WELDING, CUTTING AND HEAT TREATMENT OF LIVE TISSUES

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The paper presents the results of E.O. Paton Electric Welding Institute investigations and developments in the field of high-frequency welding and related technologies for joining, coagulation, cutting and heat treatment of live tissues, and also deals with the questions of development of specialized equipment and instruments for realization of the above processes. Experience of application of developed technologies and equipment in surgical practice is described, which is indicative of the high demands for them — at present more than 150 different surgical procedures have been mastered and more than 100 thous. surgical operations have been successfully performed in the most diverse surgical fields. Data are given on the features of live tissues restructuring and welded joint formation under the impact of high-frequency current passing through them. Derived experimental and clinical data were used to demonstrate the ability of tissue subjected to the impact of high-frequency welding, to maintain its viability, and restore its physiological properties and functions through regeneration processes. The paper presents the materials of studying the process of high-frequency welding of soft biological tissues with automatic regulation, ensuring guaranteed formation of welded joint in a broad range of properties of tissues being welded. Considered are the prospects for further development of technologies and equipment for high-frequency welding and heat treatment of live tissues, both due to further expansion of surgical applications, and due to development of new multifunctional apparatuses, combining the processes of high-frequency welding and convection-infrared treatment of live tissues, in particular self-sufficient mobile systems. 39 Ref., 17 Figures.

Keywords: *high-frequency welding, coagulation, cutting, hyperthermal treatment, live biological tissues, surgery, electrosurgical instruments*

In addition to the traditional application fields, such as joining and treatment of structural and functional materials, welding and related technologies are becoming ever wider applied in medicine. Therefore, utilization of capabilities provided by the new technologies of welding and treatment of various materials (in particular, biological tissues) for improvement of man's health, as well as his environment, now is one of priority avenues of research of the E.O. Paton Electric Welding Institute. At present these technologies include:

- high-frequency welding of live tissues for joining and recovery of vital functions of human and animal organs;
- hyperthermic processes of welding, cutting and treatment of live biological tissues;
- application of shape memory materials for manufacture of implants, prostheses and special surgical instruments;
- microplasma spraying of bioceramic coatings on endoprostheses;
- technology of electron beam physical vapour-phase deposition of composite nanomaterials for targeted delivery and enhancing the impact of medicines in a living organism;
- steam-plasma technologies for disposal of medical wastes.

In this paper we will describe the first two technologies and will consider the results of research and development of equipment and processes of high-frequency welding, as well as related technologies for joining, cutting, coagulation and treatment of soft biological tissues, performed at the E.O. Paton Electric Welding Institute (PWI) over the last years.

High-frequency welding of live tissues. History of electrosurgery is usually associated with discovery of thermal properties of electricity at the start of XVIIIth century, as well as Becquerel's invention of cauterodyne, the wire end of which was heated with subsequent cauterization of tissues.

The first evidence of application of high-frequency electrocoagulation equipment in medicine is associated with the names d'Arsonval, Tesla, Cushing, Bovie, dating back more than 100 years now. Apparatuses allowing destruction of tumours, removing damaged tissues, coagulating wound surfaces, etc., have been manufactured and improved for many years. At present numerous high-frequency electrosurgical apparatuses are available in the world market, which are produced by such leading manufacturers as Valleylab, a division of Covidien (USA), Ethicon, a division of Johnson&Johnson (USA), KLS Martin Group and ERBE (Germany), etc. [1–4]. Similar apparatuses are also manufactured in Ukraine, for instance, by ZAO «NII Prikladnoj elektroniki» (Kiev) [5]. However, problems of making reliable joints of live biological tissues and recovering the vital functions of human and animal organs by electrosurgery processes could only be solved in recent years with application of high-frequency welding technology. Welding of live tissues became a priority in cooperation of PWI specialists with a number of medical institutions of Ukraine, started already at the beginning of the 90ties of the previous century.

Process of high-frequency live tissue welding (HF LTW) developed at the E.O. Paton Electric Welding Institute in close cooperation with International Association «Welding», CSMG Company, USA and leading medical institutions of Ukraine, demonstrated its effectiveness and has been applied with success in medical practice for more than 10 years.

During this time more than 150 surgical procedures have been mastered and more than 100 thous. surgical operations have been successfully performed in such fields as general and abdominal surgery, traumatology, pulmonology, proctology, urology, mammology, otorhinolaryngology, gynaecology, ophthalmology, etc. In the opinion of the surgeons [6], this process is highly promising at transplantation of various organs. At present, 15 to 20 thous. operations are annually performed in Ukraine, by our estimates, using the apparatuses developed by PWI. The indisputable leader here is Donetsk Antitumour Center (headed by G.V. Bondar) [7].

Application of advanced equipment and technology is highly promising in veterinary medicine, both for surgical treatment and handling of domestic and wild animals (tumour removal, castration, etc.) and for sanitization of cities (sterilization of stray animals) [8].

HF LTW process ensures:

- bloodless, fast performance of operative interventions, convenient for the surgeon and low-traumatic for the patient, reliable hemostasis;
- lowering blood losses by more than 50 %;
- shortening operation time by 20–50 %;
- high ablasticity of operation performance;
- no suppurations;
- fast and complete postoperative rehabilitation;
- possibility of surgical treatment of patients earlier regarded as inoperable.

HF LTW advantages have been confirmed by numerous references of leading surgeons, and were noted more than once in the papers presented in conferences on live tissues welding, conducted at PWI on a regular basis [9–11].

For further intensification of work in the field of electric welding of live tissues and in keeping with the joint decision of Chief Administration of Health Care and Medical Provision of Kiev City Administration, National Academy of Sciences of Ukraine, National Academy of Medical Sciences of Ukraine and P.L. Shupik National Medical Academy of Post-Diploma Education, Kiev City Medical Training-Innovative Center of Electric Welding Surgery and New Surgical Technologies (headed by S.E. Podpryatov) [12] was established in 2011 at Kiev City Clinical Hospital No.1 [12].

Area of application of HF LTW apparatuses of PWI design (more than 150) covers practically all the regions of Ukraine, as well as some former CIS and foreign countries. Apparatuses are applied in the Russian Federation and Bulgaria, and the first batch of apparatuses was supplied to China. Such countries as USA, India, Vietnam, Poland, Macedonia, Baltic countries, etc. show interest in these developments.

Over the recent years, Western manufacturers began to use «welding» term in the list of functional capabilities of their equipment [13]. It should, however, be noted that this function pertains mainly to the procedure of vessel closing, and that Ukraine is the indubitable leader as to the number and diversity of surgical procedures with high-frequency welding application [14].

Appropriate equipment and instruments are the practical basis for realization of HF LTW process, as of any other technology. Starting with the first apparatuses, developed as far back as in the middle of the 90ties of the previous century, to date PWI has developed a wide range of specialized apparatuses [15].

At present PWI manufactures and sells EK-300M1 apparatuses of various modifications (earlier developments) and new EKVZ-300 «PATONMED» apparatus (Figure 1) [16].

All-purpose EKVZ-300 apparatus has passed clinical tests and state registration and is applied with success in surgical practice in more than 20 medical institutions of Ukraine. These apparatuses have been supplied to China for evaluation and demonstration of the new process that will be the basis for joint manufacturing of these apparatuses both for the Chinese market, and for markets of other countries.

Figure 1. All-purpose apparatus for live tissue welding EKVZ-300 («PATONMED»)

At development of EKVZ-300 apparatus, experience accumulated during operation of earlier developed equipment has been collected, and recommendations and proposals of surgeons of various specialties were taken into account as far as possible. EKVZ-300 supports operation in the following modes: cutting, coagulation and automatic welding. There is the capability of selection of various working algorithms, and working parameters of the process, depending on the kinds of operations and surgeons' requirements. Adaptation, modification and entering of additional programs can be performed by user preference. Apparatus operates in two working frequencies of 66 and 440 kHz with controlled power. Simultaneous connection of two instruments at surgeon's choice is envisaged. Apparatus is fitted with a basic set of electrosurgical instruments (pincers and forceps). Fitting with additional instruments for open and laparoscopic surgery can be performed.

This apparatus can operate with all the instruments for HF LTW, developed at PWI to date. It has been successfully tested during operation performance in various surgical fields, including general abdominal operations, pulmonology, urology, mammology, ophthalmology, etc. Operations with welding (closing) of vessels, resection of the lungs and liver, removal of kidney, intestinal anastomosis, and many other operations are performed.

Production, which allows both completely satisfying the needs of Ukraine in this type of equipment and exporting it, was set up at Science-Technology Complex (STC) «E.O. Paton Electric Welding Institute» (Figure 2).

Further development of equipment for live tissue welding, consisting of the apparatus proper (electronic module) and respective instruments with connecting cables, is associated, primarily, with improvement of the apparatuses proper, increasing their reliability, ergonomic characteristics, ease of operation and maintenance, and adaptation to surgeons' needs. At this stage, development of a new software product is required, which would be oriented to individual surgical procedures and user needs, as well as new systems of automatic control of the process. It is also necessary to develop a new specialized equipment for individual surgical fields (ophthalmology, cardiovascular surgery, neurosurgery, etc.) [15].

In addition, development of mobile systems designed for self-sufficient operation (ambulance stations, air medical service, disaster medicine, etc.) is urgently required. New EKVZ-300M (Figure 3, *a*) and EKVZ-300MDU (Figure 3, *b*) apparatuses, developed on the basis of EKVZ-300, can be the prototype of such equipment [15].

Appropriate instruments are not less important for HF LTW. To date many types of electric welding surgical instruments, mainly basic ones, have been developed and are manufactured through cooperation (Figure 4). Various type instruments for laparoscopic surgery are ever wider used (Figure 5).

In addition to basic instruments, various types of specialized instruments are applied in practice. Numerous instruments developed for the needs of otolaryngology can be mentioned as an example (Figure 6) [17].

Unfortunately, it should be noted that despite certain success, development and manufacture of new instruments of the required range and in the needed volume still do not satisfy the existing demand.

Simultaneously with equipment development, PWI, in close contact with leading medical and scientific-technical establishments of Ukraine and other countries, is performing ongoing research of behaviour of various types of live tissues at application of high-frequency currents to

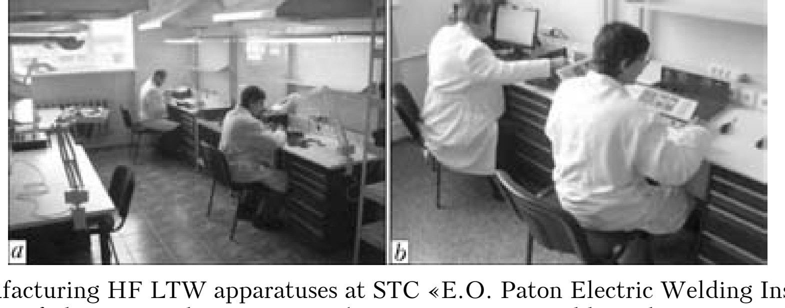

Figure 2. Area for manufacturing HF LTW apparatuses at STC «E.O. Paton Electric Welding Institute»: *a* — incoming inspection and setting-up of elements and components; *b* — apparatus assembly and programming

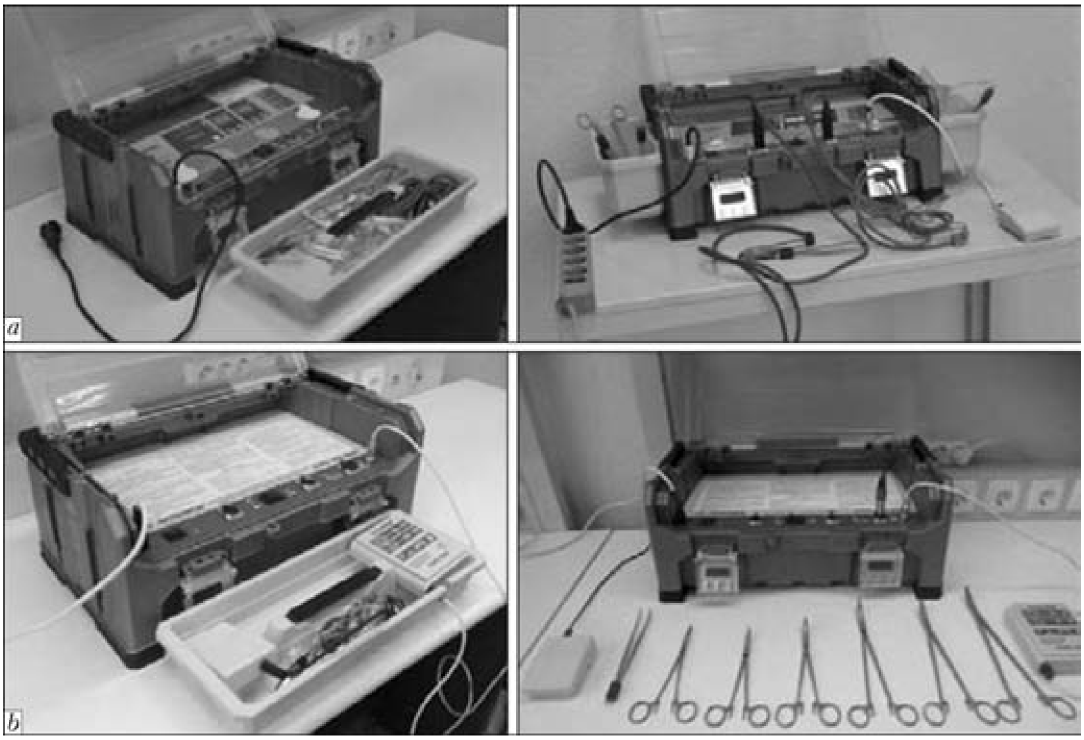

Figure 3. All-purpose mobile HF LTW apparatuses with built-in (*a*) and remote (*b*) control panel

Figure 4. Basic instruments for HF LTW: bipolar electrosurgical forceps (*a*) and pincers (*b*)

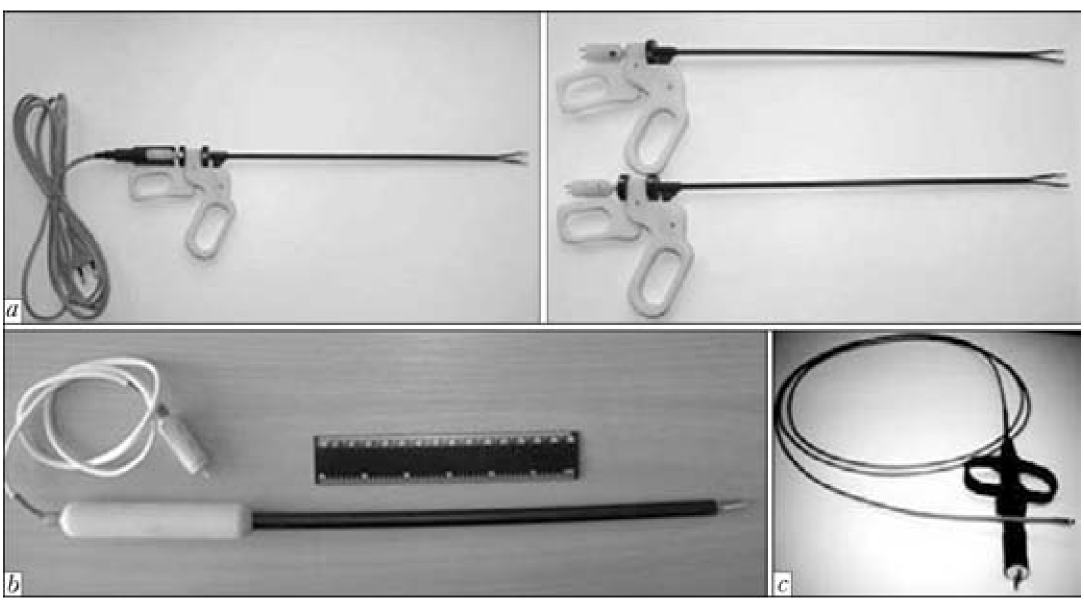

Figure 5. Bipolar laparoscopic forceps (*a*), «spoon» type probe (*b*) and flexible endoscopic instrument (*c*)

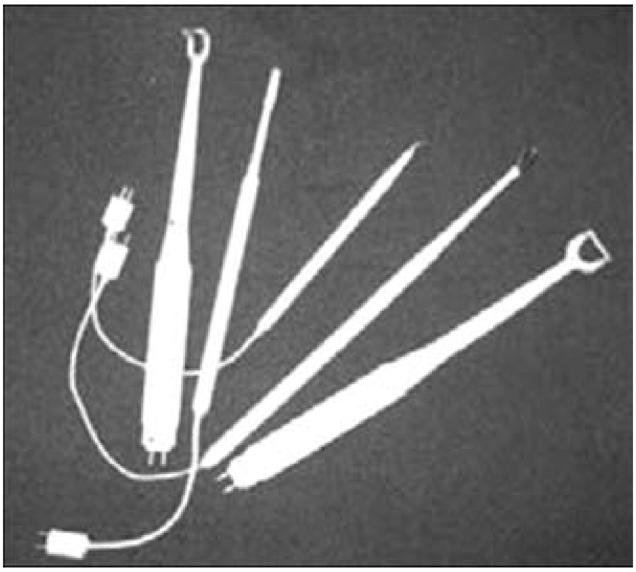

Figure 6. Instruments for HF LTW in otolaryngology

them, development of new operating algorithms for equipment on the base of research data and elaboration of new surgical procedures.

As a result of investigations conducted in cooperation with Kiev Center of Electric Welding Surgery (S.E. Podpryatov and S.G. Gichka) features of restructuring of live tissues and formation of welded joint under the impact of high-frequency current passing through them have been established for the first time [18]. The following phases of tissue restructurizing have been determined:

• separation of current-conducting structures (proteins or their complexes in the composition of collagen and muscular fibres, tissue membranes and intracellular organellas) from non-current-conducting ones (fats, glycosaminoglycans both in intertissue space and inside the cell);

• re-orientation of current-conducting structures along the current path, and of non-current-conducting ones — across the path;

• formation of fissures between current-conducting structures simultaneously with development of their undulation;

• drawing together of current-conducting structures and their coalescence with each other with formation of a homogeneous mass, which is the seam made by electric welding.

Figure 7 shows as an example, the structural changes occurring in the artery wall at its closing.

Investigation of the influence of high-frequency electrosurgical welding on the structures of various biological tissues by the method of X-ray diffraction using synchrotron radiation has been conducted in cooperation with Russian organizations: Institute of Theoretical and Experimental Biophysics of RAS and Institute of Cell Biophysics of RAS (Pushchino), as well as NITs «Kurchatov Institute» (Moscow). Derived experimental and clinical data were the basis to demonstrate the ability of the tissue exposed to the impact of HF-welding, to maintain its viability, recovering physiological properties and functions due to regeneration processes.

Operating modes of electric welding impact in the physiological range, optimized during many years of clinical practice, allowed recording the following structural changes on the molecular and nanostructural level. It is shown that in HF-welding more labile globular proteins undergo thermal denaturation: temperature increase causes structural transition of «globula-glomus» type, resulting in formation of a gluelike substance. Gluing method is widely applied in surgery. For this purpose specialized medical glues or protein preparations are used to cover the sites of joining the damaged structures, as, for instance, albumin at laser coagulation. The advantage of HF LTW (Figure 8) consists in that it is possible to avoid the presence of foreign material and problems associated with immune incompatibility.

Over the recent years PWI has conducted investigations of the process of high-frequency welding of soft biological tissues as an object of automatic regulation. Numerous experiments

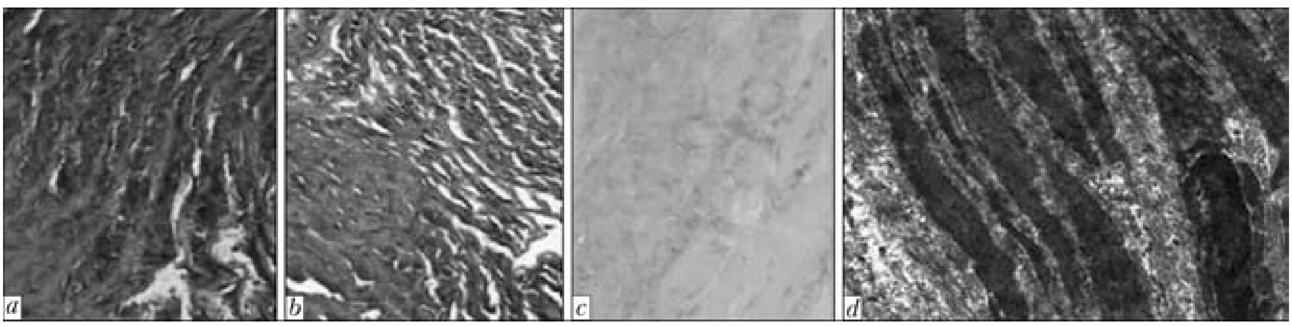

Figure 7. Structural changes occurring in artery wall at its closing: *a* — re-orientation of current-conducting structures along the direction of current passage; and of non-current-conducting ones — across current direction; *b* — formation of fissures and undulations; *c*, *d* — drawing together and coalescence of current-conducting structures with formation of a uniform mass — the welded joint

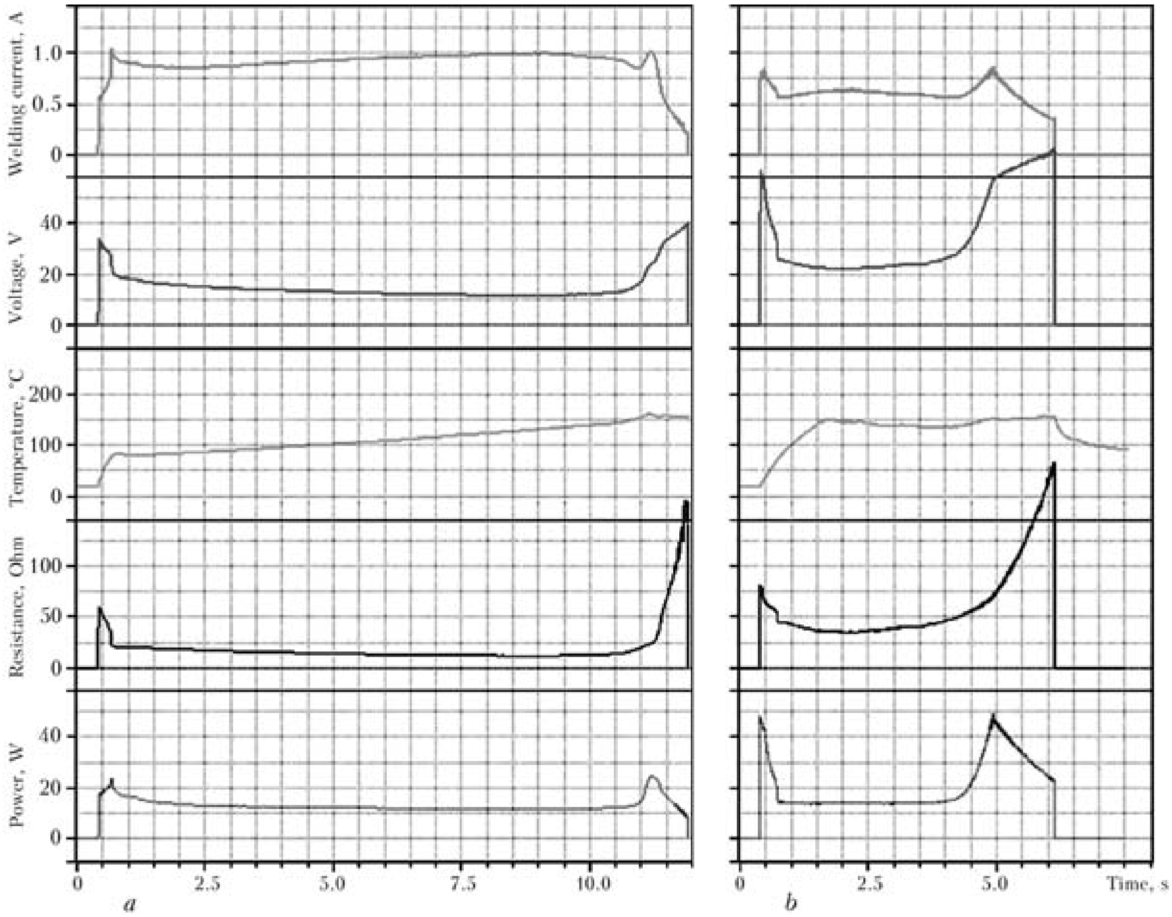

Figure 8. Oscillograms of average values of welding current and voltage, temperature in welded joint center, electrical resistance of tissue between the electrodes, power evolved in the tissue being welded: *a* — intestine; *b* — muscular tissue

were performed with recording and computer processing of electrical and physical parameters of HF LTW process. It is shown that at passage of electric current through the tissue between the electrodes, tissue temperature in welded joint center increases rapidly up to the temperature of protein coagulation and cell denaturation (60 °C), while tissue electric resistance drops 2.5–3 times. Then the temperature gradually rises up to 150–180 °C.

Tissue dehydration takes place with increase of its resistance. As a result, the fields of electric resistance, electric current and temperature become non-uniform. Current flows predominantly through sections with lower resistance at the given moment. When all the tissue between the electrodes is completely dehydrated, its integral resistance rises abruptly, that is the indication of reliably formed spot weld and signal to stop welding. Further heating will only lead to undesirable tissue carbonization.

Proceeding from the derived concepts of physical processes running in welding, a mathematical model was developed of welding soft biological tissues. Physical and the corresponding electrical parameters were determined, which characterize the end of formation of a sound welded joint. In keeping with this model, an algorithm was developed for automatic regulation of the welding process, providing guaranteed formation of a welded joint in a broad range of variation of welded tissue properties.

A fundamentally new welding apparatus was developed, which implements this algorithm. Welding mode parameters in it are set and maintained automatically by the results of identification by the system of tissue type, its state, etc. The surgeon can, at his choice, set the intensity of the welding mode — «stringent» or «soft».

These and other studies were the basis for development of new operating algorithms for live tissue welding apparatuses, one of which is schematically represented in Figure 9. Application of the proposed algorithm allows achieving an optimum impact of HF current on the tissue being operated on, that eventually enables making a high-quality joint [20]. Specific parameters are assigned proceeding from specific conditions of performance of surgical interventions.

The following can be noted as a concrete result of application of new operating algorithms. Closing of up to 8 mm arteries and up to 11 mm veins

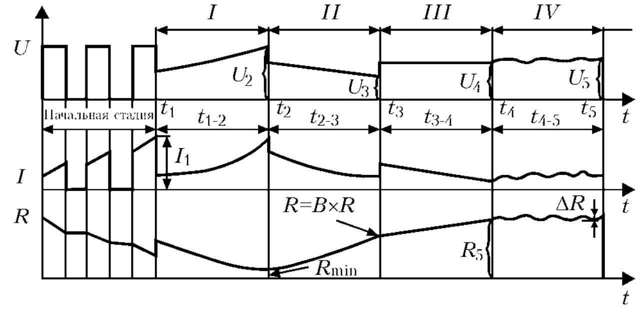

Figure 9. Typical algorithm of live tissue welding [20]

was achieved in the clinic in cooperation with the doctors of Kiev Center of Electric Welding Surgery using standard apparatus EKVZ-300 («PATONMED») and instruments [12]. Formation of the liver parenchyma seam by electric welding has been achieved for the first time. Positive results have been obtained in surgical treatment of pancreatic diabetes with application of the technology of welding live tissues in open and laparoscopic variants. New technology of retropubic prostatectomy has been verified and is applied with success in surgical treatment of prostate adenoma [21]. This technology has a number of advantages compared to the currently available one that allows characterizing it as one of the most promising in treatment of this rather wide-spread disease.

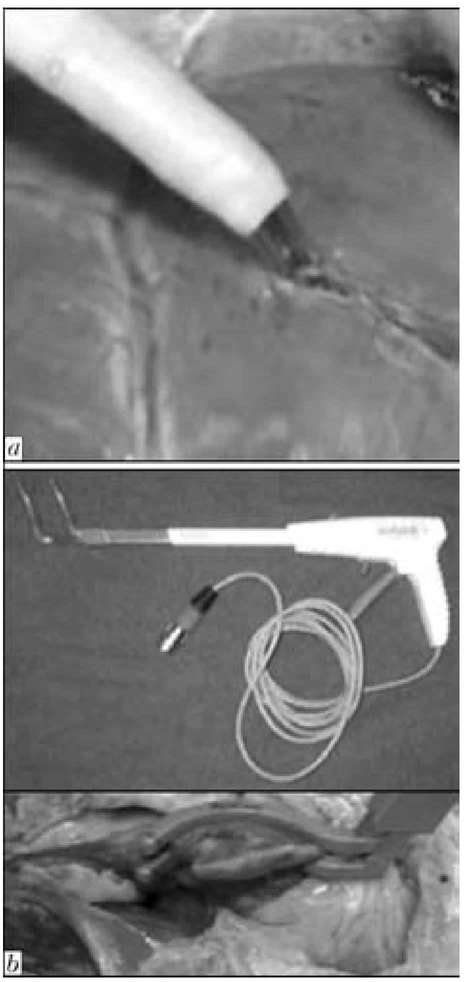

Figure 10. Test samples of instruments for cardiosurgical operations: *a* — bipolar HF-cauterodyne for operations with simultaneous tissue cutting and coagulation; *b* — bipolar forceps for transmural ablation of heart conduction tracts

Application of high-frequency electric welding in cardiosurgery seems to be promising. To widen the range of HF-welding applications in the above-mentioned surgical field and develop respective equipment, the Interbranch Center of «Cardiovascular Engineering» was established, uniting specialists of the E.O. Paton Electric Welding Institute of NASU, N.M. Amosov National Institute of Cardio-Vascular Surgery (NISSKh) and National Technical University of Ukraine «Kiev Polytechnic Institute».

This center performs development of specialized apparatuses, instruments and technologies: cardiosurgical instruments for transmural ablation of heart conduction tracts, diothermocoagulation of tissues and hemostasis, instruments for conducting cardiosurgical operations with simultaneous cutting and coagulation, etc. [22]. Test samples of the above instruments have been developed, which have successfully passed preliminary trials (Figure 10) [23].

It is planned to perform work on further improvement of apparatuses and instruments, in keeping with vascular surgery specifics, as well as develop and introduce new procedures of operational interventions at N.M. Amosov NISSKh and other cardiosurgical institutions of Ukraine.

Work on welding live tissues in ophthalmology, conducted together with specialists of V.P. Filatov Institute of Eye Diseases and Tissue Therapy of AMSU (Odessa), should be mentioned separately. So, jointly developed technology of retina welding is one of the most effective procedures at present. To date HF-electric welding is quite widely applied in ophthalmosurgical practice of the above-mentioned Institute [24–26].

In particular, HF LTW is applied during enucleation (eyeball removal) in patients with intraocular neoplasms, malignant secondary neovascular glaucoma, etc. Excision of eyeball rectus muscles from sclera, and crossing of neurovascular bundle are performed in «Cutting» mode, and adaptation of conjuctival cut edges is conducted in «Welding» mode.

In retinal and vitreous surgery electric welding is applied in patients with retina detachment, diabetic retinopathy (one of the gravest complications of pancreatic diabetes) and intraocular neoplasms.

Operations are performed using original parameters of PWI-designed apparatuses modified for ophthalmology and jointly developed original instruments (Figure 11).

In addition, experimental research is performed in the following directions:

• devitalizing malignant choroid neoplasms. The new method will allow increasing the effectiveness of treatment of patients with malignant intraocular neoplasms through improvement of ablastics quality;

• trabeculectomy. Electric welding will allow improving the effectiveness of treatment of patients with secondary neovascular glaucoma through improvement of hemostasis quality at trabecule crossing;

• retinal surgery (layer-by-layer keratoplasty). HF LTW will allow improvement of the quality of layer-by-layer keratoplasty due to seamless fixing of retinal transplant.

At the same time, PWI has successfully performed and continues work in other directions of application of HF LTW and related technologies in medicine. They include methods of contactless thermosurgery. Let us present this work in greater detail.

Hyperthermic processes of welding, cutting and treatment of live tissues. In 2001 DB «Yuzhnoje» and PWI jointly developed plasma-surgery complex «Plasmamed» [27]. This marked the beginning of development of a new medical field in Ukraine: contactless hyperthermic surgery.

At the first stage an apparatus was developed, which performs cutting of parenchymatous tissues and stopping intrawound bleeding by a jet of low-temperature argon plasma. This apparatus received positive medico-technical evaluation and a procedure of plasma welding of live tissues of the intestines and stomach was developed, as well as the method of joining the parenchymatous wound edges.

As a follow-up of these investigations PWI in cooperation with A.A. Shalimov National Institute of Surgery and Transplantology developed a procedure and apparatus for convection-infrared (CI) treatment and welding of live tissues. This process features simplicity and ease of application of apparatuses developed for it, as well as use of ambient air instead of argon. Novelty of the developments is confirmed by Ukrainian patents [28–31]. This process provides reliable hemostasis, ability to form coagulated blood films on tissue surface, absence of thermal injury of organ parenchyma, possibility of safe operation in the vicinity of great vessels and hollow organs (Figure 12).

Checking of the main design and program solutions of these apparatuses has been performed.

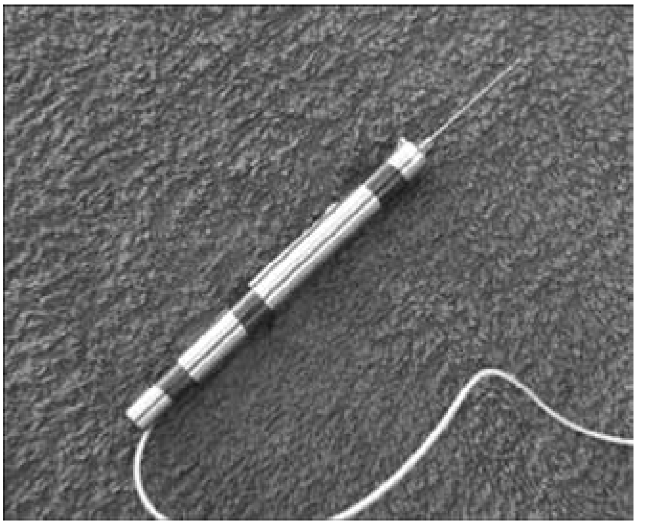

Figure 11. Instruments for HF-welding in ophthalmology

Test samples of apparatuses for CI-treatment of live tissues and instruments for them have been developed and tested. A line of apparatuses has been created for field applications: full-scale TPB-65, budget TPB-65B, automobile TPB-65Aut, wireless TPB-65Ak (Figure 13). The following apparatuses have been developed for stationary operating rooms: full-scale TPB-180, full-scale TPB-180^{UPS} with built-in UPS unit, and budget TPB-180B (Figure 14).

Most of the apparatuses can operate in self-sufficient mode and use car power system, field electric power stations as power sources, and TPB-200HF apparatus can also fulfill the manipulations of high-frequency cutting and coagulation of live tissues.

Preclinical studies of CI-apparatuses and their application procedures have been performed at A.A. Shalimov National Institute of Surgery and Transplantology with participation of specialists

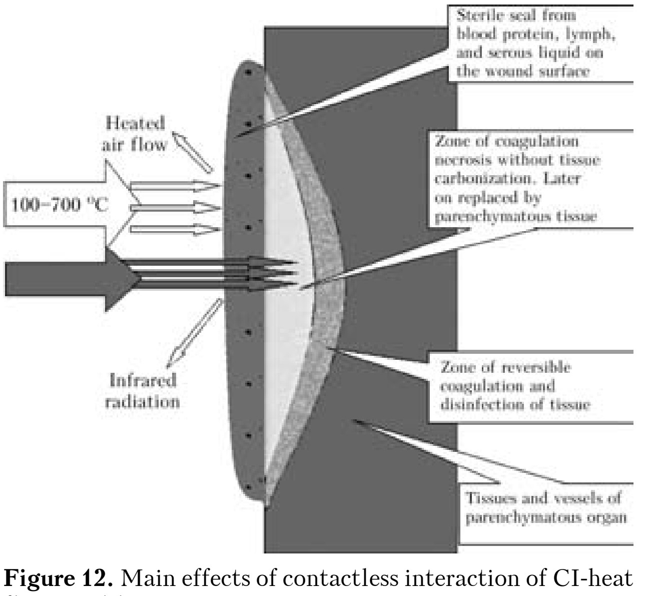

Figure 12. Main effects of contactless interaction of CI-heat flows and live tissues

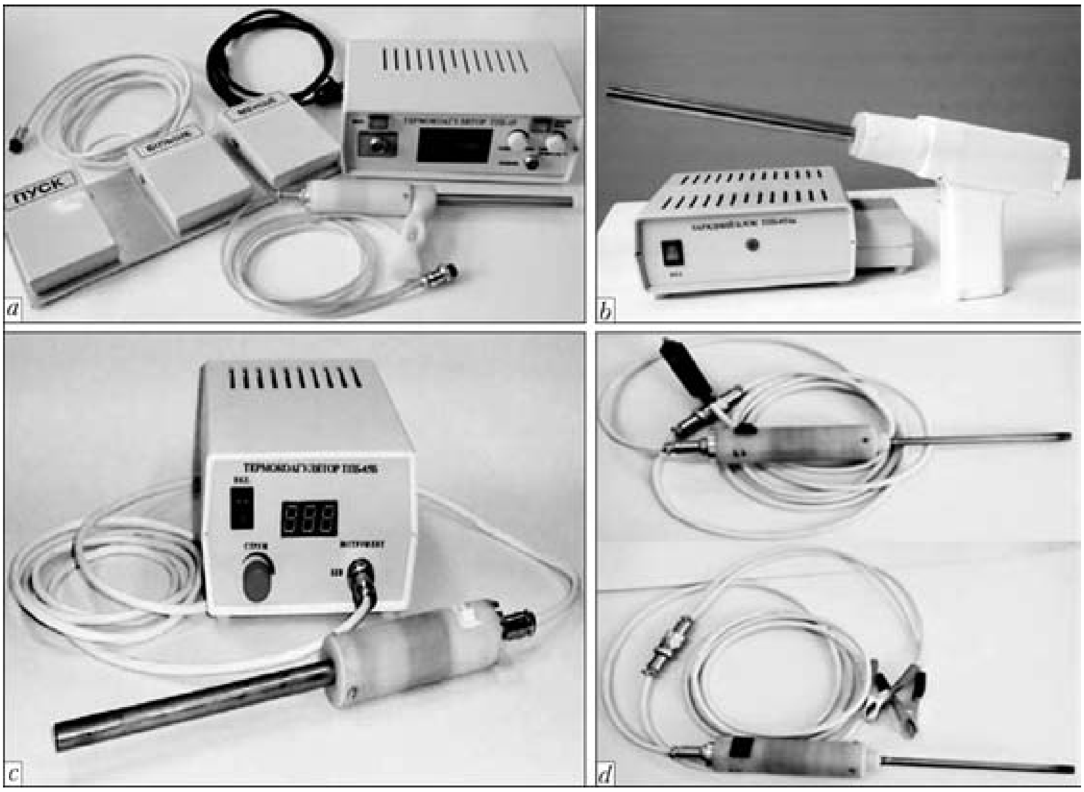

Figure 13. Apparatuses for CI-treatment of live tissues: *a* — TPB-65; *b* — TPB-65Ak; *c* — TPB-65B; TPB-65Aut

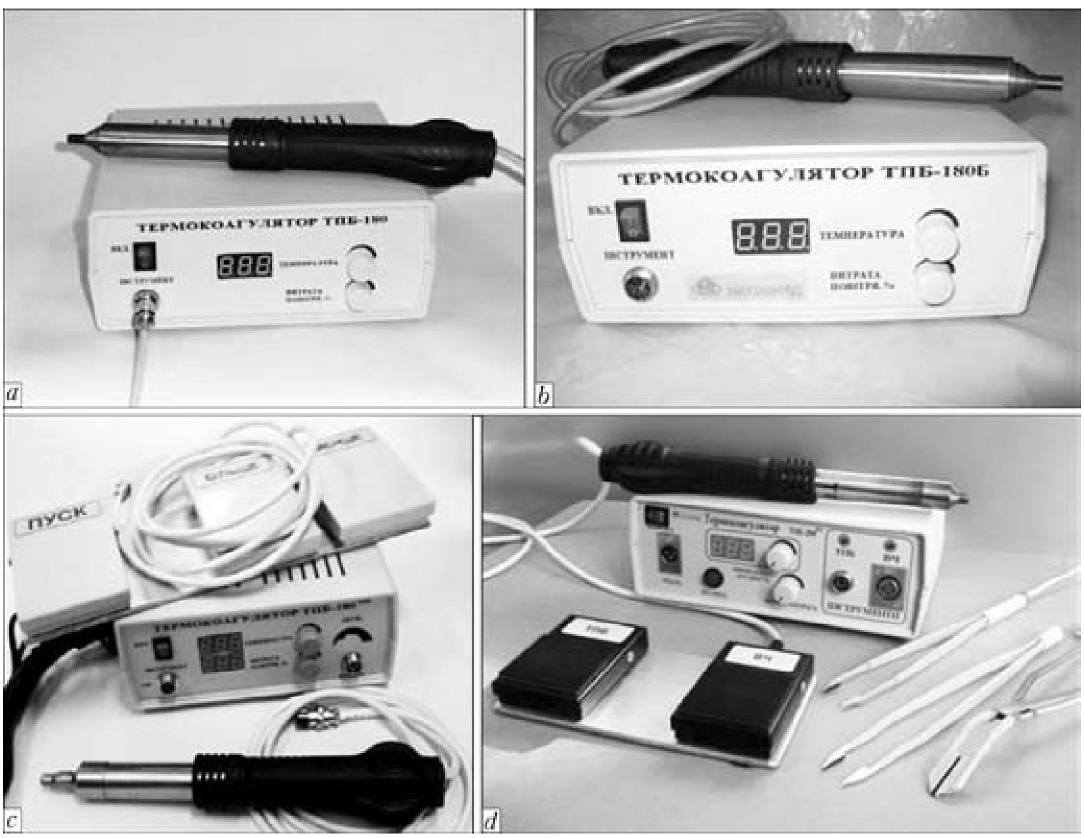

Figure 14. Apparatuses for CI-treatment of live tissues for stationary operating rooms: *a* — TPB-180; *b* — TPB-180B; *c* — TPB-180^{UPS}; *d* — TPB-200VCh

of Ukrainian Military-Medical Academy and surgeons of Main Hospital No.1 of GTOO YuZZhD.

Investigations in the field of CI-treatment of live tissues in surgery demonstrated the good prospects for this method, particularly under the conditions of surgical interventions complicated by infections. This method was modified for stopping bleeding and prophylaxis of infection development in gunshot wounds (Figure 15) [32].

High effectiveness of the method was established, irrespective of specific apparatus realization, at stopping bleeding from up to 3 mm vessels, at bleeding from damaged parenchymatous organs, trabecular bones, d-bridement of infected and chronic purulent wounds [33, 34].

A mixture of antibiotic-resistant microorganism cultures (clinical strains) consisting of colon bacillus, pneumonia klebsiella, blue pus bacillus, golden stafilococus, enterococus faecium, candida fungus, was used as infecting material in tests on laboratory animals (rats, rabbits, pigs). CI-method of wound treatment has successfully passed preclinical tests and, in the opinion of many leading surgeons, its wide introduction into surgical practice is rational. At present more than 200 operative interventions have been performed with application of the method of CI-treatment of wounds and stopping parenchymatous bleeding.

Such apparatuses can be used for rendering first aid to victims of accidents and catastrophies both in the field conditions in immediate vicinity of injury site and in hospitals. CI-apparatuses essentially improve the effectiveness of specialized and highly specialized surgical aid, particularly at polytraumas and surgical interventions complicated by infections [35, 36]. CI-technology allows stopping bleeding from parenchymatous organs, trabecular bones and vessels of 1–3 mm diameter, d-bridement of infected and chronic purulent wounds, profylaxis of purulent infection at combat injuries, welding of tissues of gastro-intestinal tract organs, tissue coagulation for performing bloodless dissection, and profylaxis of relapses and metastasis development at tumour removal (Figure 16).

Alongside the above-mentioned applications of CI-method of welding and treatment of live tissues, development of hyperthermic method for destroying malignant tumours and metastases was begun, which is an urgent and promising direction of research.

Development of multifunctional apparatuses, combining the processes of high-frequency welding and CI-treatment of live tissues, is one of the important tasks in creation and introduction of new generation of electrothermosurgical equipment. First model samples of such equipment based on EK-300M1 (Figure 17) are now passing comprehensive clinical trials. Model samples of CI-instruments for EKVZ-300 «PATONMED» apparatuses have been developed. Thus, in the future most high-frequency apparatuses for live tissue welding will have the functions of CI-treatment of tissues. In the opinion of surgeons, combination of the above processes in one multifunctional apparatus allows performing up to 80 % of standard surgical manipulations with it [37, 38].

Figure 15. Surgical treatment of infected gunshot wound by CI-flow

An independent highly promising direction of PWI activities is development of complex medical technologies aimed at solving some medical problems, such as reconstructive-restorative surgery, cardio-vascular surgery, and ophthalmology [39]. Solution of these problems requires involvement of specialists from various fields, departments and even other institutes.

Problem of reconstructive-restorative surgery covers materials, technologies, apparatuses, sur-

Figure 16. Stopping bleeding with CI-coagulator and d-bridement of an infected wound after amputation of finger bone

Figure 17. Multifunctional apparatuses for high-frequency welding and CI-treatment of live tissues, based on EK-300M1

gical procedures, used in orthopedics, traumatology, oral surgery, and stomatology to increase the effectiveness of operative interventions and shorten the periods of recovery of intactness and functions of support-motor apparatus. Individual directions also deal with prosthetics, oncology, neurosurgery and vertebrology (as regards restoration of integrity of bones, intervertebral disks, ensuring spine mobility).

For instance, during operative intervention for open fractures, high-frequency welding of live tissues is used to obtain operative approach, stopping bleeding from great vessels and welding individual elements of live tissues. D-bridement of an initially infected wound and stopping bleeding from trabecular bones are performed by CI-coagulator. Titanium composites, elements from bioactive ceramics — biosital, hydroxyapatites, β-tricalciumphosphate are used for osteosynthesis. They form a bone-ceramic block, which is gradually replaced by sound bone. Special technologies of filling bone defects with hydroxyapatites with osteoconductive and osteoinductive additives, produced using nanotechnologies, allow a significant acceleration of the process of bone restoration in the fracture zone.

Complex application of thermosurgical technologies and new materials for osteosynthesis and prosthetics allows conducting single-stage reconstructive operations without removal of osteosynthesis elements after bone restoration.

The above advantages and merits of the new processes of welding, cutting and heat treatment of live biological tissues allow anticipating their wide application. In the future, in the authors' opinion, apparatuses for high-frequency welding and CI-treatment of live tissues should become an invariable attribute of each operating room and each operating table.

1. *http*://valleylab.com/product/es/
2. *http*://www.ethicon.com/emea/ua/healthcare-professionals/
3. *http*://www.klsmartin.com/products/electrosurgery/
4. *http*://www.erbe-med.com/de/medical-technology/public/Products/Electrosurgery
5. *http*://nii-prikladnoj-elektroniki.uaprom.net/
6. Nikonenko, A.S., Zavgorodny, S.N., Polyakov, N.N. et al. (2012) First experience of application of high-frequency electric welding technology in transplantation of kidney. In: *Proc. of 7th Int. Sci.-Pract. Conf. on Welding and Heat Treatment of Live Tissues. Theory. Practice. Prospects* (Kiev, 30 Nov., 2012). Kiev: IA «Welding», 27.
7. Bondar, G.V. (2011) Widening of indications for application of electric welding complex for joining soft tissues in oncosurgery. In: *Proc. of 6th Int. Seminar on Welding of Soft Live Tissues. State-of-the-Art and Prospects of Development* (Kiev, 2–3 Dec., 2011). Kiev: PWI, 58.
8. Tarnavsky, D.V., Chumikov, A.A. (2012) Efficiency of application of HF electric welding for castration of goats, rams and bull-calves under conditions of UNPK YuF NUBiP of Ukraine «KATU». In: *Proc. of 7th Int. Sci.-Pract. Conf. on Welding and Heat Treatment of Live Tissues. Theory. Practice. Prospects* (Kiev, 30 Nov., 2012). Kiev: IA «Welding», 51.
9. (2010) *Proc. of 5th Int. Seminar on New Trends of Investigations in Field of Welding of Live Soft Tissues* (Kiev, 26–27 Nov., 2010). Kiev: PWI.
10. (2011) *Proc. of 6th Int. Seminar on Welding of soft live tissues. State-of-the-art and prospects of development* (Kiev, 2–3 Dec., 2011). Kiev: PWI.
11. (2012) *Proc. of 7th Int. Sci.-Pract. Conf. on Welding and Heat Treatment of Live Tissues. Theory. Practice. Prospects* (Kiev, 30 Nov., 2012). Kiev: IA «Welding».
12. *http*://www.zvarka.org/
13. *http*://www.erbe.ru/produktsiya/vessel-sealing
14. (2009) *Tissue-saving high-frequency electric welding surgery*: Atlas. Ed. by B.E. Paton and O.N. Ivanova. Kiev: IA «Welding».
15. Marinsky, G.S., Chernets, A.V., Tkachenko, V.A. et al. (2012) New PWI equipment for welding of live tissues. In: *Proc. of 7th Int. Sci.-Pract. Conf. on Welding and Heat Treatment of Live Tissues. Theory. Practice. Prospects* (Kiev, 30 Nov., 2012). Kiev: IA «Welding», 42.
16. Paton, B.E., Marinsky, G.S., Podpryatov, S.E. et al. *High-frequency welding electrocoagulator EKVZ-300*. Pat. 72577U Ukraine. Int. Cl. A 61 B 18/12. Fil. 24.01.2012; Publ. 27.08.2012.
17. Kosakovsky, A.L., Kosakovskaya, I.A., Semyonov, R.G. (2010) Bipolar electric instruments for high-frequency electric welding of biological tissues of ENT-organs. In: *Proc. of 5th Int. Seminar on New Trends of Investigations in Field of Welding of Live Soft Tissues* (Kiev, 26–27 Nov., 2010). Kiev: PWI, 56.
18. Podpryatov, S.E., Gichka, S.G., Podpryatov, S.S. et al. (2012) Structure of electric seam as a base of new advances in surgery. In: *Proc. of 7th Int. Sci.-Pract. Conf. on Welding and Heat Treatment of Live Tissues. Theory. Practice. Prospects* (Kiev, 30 Nov., 2012). Kiev: IA «Welding», 45.

19. Vazina, A.A., Lanina, N.F., Marinsky, G.S. et al. (2011) Influence of high-frequency electrosurgical welding on functional stability of biological tissue structure. In: *Proc. of 6th Int. Seminar on Welding of Soft Live Tissues. State-of-the-Art and Prospects for Development* (Kiev, 2–3 Dec., 2011). Kiev: PWI, 53.
20. Paton, B.E., Tkachenko, V.A., Marinsky, G.S. et al. *Method of joining of human and animal biological tissues using high-frequency current*. Application 201209185. Publ. 26.07.2012.
21. Vitrenko, A.V., Podpryatov, S.E., Gichka, S.G. et al. (2012) Efficiency of performance of retropubic prostatectomy. In: *Proc. of 7th Int. Sci.-Pract. Conf. on Welding and Heat Treatment of Live Tissues. Theory. Practice. Prospects* (Kiev, 30 Nov., 2012). Kiev: IA «Welding», 36.
22. Krivtsun, I.V., Marinsky, G.S., Chernets, O.V. et al. (2012) Some prospects for application of high-frequency electric welding in cardiosurgery. In: *Proc. of Int. Med. Forum 2012: Sci.-Pract. Conf. on Results of Introduction in Medical Practice of Technologies of General and Local Thermal Impact on Human Organism* (Kiev, 25 Sept., 2012). Kiev: PWI, 239.
23. Vasylchenko, V.A., Marynsky, G.S., *Chernets, O.V. et al. Bipolar electrosurgical instrument (electroknife) for high-frequency electrosurgery*. Pat. 80729U Ukraine. Fil. 14.12.2012; Publ. 10.06.2012.
24. Pasechnikova, N.V., Naumenko, V.A., Umanets, N.N. (2012) Experimental substantiation of applicability of high-frequency electric welding of biological tissues in vitreoretinal surgery. In: *Proc. of 7th Int. Sci.-Pract. Conf. on Welding and Heat Treatment of Live Tissues. Theory. Practice. Prospects* (Kiev, 30 Nov., 2012). Kiev: IA «Welding», 22.
25. Pasechnikova, N.V., Naumenko, V.A., Maletsky, A.P. et al. (2012) Ultrastructural changes in eye socket tissues at eyeball enucleation using high-frequency electric welding of biological tissues. *Ibid*. Kiev: IA «Welding», 44.
26. Pasechnikova, N.V., Naumenko, V.A., Umanets, N.N. (2011) Our experience in application of the method of high-frequency electric welding of biological tissues during endovitreal interventions. In: *Proc. of 6th Int. Seminar on Welding of Soft Live Tissues. State-of-the-Art and Prospects for Development* (Kiev, 2–3 Dec., 2011). Kiev: PWI, 24.
27. Paton, B.E., Krivtsun, I.V., Gvozdetsky, V.S. et al. *Method of ligatureless joining of defects of soft live tissues*. Pat. 23204 Ukraine. Int. Cl. A 61 B 17/00. Fil. 28.12.2006; Publ. 10.06.2007.
28. Furmanov, Yu.O., Khomyak, I.V., Gvozdetsky, V.S. et al. *Method of sanation of suppurative-septic foci of pancreas*. Pat. 32900 Ukraine. Int. Cl. A 61 B 17/22. Fil. 28.12.2006; Publ. 10.06.2007.
29. Paton, B.E., Krivtsun, I.V., Khudetsky, I.Yu. *Thermo-spray surgical instrument*. Pat. 20479/ZU/11 Ukraine. Int. Cl. A 61 M 11/00, A 61 N 5/00. Fil. 23.05.2011; Publ. 07.11.2011.
30. Sukhin, I.A., Krivtsun, I.V., Khudetsky, I.Yu. et al. *Method of surgical operation performance*. Pat. 70151 Ukraine. Int. Cl. A 61 M 11/00. Fil. 29.11.2011; Publ. 25.05.2012.
31. Paton, B.E., Gvozdetsky, V.S., Furmanov, Yu.O. et al. *Method of gunshot wound healing*. Pat. 30372 Ukraine. Int. Cl. A61 B 18/04. Fil. 25.10.2007; Publ. 25.02.2008.
32. Khudetskyy, I., Krivtsun, I., Gvozdetsky, V. et al. (2009) Usage of portable thermo-spray device for treatment of wounds contaminated by microbes. In: *Counteraction to chemical and biological terrorism in East European countries*. Dordrexht: Springer.
33. Khudetskyy, I., Krivtsun, I., Terekhov, V.G. et al. (2010) Further development of apparatuses for hemostasis, treatment and healing of infected wounds by high-temperature flow. *Klinichna Khirurgiya*, **7**, 53–55.
34. Sukhin, I.A., Khudetsky, I.Yu., Kachan, S.G. et al. (2012) Examination of the influence of high-temperature methods of dissection and coagulation of tissues on parenchymatous organs in experimental conditions. *Ibid*., **1**, 76–78.
35. Khudetskyy, I., Krivtsun, I., Furmanov, J. et al. (2011) Contactless convection-infrared technology to thermal surgery. In: *Proc. of the Special Forum & Exhibition on Best of East Europe for Eastern Partnership: Challenges and Opportunities for Collaboration European Union-Poland-Eastern Europe Countries* (Warsaw, 28–30 Nov., 2011, Poland) and *4th Int. Science and Technology Days Poland-East* (Bialowieza, 12–14 April, 2011). Bialystok: ORGMASZ, 2012, 37–47.
36. Sukhin, I.A., Kachan, S.G., Bililovets, A.N. et al. (2011) Monobloc application of apparatuses for high-frequency electric welding of biological tissues and pneumo-thermocoagulation in surgery. *Klinichna Khirurgiya*, **5**, 48.
37. Krivtsun, I.V., Khudetsky, I.Yu., Sukhin, I.A. et al. (2012) Prospects for further development of multifunctional and specialized thermosurgical apparatuses. In: *Proc. of 7th Int. Sci.-Pract. Conf. on Welding and Heat Treatment of Live Tissues. Theory. Practice. Prospects* (Kiev, 30 Nov., 2012). Kiev: IA «Welding», 48.
38. Krivtsun, I.V., Khudetsky, I.Yu., Kamalov, R. et al. (2012) Creating innovative equipment and technology for the specialized care in cardiology, orthopedics, dentistry and maxillofacial surgery. In: *Proc. of 6th Int. Forum on Innovative Technologies for Medicine ITMED 2012* (Bialystok, 21–23 Nov., 2012). Bialystok: Innovative Eastern Poland Assoc., 39.
39. Khudetsky, I.Yu., Kamalov, R.Kh., Ponomarenko, V.O. et al. (2012) Complex electrothermosurgical technologies, apparatuses and instruments for dentistry and maxillofacial surgery. In: *Proc. of 7th Int. Sci.-Pract. Conf. on Welding and Heat Treatment of Live Tissues. Theory. Practice. Prospects* (Kiev, 30 Nov., 2012). Kiev: IA «Welding», 49.