrosis with minimal trauma to granulation tissue (Fig. 29).



Fig. 29 — Wound on the 11th day of ultrasonic debridement

From the 10–14th days, non-contact wound debridement was carried out in the "BASIC" mode. During this period, filling of wounds with granulation tissue, adhesion of intermuscular "pockets" and edge epithelization were noted.

On the 16th day, the patient was discharged from the hospital with an actively granulating wound (Fig. 30).



Fig. 30 — Wound on the 16th day of ultrasonic debridement

Two months later, the patient was rehospitalized to close the skin defect (Fig. 31).



Fig. 31 — Wound before autodermoplasty

On the day of hospitalization and the day before the operation, the patient underwent non-contact ultrasonic wound debridement.

Autodermoplasty with a split perforated skin flap was performed. On the 7th day after autodermoplasty, the patient was discharged for outpatient treatment. The wound 1 year after autodermoplasty is shown in Fig. 32.



Fig. 32 — 1 year after autodermoplasty

Conclusions

The use of low-frequency ultrasonic debridement of the wound with ultrasonic surgery cavitation device “FOTEK” increases the effectiveness of treatment by normalizing the wound process, reducing exudation, accelerating the mature granulation tissue, the formation of early epithelization, that reduce the preparation period of wounds for closure, as well as the patient’s hospitalization.

Conclusion

Ultrasonic exposure due to its physical and biological effects allows gentle and complete debridement of SI foci. Laboratory studies and clinical testing of the method proved that, in comparison with conventional methods of local exposure, LFUS stops inflammation in a shorter time, accelerates the process of cleansing from purulent-necrotic deposits, contributes to a significant reduction in microbial contamination of the wound bed and improves microcirculation in the inflammatory foci.

The use of LFUS in the complex treatment of SIs can reduce the average length of stay in a hospital, the cost of their treatment, the number of undesirable complications.

The described technology for SI treatment is less traumatic, technically simple, has no specific complications, and can be used by surgeons both on an inpatient and an outpatient basis. The experience, presented in the guidelines, allows us to recommend the method of ultrasonic debridement for wide application in the treatment of SIs, burns, diabetic foot syndrome, vascular surgery, etc.

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Equipment for electrosurgery, argon plasma ablation and low-frequency ultrasonic wound debridement

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